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The challenges of index-based insurance for food security in developing countries

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The challenges of index-based insurance for food security in developing countries

Proceedings of a technical workshop organised by the EC Joint Research Centre (JRC) and the International Research Institute for Climate and Society (IRI, Earth Institute, Columbia University)

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Foreword

Over the past decade, the importance of weather index insurance for agriculture has been increasing in developing countries. This interest can be explained by the potential that index insurance offers as a risk management instrument for small farmers. More generally, it should be seen in the context of renewed attention to agricultural development as one of the vectors of poverty reduction and increased food security and the accompanying efforts from various stakeholders to develop agricultural risk management instruments, including agricultural insurance products.

Agricultural insurance aims to reduce the risk associated with crop production and animal husbandry. With index insurance, settlements are based on the value taken by an objective index rather than on a case-by-case assessment of crop or livestock losses. Index insurance aims to be affordable to all producers, including smallholders. Index insurance could provide a safety net against weather-related risks for all members of the farming community, thereby increasing food security and reducing the vulnerability of rural populations to weather shocks. Index insurance, furthermore, can be combined with credits for insured smallholders, as the risk of non-repayment for lenders is reduced. This boosts the use of agricultural inputs and equipment, leading to increased and more stable crop production. It also makes participation in the market for agricultural insurance and credit attractive for the private sector, taking some of the burden to provide state-sponsored insurance and credit systems away from governments.

Realising the potential of weather index insurance for supporting agricultural development, the European Commission has encouraged and supported numerous schemes and initiatives, the most important one being the Global Index Insurance Facility jointly created by the International Finance Corporation (IFC) and the International Bank for Reconstruction and Development (IBRD) in 2008. The past years have seen the emergence of a number of weather index insurance pilot projects, many of them in sub-Saharan Africa. During the same period, noticeable progress has been made in research on the development of better, more widely applicable indices, on the design and marketing of index insurance products, on forms of linkages to agricultural credit, on ways for the successful operation of insurance schemes, on suitable policy frameworks and on many other aspects of index insurance. It was therefore timely to invite experts and stakeholders to meet to examine the state of weather index insurance from various angles, and to discuss some of the main challenges it faces.

The progress in research and the experience from various pilot projects opens new possibilities for expanded and more equitable index insurance schemes that the European Union may promote in the framework of its external assistance. It also provides good examples of research-based evidence for use in our development cooperation programmes.

However, while a number of pilots confirm the potential of the approach, there remain challenges and issues to be further analysed before it can be considered ready for larger-scale commercialisation. It is equally important to position index insurance as just one among other complementary financial and other policy instruments to help farmers reduce their financial risks while facilitating their productivity and income-increasing investments.

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1. INTRODUCTION

Since the late 1970s, early warning systems for food security supplemented by humanitarian aid have been the traditional response to food shocks. However, in spite of three decades of humanitarian aid and early warning activities, food insecurity still prevails in many areas of the globe (Bailey, 2013). Different and innovative ways to tackle the problem are needed, and advantage must be taken of new global and local conditions that have developed since the seventies, especially in terms of communication and information technology.

The renewed interest in insurance for smallholder farmers indicates that such solutions are being sought by many international development and research organisations, for example the World Bank, several UN organisations, research institutions and many others (see, for example, the papers by Arce, Coleman et al. and Osgood in this volume).

The idea is to tackle the problem at its roots and to transfer, at least partially, production risks from farmers to insurance institutions. Crop insurance schemes that have recently been proposed in developing countries almost exclusively focus on index-based approaches, an approach by which large numbers of farmers can be insured for limited transaction costs. It is generally believed that this potentially makes the insurance profitable for private insurance companies and affordable for food producers, although some authors (e.g. Herbold in this volume) consider that development costs are substantially higher for index products than for classical multi-peril insurance.

The collection of short papers in this publication is the outcome of the workshop 'The Challenges of Index-Based Insurance for Food Security in Developing Countries', jointly organised by the Joint Research Centre of the European Commission (EC/JRC) (1) and the International Research Institute for Climate and Society (IRI), Earth Institute, Columbia University (2). The JRC and IRI collaborate in some technical areas of mutual interest, including food security. Both institutions recognise that repeated environmental shocks are a major threat for food security in developing

1 More specifically, the Food Security Action (FoodSec), Monitoring Agricultural Resources unit (MARS) in the Institute for Environment and Sustainability (IES): details are available online (http://mars.jrc.ec.europa.eu).

2 The IRI counterpart was the Center for Research on Environmental Decisions, Financial Instruments Sector Team.

countries. Moreover, the induced risk prevents smallholder farmers from adopting investment strategies that would have the potential to finally lift them above the level of subsistence.

The IRI has a long and recognised experience in the area of Agricultural Index Insurance (AgII) and numerous publications have been issued on basic principles of AgII and pilot projects (Brown and Osgood., 2012; Carriquiri and Osgood, 2012; de Nicola et al., 2011; Dinku et al., 2009; Hellmuth et al., 2009).

Next to the FAO's Global Information and Early Warning System (GIEWS), the USDA's Foreign Agricultural Service (FAS), Famine Early Warning Systems Network (FEWS NET) and China' s CropWatch System (Wu et al., 2010; Qiangzi Li et al., 2011; Bingfang Wu and Qiangzi Li, 2012), the JRC, through its unit for Monitoring Agricultural Resources (MARS) is one of the major global players in the area of quantitative crop condition assessments (Baruth et al., 2007; Cantelaube and Terres, 2005; Chavula and Gommes, 2006; Gommes et al., 2010; Kayitakire et al., 2010; Rojas Mora et al., 2005; Rojas Mora et al., 2011; Vancutsem et al., 2011).

When the MARS programme was established in the mid 1980s, a number of systematic studies were launched to test and eventually establish many of the methods that have now become standard approaches in regional crop forecasting and monitoring, such as the geostatistics of climate data, Geographic Information Systems (GIS), reliable techniques to estimate crop water requirements, etc. An excellent account of the subject is given by Rijks et al. (1998). Experience with crop insurance is available, but mostly in Europe (Bielza Diaz-Caneja et al., 2009a; Bielza Diaz-Caneja and Colmenero, 2009b). It is interesting to note that Bielza Diaz-Caneja et al. (2009) concluded that index insurance would be difficult to implement in Europe.

2. MEETING OBJECTIVES AND RATIONALE

In many developing countries, aid organisations in partnership with government and private partners have been seeking index-related solutions for agricultural insurance on a more or less experimental basis. From these experiences, lessons learnt and results are becoming available. Several papers in this volume describe such national experiences.

The meeting was based on the perception that indices are a pivotal component in index-based crop insurance systems, because of: (i) the technical difficulties in achieving a good statistical relationship with losses, and the implications of this for mitigating the basis risk; (ii) the existing trade-off between sophistication and transparency of methods; and (iii) the data sources, availability and reliability of data that constrain the development and operational use of the indices. Moreover, as there is no guarantee that the best index (from an agronomic point of view) fits the best contract (from an economic view), it is believed that only a multidisciplinary approach will lead to the development of an insurance product, and the associated index, that is technically sound, specifically designed to target the key problems and risk management gaps that farmers face and where the insurance benefits outweigh premiums. Through this broader approach, the objective is to arrive at insurance packages with the greatest potential for reducing poverty, strengthening farmers' resilience to shocks of various origins and improving rural food security.

This is why the meeting involved some major partners from the private sector (insurance and reinsurance companies), development agencies, technical institutions dealing with the development of comprehensive insurance schemes and experts in climate and crop-climate interactions, who usually are responsible for the development of indices in collaboration with the other players.

The meeting objectives included gaining an overview of existing indices, their scope and adequacy, in particular with respect to different contractual arrangements, and their potential to lift subsistence farmers and herders out of food insecurity. Particular attention was paid to techniques of index development that can improve the appeal of insurance schemes and their fairness to farmers, as well as to the economic feasibility of the insurance systems.

3. STRUCTURE OF THIS REPORT

The first section of this report after the present overview summarises the main conclusions of the meeting, jointly prepared by the JRC and IRI. The conclusions highlight the main points of the discussions. The third section is a collection of the extended abstracts of the different presentations.

3.1. Setting the scene

Three presentations set the scene for the debates, starting with opening remarks by the MARS unit head and the main host for the event, followed by the presentation of the philosophy at the base of much of the work of IRI (i.e. that insurance products sold to smallholders in developing countries will be fair only if the farmers participate in product development) and, finally, Munich Re had a sober look at index-based insurance and spelled out some conditions for AgII to be eventually successful.

3.2. International partners

The papers collected under this heading present the experience of some major supporters of AgII worldwide, either as development agencies or through reinsuring the pilot projects. Reinsurance is a sine qua non condition for national commercial aspects of AgII to succeed, even if the modalities and the approaches may differ widely among insurers.

3.3. National experiences

The section contains seven articles having the common theme of describing national initiatives, either pilots or actual AgII implementations by insurance companies. The similarities end here, as the articles describe very different realities, from area-yield insurance in Peru to livestock insurance in Kenya and crop yield estimation approaches in Australia.

3.4. Index philosophy

These articles debate some basic technical and operational issues that must be examined when planning and implementing AgII. The first papers discuss the identification of areas where insurance is most needed (Potgieter et al.), the question of assessing actual demand by farmers (Tadesse et al. and Sarris) and their willingness to pay (Kakumanu et al. presenting an Indian experiment), issues related to bridging the gap between pilot and actual commercial implementation (Boissonnade et al., and Maina). The paper by Gulseven on a pilot project in Turkey could have been in the section on national experiences, but since it describes a novel approach, it fits well in this section, too.

3.5. Index science and technology

The largest number of articles belong under this section, essentially because, as indicated above (under Meeting objectives and rationale) the JRC and IRI are well aware that many indices are too inefficient to solve many of the basic issues linked with AgII, especially basis risk. These articles can be grouped under the headings *Climate science* and *Alternatives to simple rainfall-based indices*.

Climate science

The section starts with several papers dealing with data, since real-time weather data and historical climate information are both needed for AgII. They have to be provided by National Weather Services (NWS) (Chavula) supported and coordinated by WMO (Camacho), or else taken from existing public data bases (Fisher et al.). In fact, AgII could become a major buyer of weather services in the long term, a fact that is not always correctly appreciated by NWSs.

Four papers describe in some detail basic features of weather variables, some of which are often overlooked when designing insurance products, including inherent and natural variability (Lyon), the role of advanced techniques to complement ground observations (Dorling), and spatial variability (Greatrex, Gommes and Göbel).

Alternatives to simple rainfall-based indices

Simple variables can be used as indices. Indeed, AgII indices can vary greatly in their complexity, but agronomic experience tells us that some variables or simple combinations of variables can efficiently capture and synthesise environmental conditions. The provided examples pertain to the Sudan (Adam and Gomaha Gaber) and India (Krishna Murthy). Most articles in the section deal with remote sensing products, which will no doubt constitute one of the mainstays of future AgII systems. They do capture spatial variability but they are not devoid of their own problems. The potential of remote sensing can be seen in complementing weather and phenological observations (Meroni et al.), assessing crop stress conditions (Rojas and Ahmed) using, among other things, recent developments in satellite vegetation monitoring (Tadesse) and, eventually, making it possible to develop crop yield indices, that basically would make the current qualitative weather indices obsolete (de Bie and Morsink).

There is now a wide palette of different insurance products and a good scientific basis for developing efficient indices. Many technical, institutional and financial problems remain to be solved but, as mentioned by Thomas Loster (Munich Re Foundation), all current successful insurance products initially started as small scale pilots.

4. A WORD ABOUT THE ARTICLE PREPARATION PROCESS

The authors of the articles submitted their contributions between the end of the meeting (3 May 2012) and 2 November 2012, in the form of 'extended abstracts' for the most part. All articles were edited and proofread, reformatted if necessary, and generally had their visual aspects harmonised. Authors received a near-final version of their papers for scrutiny before they were declared 'final'. In the case of any disagreement about details between editor and author, the author's opinion has always prevailed.

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Meeting conclusions

JRC and IRI

1. GENERIC FINDINGS

The technical workshop 'The Challenges of Index-Based Insurance for Food Security in Developing Countries', organised by the JRC and the International Research Institute for Climate and Society (IRI), was held in Ispra, Italy, 2 and 3 May 2012. Attendants from a wide spectrum of technical areas (remote sensing to crop modelling and economics), types of business (insurance and reinsurance companies to government and international organisations) and levels of involvement with the farming community (from research to actual insurance implementation on a commercial basis) were well represented at the conference.

Participants discussed the need for stakeholders in index-based weather insurance (WII) to reconcile conflicting views and interests if WII is to lift itself above the level of research and pilot projects, which is still the dominant condition of implementation of WII. It was highlighted that insurance will be sustainable only if it appeals to people by increasing and stabilising their food production and income. In addition, speakers mentioned that there is currently a risk that insurance may actually make farmers poorer or even precipitate them into the poverty trap. It was recommended that insurance must be the first step to more adaptive behaviours, including diversification of crops and practices. Insurance must be more cost effective than *ex post* risk management to have a meaningful role.

Conference speakers also pointed out that a prerequisite for efficient and sustainable WII is to understand the priorities of insured people and how they respond to risk. For example, one key question that needs to be better understood in a variety of contexts is how can insurance unlock access to credit, since farmers are usually more interested in credit than in insurance? Another prerequisite, suggested during the meeting, was a long-term commitment of all partners as a way to build confidence among all participants (from farmer to reinsurer) and to minimise reputational risk for insurers.

Drought was one of the main focuses of the conference and has, so far, received a lot of attention in WII: this is because drought often affects large areas and water shortage is often a main single factor behind crop yield variation. Other risks were highlighted that relate to livestock, crop diseases and pests (including birds and locusts) and it was suggested that these topics deserve greater attention. Participants also recommended that a greater focus should be given to comprehensive systems approaches (including farm income insurance), rather than single crop weather or even yield indices. This would pave the way from insurance-only to more comprehensive but well-layered joint private sector-government risk management systems. The layers are dealt with by different risk-takers, from people for small risks, to insurers (medium risk at regional (meso) scale and catastrophes of national importance (governments).

Basis risk was highlighted as an obvious problem with WII, and basis risk funds were discussed as a workable approach to ensure payouts in the event when losses occur and indices do not trigger.

Finally, participants in the workshop recommended that the WII community needs to accumulate more experience and: (i) continue to build confidence for a range of insurance products, technical options, methods and tools and their reliability (e.g. missing data estimation and sophisticated simulation techniques); (ii) develop methods to efficiently advocate, communicate, train and sell WII (from farmers to governments, under low and high technology conditions); (iii) ensure that products are consistent and integrated packages optimised for all levels, whether they are simple rainfall-based indices, yield indices or complex farm-income indices.

2. SPECIFIC ISSUES

Conference participants discussed and generally agreed on the following issues.

2.1. Scale

It was mentioned that WII often works better (i.e. minimises basis risk) when the meso scale and aggregated hazards are targeted, rather than individual farmers. Care must be taken to understand the most appropriate policyholder (e.g. a micro-finance institution or a farmer). It may be particularly effective, especially for farmer level products, for indexes to be bundled with complementary risk management tools that could address idiosyncratic risks. This is also why satellites (which rely on relatively large pixel sizes) are seen as a promising ingredient of indices, and why area-yield insurance schemes have the potential to address many perceived or real shortcomings of pure WII, possibly in combination with a basis risk fund.

2.2. Cost

Low transaction costs are frequently listed as one of the main advantages of WII. However, this potential benefit is derived through a greatly increased development cost, which is important to take into account when weighing alternative insurance strategies and budgeting insurance projects.

2.3. Reference data

Weather station data used to assess risk statistics needs to be representative of current farming conditions and of the area around the station where insurance is sold. It is necessary for the WII community to further discuss and resolve the confusion surrounding what is the appropriate length of historical climate data necessary to create robust products. Some stakeholders mentioned that 30 years is necessary, while others have recommended adopting shorter periods where feasible (e.g. 15–20 years).

2.4. Timing

The proper timing of product design and marketing is crucial to avoid 'post-inception' insurance sale, and also to allow insurers and insurance buyers to be aware of costs (e.g. fertiliser, seeds), of climate trends (e.g. El Niño signal or climate fluctuations), and to take into account actual planting dates (including delays).

2.5. Index technology

There exists a variety of tools that have been successfully (and routinely) used for at least two decades in crop forecasting and crop monitoring at the regional and local scale. They include geostatistics and geographic information systems (GISs) for spatial interpolation and generic mapping of crops and weather, weather radar (where available) for accurate mapping of spatial variability of rainfall, stochastic weather generators (to make responsible use of limited length time series), combination of sources and methods (ground data and satellites). While it was acknowledged that insurance companies have to use the information that is currently available, efforts should be made to start using and building confidence in these new tools.

2.6. Transparency and simplicity

The above mentioned tools are mostly used in a relatively advanced institutional setting of crop forecasting and monitoring for food security, where simplicity is not a mandatory constraint. On the contrary, reconciling simplicity, transparency and efficiency of the more advanced technologies is a major current bottleneck in WII. Interestingly, the problem is perceived across all partners of the insurance development and implementation cycle, including the extremes (i.e. farmers and reinsurers). It can, hopefully, be overcome through more regular contact among all stakeholders, outreach (regular dissemination and publication of indices throughout the cropping season, though the national media, agricultural extension and TV weather forecasts), the design of consistent standard contracts, and the gradual accumulation of mutual trust between stakeholders, especially between farmers and insurers.

1 Opening remarks

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It gave me great pleasure to open the workshop on index-based insurance for food security, and to follow several of the technical sessions including the discussions leading to the derivation of the meeting conclusions. A part of the results are, indeed, these workshop proceedings and, here, I would like to add a few words of introduction.

The general goals of the workshop fit very well within the overall mission of the JRC as the European Commission's in-house science service. The JRC provides the science for policy decisions, with a view to ensuring that the EU achieves its Europe 2020 goals for a productive economy as well as a safe, secure and sustainable future. The JRC plays a key role in the European Research Area and reinforces its multi-disciplinarity by networking extensively with leading scientific organisations in the Member States, associated countries and worldwide. In the agricultural field, the work undertaken serves the agriculture and food policies of the European Union, their impact on rural economies and on the environment, encompassing the global issues of food security and climate change.

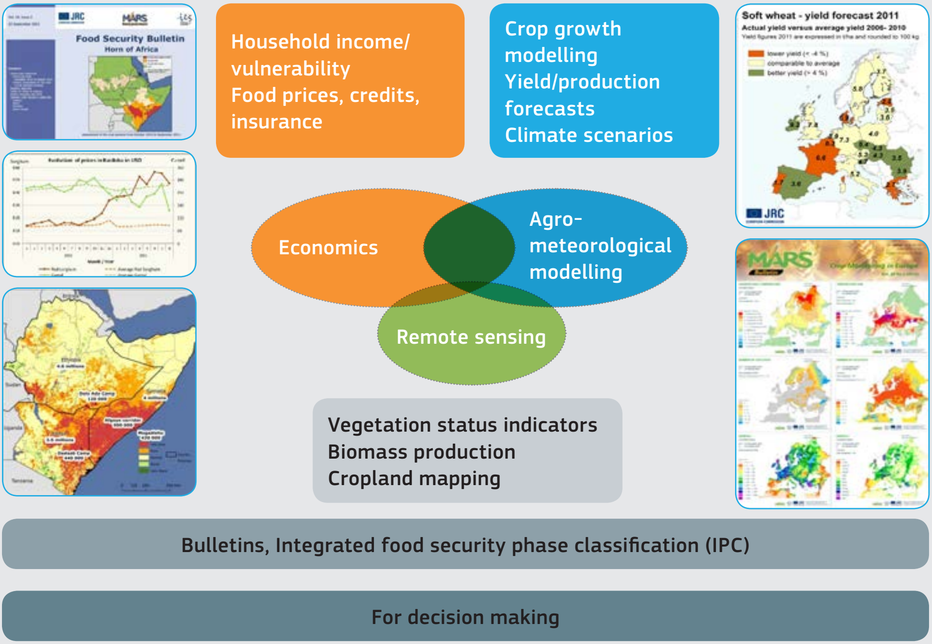
Food security is a key part of the European Commission's goals for both the near-future work programme (Europe 2020 objectives) and for the longer-term challenge of providing sufficient food for a growing global population. Focusing on crop production and agricultural activities supporting agricultural production, the work of the MARS Unit provides timely forecasts, early assessments and the scientific underpinning for efficient monitoring and control systems.

When it comes to growing and buying/selling food, key activities come from the combination of information from economics, agrometeorology and remote sensing (Figure 1). It is here where the activities of the MARS Unit have been the strongest, and it is from this nexus that the workshop on index-based methods for crop insurance has been developed.

I warmly welcomed the many participants to the workshop, including several who have travelled from Africa or from even further afield.

The structure of the seven sessions has been chosen to reflect the key issues encompassing the main actors who can determine a successful system, notably the insurer's perspective, the scientific input and the view of the practitioners who implement the schemes. The results from the meeting, documented in these proceedings, should help progress towards more efficient implementation of these insurance schemes to the benefit of the parties involved, and to the overall achievement of improved risk management and consequent reliability of food production.

Figure 1: Sources of information from economics, agrometeorology and remote sensing



2 Responsibility in index insurance: The importance of a solid science base for farmer-driven design

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KEYWORDS: index insurance, climate risk management, climate adaptation

SUMMARY

It is becoming increasingly important to prevent large numbers of farmers from being exposed to problematic insurance products. It is essential that a system be developed in which farmers themselves, who are the only ones who truly know their needs, drive a multidisciplinary design process built on solid science and the real-world constraints of insurance companies and development partners. For success, the poorest farmers in the world must interact with the researchers expanding the frontiers of the most advanced technologies.

1. INTRODUCTION

Until recently, many have doubted that index insurance could be scaled to the large numbers of farmers needed to meaningfully address poverty. There has been worry about low demand as well as concern that supply is blocked by technology, data, and infrastructure limitations.

New projects have solved many of these problems; these insurance projects have overcome many barriers.

As this progress continues, responsibility is increasingly important in index insurance projects. In small-scale pilots, it is possible to have expert, hand-crafted solutions and manually validate the products. At small scales, it is possible to respond effectively and fix a problematic product. As implementation scales increase, we must dramatically improve the robustness of our approaches. Prototype experimental solutions are no longer adequate.

At the IRI, we seek to bring advances in the use of seasonal climate information and financial mechanisms to improve livelihoods in developing countries. We have been involved in insurance, research, design, and evaluation for development and adaptation- oriented projects in over a dozen countries, working with partners to overcome barriers in index insurance through products with a solid science base, high take-up, dramatic scaling, and quantified positive impacts. Tens of thousands of smallholder farmers have purchased insurance contracts we have helped design through farmer-driven processes. We represent our insurance work in global policy processes such as the UN COP (Conference of the Parties) and GHF (Global Humanitarian Forum) meetings and our work has received attention in popular press outlets such as *The Guardian*, *Nature*, *The New York Times*, and by Reuters. In this text, we provide some of our perspectives on the important issues we have experienced in working to build a solid science base for farmer-riven index insurance. Since this text is not a literature review on issues in insurance, but rather a discussion on the role of science based on our perspectives, we direct the reader to the other abstracts in this conference volume, as well as Volume 2 of the Climate and Society publication [(1)], and its technical annex.

2. ISSUES, EXAMPLES AND SCIENCE

2.1. Key pieces

Index insurance is still in its early years and, as a global community, we are not only working on the technical challenges, but also still learning about its best role in climate risk management, development, and adaptation. Because index insurance does not provide effective protection against much of the risk that farmers face, it must be specifically designed to complement other risk management activities. Instead of attempting to build a tool that removes all risk from a farmer's life, the challenge with index insurance is how to build a tool that provides a farmer with the best risk reduction for the first dollar spent, when only a few dollars will be spent on insurance. The insurance must reduce the risk that cannot be addressed more effectively through other means, as the last piece of a livelihood and climate risk management system.

Identifying the appropriate insurance solution, while putting in place the necessary complementary solutions, requires that the farmer and the scientist both have a deep understanding of the products, trade-offs, solutions, and limitations. The process must be formally farmer-driven through an approach in which they can take ownership and responsibility of

1 http://portal.iri.columbia.edu/csp2

the results. Only the farmers truly understand the challenges that they face, and they are the end decision-makers who must help craft, and have a deep understanding of, the tools they use.

The process must also be built on solid science. If implementations are crafted without collaborating meaningfully with the experts who have developed the science tools used, then known limitations of the tools will be ignored, opportunities missed, and avenues for expanding the science to overcome challenges will not be identified and pursued.

The end goal of this effort is to make the insurance reliable and useful. If the insurance does not make the farmer money, then it is unlikely to be demanded, even if the premium is highly subsidised. In this respect, insurance is like a loan: if you take out insurance without using it to do something useful, you are losing money. The centrepiece of most successful index insurance projects is that they identify a productive activity that cannot be undertaken because of risk, and they build a risk management package completed by a little bit of insurance that allows the farmer to take that productive activity.

If a farmer cannot repay a loan for inputs one year out of five, the farmer may forego hundreds of dollars of potential profits in the other four years — even if the drought never occurs.

When insurance completes a package that reduces the risk of a farmer not being able to repay a loan for inputs enough such that it is safe for a farmer to take out the loan and use the inputs, the hundreds of dollars can often easily cover the insurance premium. It is, therefore, not a question of how much a farmer is willing to pay for insurance, but rather that the design process can arrive at insurance that unlocks more profit than the cost of the insurance, and how to address liquidity problems between the timing of the purchase of the insurance and the profits from the yields. This is very often a substantially different challenge than trying to find an index that is most closely correlated with historical yields, and requires a very sophisticated understanding of the problem by farmers, implementers, and scientists.

2.2. Examples

Beginning with transactions in about 2003, the BASIX project in India provided perhaps the first example of index insurance in the developing world: as it was breaking ground in exploring whether an index contract was possible at all, much of the focus was on the demonstration of concept. Therefore, the groundbreaking product was somewhat insurance-centric, focusing on what was implementable as a first step. Because insurance was not yet an existing product to be built into a holistic risk management and productivity-enhancing suite, the focus was on getting the insurance off the ground. The insurance was framed as a fairly literal translation of agricultural water stress models into derivative contracts in a way which resembled a traditional indemnity product as much as possible.

The early product forms the basis for much of the insurance today, and although groundbreaking, was only the first step. Since that initial work, many limitations have been uncovered and improved strategies developed. Some of the features of the early products make them challenging to integrate seamlessly into a holistic risk management and productivity enhancing solution. Other features of the initial indexes can amplify measurement noise. It is, therefore, important to remember that although it is a seminal starting point, many additional steps forward have been taken, even though index insurance is still very young.

Two years later, the World Bank led a project in Malawi providing a seminal example of index insurance targeting development. Built on a structure requested by farmers, it was a complete productivity-enhancing package. In this package, farmers received access to groundnuts through an index insurance product that specifically targeted the remaining covariate repayment risks remaining after farmers used joint liability groups, diversified crops, savings, and livestock. Although farmers paid the complete cost of the insurance, inputs, loan interest, and even tax, the demand for the product outstripped the insurance project capacity as well as that of related supply chains, constraining the size of the project to 1 000–2 000 farmers (see the case study in CSP2 for more details, as well as the other abstracts in these proceedings providing updates on Malawi insurance activities).

New projects have been overcoming many of these problems. These projects address liquidity constraints, use farmer-driven design, and carefully craft insurance to complement other risk management options. Logistical delivery challenges are being addressed by leveraging existing distribution systems, such as microfinance networks, seed distributors, work on food safety net programmes, and farmer cooperatives that are already delivering related products to large numbers of farmers.

A year or so ago, the largest African index insurance projects had around a thousand farmers. This year, multiple projects in Africa have tens of thousands of farmers buying insurance [2]. In parallel, projects in India have quickly moved to large scales, reaching about 10 million farmers by connecting with existing, subsidised government programs for loans [3].

At this level of scaling, it is becoming increasingly important to prevent large numbers of farmers from being exposed to problematic insurance products. It is essential that a system be developed in which farmers themselves, who are the only ones who truly know their needs, drive a multidisciplinary design process built on solid science and the real-world constraints of insurance companies and development partners. For success, the poorest farmers in the world must interact with the researchers expanding the frontiers of the most advanced technologies.

2.3. Science and insurance

When building a solid science basis for index insurance, a key challenge is to prevent the use of science as a technocratic and naive application of black-box ‘magical’ technologies. Instead, down-to-earth tool development based on meaningful design discussions between

2 For example: http://www.syngentafoundation.org/index.cfm? pageID=562; http://www.oxfamamerica.org/files/HARITA-quarterly-report-April-June-2011.pdf/at_download/file

3 http://econ.worldbank.org/external/default/main?pagePK=64165259&theSitePK=469372&piPK=64165421&menuPK=64166322&entityID=000158349_20120305105832

scientists, implementers, and farmers is needed. Often, science-based tools have known potential problems that implementers could easily check for, but do not because they are unaware of the issues. In other cases, science products may have applications in which they perform very well, but these applications are not identified — because the scientists are focused on an overly narrow insurance index correlation exercise and are not aware of the set of options in the broader design problem involving insurance as a piece of a full package.

For example, because insurance typically provides payments at a rate of one in five or ten years, it is only the most severe years that need to be triggered for payouts. Tools that may be inaccurate at quantifying yields in normal years might function well when configured to identify only the worst year out of five.

It may be that the challenge is even simpler. In many cases, for the best production, the farmer's challenge is to find a portfolio of crops that take advantage of as much time as possible. In other words, the farmer benefits from pushing the boundaries at the beginning and end of the rainfall season and is, therefore, highly vulnerable to the rainfall season starting late or ending early. Although not universal (e.g. in places with two rainfall seasons), it is common that all of the historical major loss years can be easily identified based on the rainfall failing at the beginning or end of the season.

If the key role of the insurance is to help the farmer take an expensive, but profitable, risk, the main reason the farmer may be interested in insurance may be simply to provide a meaningful payment to help them repay a loan in one of the years with an early or late rainfall season failure.

Therefore, technology may not be needed to measure precise yields, or exact rainfall, but instead flag a very obvious condition, such as the rainfall season being too short. Often, technologies work much more reliably on these kinds of tasks.

The challenge in this case is to find out if the technology can play a useful role reliably. Science does not necessarily have to provide the explicit trigger for the index, but instead provide the knowledge that the project is simplifying the problem correctly, that the, perhaps, simple trigger being used does, in fact, represent the key risk faced, and to bring the products up to a level of validation and reliability that can be quantified and communicated.

In some cases, a simple solution will be inadequate or inappropriate. It is important that we use science and a dialogue with partners and farmers to identify the right tools for the job, using sophisticated or simple solutions when appropriate.

The absence of comprehensive rainfall and crop data remains a key constraint in scaling insurance, since data is needed for index design and determining payouts. Index insurance is not scalable if it only works in areas covered by existing rain gauges with long histories. Many are hoping satellites could be the solution to this 'data poverty' problem.

However, satellite estimates are inaccurate and have many known failings. They cannot be applied blindly across all landscapes. For example, satellites face different problems interpreting a landscape with a lot of rocks, versus one covered by trees, or blanketed by grasses, or with a lot of water. One side of a mountain range may be fundamentally different from the other. Developing and validating the appropriate strategy for each location is essential so that farmers are not hurt by indexes based on bad data. This requires a more sophisticated use of geospatial data than ever before to link on-the-ground data, experiences, needs, and concerns with advanced satellite and climate model information.

Both rainfall and vegetation satellite indexes have been utilised in index insurance, with mixed results. Keys to success tend to be validation of the products, and application of the products in ways that they perform well (e.g. the failure of the end of the rainfall season). Often, it is not possible to accurately estimate rainfall or crop yields. However, these same tools are often reliable at flagging that the there were no cold, heavy clouds over a village when there should have been, indicating the rainfall season ended early, or that the entire landscape turned ‘brown’ in response to the early end of the season.

Because satellite vegetation products are based on completely different information to satellite rainfall products, and have very different strengths and weaknesses, satellite vegetation may be a good cross-check of how well satellite estimates of rainfall catch the bad years. However, initial diagnostics suggest there is much work to be done (4).

Many of the other abstracts in these proceedings will discuss exciting activity being undertaken to address these issues. From the IRI perspective, we have active projects with the UN International Labour Organisation (ILO) and USAID (5) to move forward, and we are building on our relationships with the JRC, NASA and other space agencies, and several index insurance implementation groups to try to provide more robust solutions so that projects can continue to be reliable as they expand. It is critical that multidisciplinary efforts not only include implementers and social scientists, but also earth scientists in a meaningful way.

One notable effort is the Google.org-funded work that the Ethiopian National Meteorology Agency has done in partnership with Reading University and the IRI (6). Using their expertise, knowledge of local rainfall patterns, and weather station network, the Ethiopian NMA has built a blended satellite/rain gauge gridded rainfall product of unprecedented coverage and accuracy (7). The launch of this product has provided a very important source of information for the R4/HARITA insurance efforts, which currently uses the US NOAA ARC satellite rainfall product to trigger payouts. Anyone online can access this advanced product through the Ethiopian NMA’s geospatial web server.

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4 http://iri.columbia.edu/publications/id=1002

5 http://www.microinsurancefacility.org/en/grantee/ig/ international-research-institute-climate-and-society-iri and http://iri.columbia.edu/media/ProjectandPartnerships/EGAT_FLYER_4_13.pdf

6 http://iri.columbia.edu/features/2012/a_model_ for_improving_climate_services_in_africa.html

7 http://www.wmo.int/pages/publications/bulletin_en/60_2_Tufa_en.html

Because of the high level of ground validation in the Ethiopian NMA product, it can make estimates using satellites that have been in orbit for decades and are more accurate than what has been done with the newest, most advanced satellites. This is extremely valuable for insurance because estimates using old satellites may be the only option to access the decades of uniform historical data necessary for index design, pricing, and studying climate trends. Ongoing efforts to bring this approach to other parts of Africa are likely to yield valuable satellite rainfall estimates for a wide range of projects.

In agricultural systems science, there are obvious connections to index insurance. Often, a crop growth model can be directly applied as an index. However, it is essential that this is done with care, as inappropriate models may have very little relationship to the losses that the farmer experiences [8], and some of the features of the models can amplify measurement noise dramatically, leading to expensive and inappropriate coverage [9]. Often, models require much more information than is available in an insurance application. Skilful application of models through meaningful interaction between scientists, implementers and farmers must be further encouraged, so that they are validated, and assured to filter noisy data and accurately target losses, as is described by other abstracts in this proceedings.

Perhaps the most valuable role of agricultural systems science is in identifying the productive opportunity blocked by risk that insurance might unlock, and providing insight and validation for whatever index approach is under consideration.

The 'dismal science' of economics has natural relevance in index insurance. However, as has occurred with many other scientific disciplines, there has been a great deal of naive application of economics, and it is very important to increase the sophistication of the link between economics and index insurance. Much of the academic insurance discussion is divorced from the implementation experience. The economic discussion on farmer demand is confusing and must be more directly and coherently linked to policy and implementation issues. Much of the economics research focuses on things that are easy to measure, as opposed to important, in informing projects. Economics, like agricultural systems, can provide a great deal of wisdom on how to unlock productive opportunities, identify complementary risk management options, quantify impacts, and provide insights on how to offer the appropriate integrated package of tools.

Seasonal forecasting in climate science has an intimate link to index insurance. In a naive insurance product, seasonal forecasts can undermine the financial viability of the insurance. For example, forecasts of drought can lead farmers to buy insurance only when there will be payouts, providing no premiums from non-payout years to cover the payouts.

But, there is a synergy between forecasts and insurance that might provide benefits greater than either intervention alone. Crafted together, insurance may remove sufficient

8 http://iri.columbia.edu/~deo/IRI-CRMG-Africa-Insurance-Report-6-2007/IRI-CRMG-Kenya-Tanzania-Malawi-Insurance-Report-6-2007.pdf

9 http://iri.columbia.edu/publications/id=875

risk from taking productive chances during ‘good’ forecasts to allow those chances to be taken, and may provide incentives for farmers not to take chances when the forecasts are ‘bad’.

Both the science and practical challenges in implementing this kind of insurance are formidable. However, very recently, important progress has been made on the practical implementation front with El Niño insurance being transacted in Peru and insurance being sold in Australia that pays out if seasonal forecasts lead crop models to predict yield failures (see other abstracts in these proceedings for more information).

Given these major implementation steps in the past year or two, it is clear that climate science and related statistical and financial innovations must move forward to assure that these and related implementations are indeed built on a solid science base.

Climate trends play an important role in insurance pricing. If the probability of drought is increasing, then prices should increase. Because insurance is priced for the upcoming year, it is not necessary to have complete knowledge of the climate 50 years into the future to be able to move forward. However, it is still very important to reflect the best state of knowledge about the changes that are occurring in order to accurate update probabilities and prices. Other abstracts in these proceedings will provide additional discussion.

One valuable role of science is in providing credible bounds on uncertainty, not only for climate change, but in each aspect of index insurance. If an insurance company has no knowledge of how bad things might be, the insurance company must put financial resources in place for the worst case, and a substantial cost to the end client. If absurd cases can be eliminated by science, then the costs can be lowered to reasonable levels. More generally, because insurance is a tool that provides protection for uncertainty, if the level of uncertainty can be quantified, protection can be provided, at a price. If the price is substantially less than the benefits of the productive activity to be taken, then the insurance is still effective in unlocking development and adaptation.

Insurance that responsibly reflects the best knowledge of decadal and long-term trends (and reasonable bounds on the uncertainty in those trends) can be important for adaptation. If climate change means that there will be more ‘bad’ years, then being more productive in ‘non-bad’ years is central to adaptation, which may be possible with well-designed insurance packages. Furthermore, if prices reflect the true probability of increasing drought in the face of climate change, they can incentivise transitions into improved practices or alternate livelihoods while, at the same time, providing protection from year-to-year risk so that short-term events do not undermine long-term adaptation trajectories.

In fact, many index insurance projects are specifically intended to help farmers adapt to climate change. However, it is rare to find a project that explicitly uses an adaptation framing to design the insurance product, or that concretely builds insurance into an adaptation program. Here, science has an important role to rebuild the index design and packaging process to revolve around climate change features and the specific adaptation issues and opportunities that exist.

3. CONCLUSIONS

As index insurance reaches larger scales, it is increasingly important to make a much more solid science base to insurance projects. We must find ways to make sure products are useful and safe for farmers, prevent science and technology from being applied naively and without scrutiny as 'false idols' but bring them down to earth through a meaningful dialogue, acknowledging their limitations. We must be able to identify when, and where, a product or technology is not sufficiently robust to offer as a solution, and make sure that scientists, insurance stakeholders, and farmers are all part of a meaningful and scalable process.

3 Index-based insurance: ideal solution or dangerous adventure — Some reflections

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KEYWORDS: **weaknesses of indices, remote sensing, reputation loss, training and awareness-raising**

SUMMARY

Weather Index Insurance (WII) in agriculture is urgently needed. It can be a good solution where better systems cannot be applied, for example in approaches based on public-private partnerships (PPP). Promising pilots of all sizes have existed for a few years in different models covering only a few smallholder farmers up to whole governments.

A new solution for the African Union is under way. The African Risk Capacity (ARC) has attracted some 15 countries from all over the continent. However, there are a number of bottlenecks, too. A current bottleneck to the wide implementation of WII is the weakness of indices; there will be little improvement without more efficient indices and additional experience gained from the implementation of WII products in the developing world. Current trends in index technology are exciting and they actuate high expectations, especially the development of yield indices and the use of remote sensing inputs. Risk protection and insurance illiteracy constitute another bottleneck, which has to be addressed by training and awareness-raising at all levels, from farmers to farmers' associations, micro-insurance partners, as well as senior decision-makers in insurance, banking, and politics. It is essential that all stakeholders (especially the insured) perfectly understand the principles of index insurance, as otherwise the insurer — even the whole concept of insurance — is at risk of reputation loss for years or decades. For now, it is urgent to lift WII above the pilot stage, which can only be achieved through the multi-annual commitment of all stakeholders. But WII will make its own way; what is seen today as globally successful insurance once started on a small scale.

International partners

4 Practical lessons from implementing weather index insurance for agriculture

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KEYWORDS: **weather, risk, agriculture, index, insurance**

SUMMARY

Since the late 1990s, there has been a lot of discussion and debate about the promise and potential uses of index-based agriculture insurance to manage weather risks in agriculture. The 2005 World Bank publication *Managing Agricultural Production Risk — Innovations in Developing Countries* set out, in some detail, the potential benefits of index insurance and some early examples of its application in developing countries. Since that time, a large amount of research and piloting of the product has been undertaken both within and outside the World Bank, largely targeting small farmers. However, despite this experience and effort, there have been few examples of successful scale-up at the farmer level, unless achieved through policy or financial tools by governments and/or significant financial support from donors. This note is based on the recently released World Bank Discussion paper *Weather Index Insurance for Agriculture: Guidance for Development Practitioners*, which is a summary of the findings of almost 8 years of research and development work into the topic.

1. INTRODUCTION

Weather Index Insurance (WII) aims to protect farmers against weather risks such as droughts and floods. An index-based weather insurance policy links possible insurance payouts with the weather requirements of the crop being insured: the insurer pays an indemnity whenever the realised value of the weather index meets a specified threshold. Whereas payouts in traditional insurance programmes are pegged to actual crop damages, a farmer insured under a weather index insurance contract may receive a payout, for example, in the event of too little, or too much rain. In this case, rainfall serves as a proxy for crop water need, which, in turn, is correlated with actual crop losses.

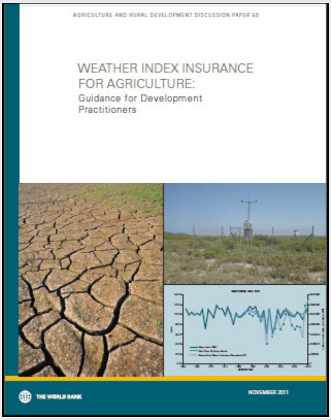

Figure 1: *Weather Index Insurance for Agriculture: Guidance for development Practitioners*, World Bank (2011)

Some potential advantages of index insurance over traditional crop insurance include: the elimination of field loss assessments; reduced information requirements and bureaucracy; greater transparency that facilitates reinsurance; and lower costs and greater affordability for farmers.

While insurance is generally the first thing that comes to mind for most people when they think of risk, it is important to understand that in agriculture, risk management mainly consists of three types of activity: mitigation, transfer, and coping. Mitigation covers a number of traditional activities. From irrigation to hybrid seeds, from vaccinations to pest control, many agricultural activities are really the application of risk management approaches. Transfer is the simple act of passing one's financial risk to a third party, who is prepared to accept it because they charge a fee or premium for the service — as, for example, in insurance and commodity price hedging. Coping comes into play after the fact, when an individual takes physical or financial measures to deal with the impact of a risk once it is realised. Before embarking on the use of a particular product, it is imperative to identify the risk and assess the potential application of one or a combination of the above risk management activities, including insurance.

Since the late 1990s, there has been a lot of discussion and debate about the promise and potential uses of index-based insurance in agriculture in developing countries. The 2005 World Bank publication *Managing Agricultural Production Risk — Innovations in Developing Countries* set out, in some detail, the potential benefits of index insurance and some early examples of its application in developing countries.

Since that time, a large amount of research and piloting of the product has been undertaken both within and outside the World Bank, largely targeting small farmers. However, despite this experience and effort, there have been few examples of successful scale-up at the farmer level without the help of policy or financial tools by governments, significant financial support from donors, or both. This paper is based on the recently released Discussion paper from the Agriculture and Rural Development Department (Figure 1).

2. LESSONS LEARNED

2.1. Pre-feasibility work

Pre-feasibility work is important, since data series may be incomplete or missing. The need for accurate and reliable data for the establishment of the index creates major challenges in many developing countries. For years, there has been underinvestment in meteorological services and infrastructure in developing countries: as a result, data series are very often simply not available. These data are necessary for the implementation of pilot programmes, and practitioners should identify whether these are available at the outset of the activity. In certain cases, there may be alternative solutions, by, for example, constructing synthetic weather data by interpolating field and satellite-based observations to create a higher resolution data grid.

2.2. Implementation of index insurance schemes

The implementation of index insurance schemes is technically very challenging and there is a lack of capacity in those countries where it would be most useful. There is currently a lack of technical capacity in the insurance sectors of most developing countries, which is a constraint to the scaling up and further development of WII. While it is possible, on a pilot basis, to use external consultants to design an index product and assist in roll-out, marketing, and sales, such assistance is not possible on a wide scale, simply because of the lack of qualified professionals. It usually requires intricate mathematical modelling, data manipulation, and expertise in crop simulation (the study of how plants relate to environmental variables, including climate) to design an index. Until such time as local capacity in these and other areas is developed, there will be a heavy reliance on scarcely available international technical assistance. The technical expertise required also makes the product expensive and difficult to market to potential policyholders.

2.3. Farmers actually want full indemnity

The very nature of an index-based product creates the chance that an insured party may not be paid when they suffer loss. Index products do not offer exact indemnity: a farmer can suffer a loss and not receive a payout, either because the index was not triggered, or because the loss was caused by a variable not covered by the index. This would be the case if, for example, a farmer had drought coverage and his crop was destroyed by a pest. Generally, farmers want indemnity from loss, no matter what the cause.

It is possible to structure insurance with multiple indexes, but this increases the complexity of the product and makes it difficult for farmers to comprehend it. 'Basis risk' is also a particular problem for index products. It is frequently caused by the fact that measurements of a particularly variable, such as rain, may differ at the insurer's measurement site and in the farmer's field. This also creates problems for insurance providers. Insurers face serious reputational problems when farmers pay premiums and suffer losses not covered under the index. Insurers run the risk that such incidents negatively impact other products that they sell in the market. Part of the reason the scaling up of index products has failed is that both insurers and farmers suffer from this basis risk.

2.4. Practical challenges

There are practical challenges to product roll-out and the establishment of a sustainable pilot, including the willingness of farmers to pay. The roll-out of a product and its sale to potential policyholders can be very time-consuming and complicated. In addition to all the technical challenges of establishing a weather index, it is not assured that farmers will be willing or able to pay premiums. Most farmers in developing countries have extremely low disposable incomes and a limited awareness of financial products such as insurance. Given this, most are reluctant to pay insurance premiums, as many do not monetise their crops — especially if their government has a history of writing off debts or providing compensation. Add to this the complexity of explaining how WII works and on what basis payouts are calculated and one can see that demand is a real obstacle to scaling up.

While WII may not require local presence in respect to field level assessments, it does require local presence during product roll-out and sales. To ensure that farmers understand the product, extensive awareness activities and training are needed. The costs inherent in such a process are prohibitive for most local insurance companies and, therefore, a major constraint to product development. Likewise, banks and local partners may be hesitant to cooperate and it may take a long time to market and sell the product to consumers in potentially remote farming communities.

2.5. Legal ambiguity

Legal ambiguity will continue to threaten the use of WII. It should be borne in mind that there is a lack of clarity as to the regulatory and legal status of index-based products in nearly all jurisdictions. Clearly, index products do not align with the traditional definition of insurance, as they do not indemnify actual loss and a policyholder does not need to have an insurable interest before they purchase an index-based contract. Certain commentators have referred to these products as little more than gaming or lottery type activities. Without strict regulation, buyers of these products will not have their interests protected by law.

3. CONCLUSIONS

Experience with the product has been mixed, but there appear to be some promising applications that can benefit farmers in developing countries. The following are areas in which WII or other index-type products show promise.

- **Large-scale commercial farming**

For large-scale farmers who have clearly identifiable and insurable losses, and revenue streams that enable them to pay premiums, WII can be an interesting option, especially where traditional insurance is not available or too expensive.

- **Financing tool for social protection schemes**

WII may not be for the 'poorest of the poor', because of their inability to pay premiums or lack of insurable interests, but the use of indexes at a district, regional, or national level can be a useful tool to generate funds for social protection measures in the case of natural disasters. Obviously, the issue of who will pay the premium and the establishment of distribution channels are important parts of the product design.

- **Portfolio risk management for intermediaries**

Input suppliers, banks, and processors often lend cash or product to a wide group of farmers and are, therefore, exposed to the same production risks. The use of WII by such intermediary stakeholders can be effective in reducing their exposure to certain risks. However, care should be taken, as many risks that actually drive farmer default cannot be covered by WII (e.g. side selling, price risk, and quality issues). In addition, there is a possibility that if a farmer is aware that their counterparty has insurance, the farmer will be more likely to default, even in cases where default is not due to a risk covered by the index.

- **Sovereign risk transfer at the macro level**

If a country is running a contingent risk that relates to a weather variable, the use of a WII product can be extremely useful. Although at this level, the product is slightly different in nature — a derivative, as opposed to insurance — the general principles are the same. The payouts received from such a derivative could be used to stabilise budgetary shocks, purchase food for vulnerable populations, or finance social safety net programs. While this is a very attractive form of risk management, countries often cannot finance premiums, or they face political challenges in the use of public funds for nontangible and potentially 'risky' premium payments.

- **Contingent finance, as opposed to risk transfer**

Very similar to the previous application, the use of parametrics related to contingent financing is another interesting use of the index model. However, in the case of contingent financing, a country faces slightly less 'risky' premium payments, which are replaced by much smaller commitment fees to access a line of credit, if needed. The main advantage for politicians is that they do not have to pay relatively large amounts of money and potentially receive nothing in return; with contingent finance, they have to pay back the credit used to compensate losses, but only in the case of the risk being realised.

This paper describes lessons derived from a number of agricultural index-based weather insurance pilot activities by The World Bank and its partners. It should be noted, however, that the field continues to develop, evolve, and benefit from innovations in many technical areas, with a number of new approaches being tested by other institutions. Weather index insurance faces many challenges but if a number of obstacles are overcome, it might still hold some potential for risk transfer in the agricultural sector in developing countries.

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Index insurance and risk management for food security and rural development: Experience from IFAD and WFP

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KEYWORDS: index Insurance, risk management, food security, rural development

SUMMARY

Half of the world's hungry people live on small farms. About 1.3 billion people live on less than a dollar a day, and 70 % of this population depends on agriculture to survive. They often live on marginal lands characterised by low rainfall, sloping terrain, fragile soil, and poor market access. Risk management tools such as index-referenced financial support mechanisms, including insurance, have proven to be an effective instrument in addressing food insecurity and poverty at national and community levels. This paper introduces a cutting-edge research project conducted by the IFAD-WFP Weather Risk Management Facility that examines how remote sensing can support the development, scaling up and sustainability of index insurance for food security. Outcomes of the research will directly feed into the application of index insurance at various levels including the WFP and Oxfam America-led R4 Rural Resilience Initiative, the largest global innovative and groundbreaking comprehensive risk management initiative that combines risk reduction with savings, credit and risk transfer.

1. INTRODUCTION

Half of the world's hungry people live on small farms. About 1.3 billion people live on less than a dollar a day, and 70 % of this population depends on agriculture to survive. They often live on marginal lands characterised by low rainfall, sloping terrain, fragile soil, and poor market access. Yields are typically at or below subsistence level. Frequent natural and man-made disasters have exhausted communities' coping capacities. Stagnant investments in agricultural production, by the governments of underdeveloped countries, donor countries, and intergovernmental institutions, have led to declining harvests and severely degraded land.

For the poorest rural families, the inherent risks of agriculture are life-threatening. These risks are magnified by increasingly unpredictable climate patterns: more than 40 % of farmers in developing countries already face weather-related threats to their crops (World Bank, 2005). The effects of climate change are expected, in the coming years, to exacerbate the already high risk of weather shocks faced by these populations. Conservative projections indicate that unless there are significant efforts to improve livelihoods, reduce poverty, and build climate resilience, by 2050, climate change will increase by 100 to 200 million the number of food-insecure people worldwide (Parry, et al. 2009).

In light of their precarious existence, and in the absence of financial services that meet their needs, poor rural households adopt extremely conservative risk-taking strategies that often compromise their ability to improve their well-being in the near term and can have long-term consequences such as poverty, malnutrition, low education levels and low life expectancy. Indeed, studies have shown that households sacrifice up to 30 % of their current income by investing in low-risk, low-return activities (Morduch, 1995). The decision to avoid any high-return risk taking — such as using credit to purchase improved seeds and hire labour — precludes long-term livelihood improvement. Micro-finance institutions are typically reluctant to offer credit to the poorest households because they have no reserves to tap when repayment is due. If a harvest fails, farmers lose everything.

As a result, poor households often rely on informal mechanisms to self-insure against risk, such as community-based savings and lending groups. However, shocks that affect whole villages or regions, such as droughts, can quickly overwhelm these traditional strategies. To survive, households are often forced to resort to negative coping strategies, such as reducing food consumption, removing children from school, or selling productive assets during periods of stress. While these strategies ensure short-term survival, they compromise future ability to diversify and improve livelihoods.

2. WEATHER RISK MANAGEMENT FACILITY

2.1. Background

The Weather Risk Management Facility (WRMF) [(1)] is a joint initiative between two United Nations agencies, the International Fund for Agricultural Development (IFAD) and the World Food Programme (WFP). Launched in 2008 with the support of the Bill and Melinda Gates Foundation, the WRMF draws on IFAD's experience in rural finance and on WFP's expertise in disaster-risk reduction and management. As such, it aims to support the development of innovative weather and climate risk management tools that improve rural livelihoods and reduce hunger.

One way the WRMF does this is by developing and supporting innovative weather and climate risk management tools, including index insurance. Building on lessons learned from pilots and research, the WRMF identified key constraints and success factors in the uptake, sustainability and scalability of index insurance [(2)].

IFAD and WFP are now working on trying to address the identified key constraints including limited availability and accessibility of quality weather data. In order to do so, the WRMF have launched a new applied research project to understand if, and how, remote sensing can be best applied to index insurance

2.2. Remote sensing for index insurance

'Improving Weather Risk Management in West Africa: Evaluation of Remote Sensing for Index Insurance' is an applied research project designed to test the feasibility of index implementation based on remote sensing technology for poor rural smallholders vulnerable to drought risk.

Conventional weather index insurance (using weather stations) and area yield index insurance (using crop yield data) —especially at the micro level — suffer from significant constraints, such as lack of appropriate weather station coverage and adequate yield information. In many cases, these constraints represent a severe limitation to the introduction and scaling up of insurance products — both traditional crop and indexed insurance.

Remote sensing offers strong opportunities for development of new insurance instruments for indexation and, despite a different set of technical, organisational and financial challenges, it may offer new opportunities by removing some of the obstacles encountered by other approaches. Despite the promise, there is a need for public investment in researching and developing a sound approach. The specific goal of this project is, therefore, to research and

1 http://www.ifad.org/ruralfinance/wrmf/

2 http://www.ifad.org/ruralfinance/pub/weather.pdf

develop sustainable index insurance products for smallholder farmers who are producing crops in drought-prone areas of developing countries. Any successfully piloted methodologies could then feed into existing IFAD and WFP programmes such as the R4 Rural Resilience Initiative (Chapter 3).

The project will focus on West Africa as the vulnerability of smallholders to weather risk there presents a strong case for index insurance, yet it has the existing constraints of lack of sufficient ground-based weather and yield data, together with complex climatic, weather and agricultural characteristics. The project will, therefore, address implementation needs, research and evaluate methodologies (Table 1), focusing on selected test locations in West Africa.

Table 1: Improving Weather Risk Management: Evaluation of Remote Sensing for Index Insurance in West Africa — Project phases and activities

Phases	Main activities
Phase 1: Detailed weather risk vulnerability assessment and mapping	One to four pilot areas selected for testing in Phase 3
Phase 2: Identification of remote sensing methodologies for index insurance	Review of technologies, applications, constraints, opportunities; key players
	Selection of up to four technologies to test
Phase 3: Development and testing of methodologies in pilot area(s)	Operation during cropping season
	Ground evaluation
Phase 4: Overall assessment of results and dissemination	Relevance and application of remote sensing for index insurance
	Integration of successful methodologies into IFAD, WFP and wider programmes

Beyond the test locations, the activities proposed in this project could represent a new model for index insurance, which could push the frontier for the entire industry. If it succeeds in the test locations, the results would have positive implications for other countries in sub-Saharan Africa, particularly the Sahel, which may also benefit from index insurance, that have yet to make significant progress in its implementation. Although the primary focus of this project is on remote sensing to support index insurance, it is expected to inform and indicate potential wider benefits of the technology in: promoting increased food security and productivity; protecting smallholder farmers against drought shocks; discussing wider potential applications; and the integration of the technology into WFP and IFAD initiatives.

3. R4 RURAL RESILIENCE INITIATIVE

3.1. Background

The Rural Resilience Initiative (R4) is a joint initiative of the United Nations World Food Programme (WFP) and Oxfam America (Oxfam America) to build on the initial success of HARITA [(3)] by launching the model at a large scale in multiple countries. The partnership leverages Oxfam America's expertise in disaster risk reduction (DRR), private sector engagement, cash and food-for-work projects, and partnership management, and the WFP's technical capacity and experience with safety nets, food assistance, cash and food-for-work, and insurance.

The mission of the R4 partnership reflects the strategic goals of both organisations. The WFP, through its Strategic Plan 2008–13, is moving from food aid to food assistance, in which the scope of food assistance in context of WFP's interventions includes meeting hunger needs, strengthening local markets, increasing small farm-holder productivity and building national capacities. Oxfam America's strategic intent is underpinned by a comprehensive methodology to address the root causes of poverty, hunger and injustice through a rights-based approach focusing on capacity-building and sustainable livelihood solutions [(4)].

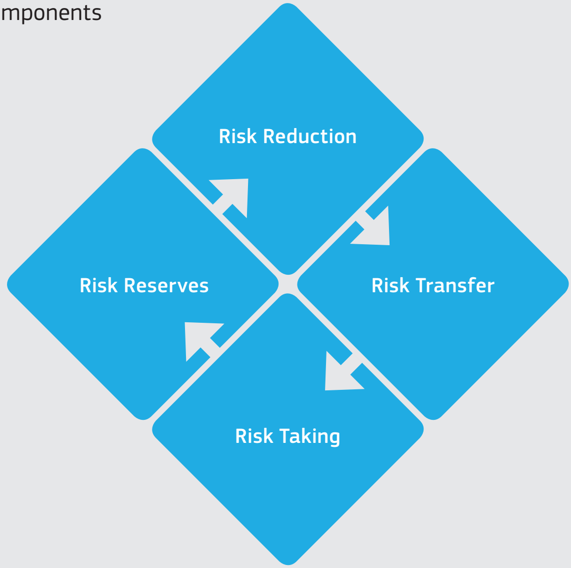
R4 provides a new model for building resilience, using existing government-owned and led productive safety nets to reduce disaster risk and as a delivery mechanism to expand insurance and other financial services to create an enabling environment for pro-poor market growth. By working in diverse microclimates, R4 allows insurance companies to diversify risk and open up new markets. This will attract additional insurance and reinsurance companies to the agricultural market in developing countries. In turn, farmers will benefit from an increasingly broad array of insurance products from which to choose and competitive pricing that should bring down premium rates over time. Founded on the principles of collaboration and mutual support by the public and private sectors, farmer-owned agricultural cooperatives, and intergovernmental organisations, R4 focuses on long-term, sustainable solutions to reduce poverty and hunger by building rural resiliency.

From a donor perspective, the R4 model doubles investment value: while a certain dollar amount of aid could be used in traditional development programmes either to pay an insurance premium or to pay farmers to carry out risk-reduction measures, in this project, the same amount of money yields insurance and risk reduction simultaneously.

3 The Horn of Africa Risk Transfer for Adaptation (HARITA) is an integrated risk-management framework developed by Oxfam America, the Relief Society of Tigray and their partners. HARITA has broken new ground in the field of rural risk management by enabling Ethiopia's poorest farmers to pay for crop insurance with their own labour. HARITA has shown promising results and has grown from 200 households in one village in 2009 to over 13 000 enrolled households in 43 villages in 2011, directly affecting 75 000 people.

4 http://www.oxfamamerica.org/issues/insurance

Figure 1: The four interlinked R4 components



3.2. R4 Approach

The R4 approach to managing rural risk integrates four risk management strategies to support poor rural households and small farmers to build resilience, achieve food security and develop and protect their livelihoods (Figure 1).

Risk reduction: Safety nets

The core of the R4 approach is to link labour-based safety nets, which provide cash or food in exchange for work on community and household assets, with community risk reduction activities that protect assets against disasters and improve productivity.

While WFP is widely known for providing food assistance to vulnerable populations, it also seeks to support hunger solutions that go beyond direct provision of food. The WFP provides technical support to government-run safety nets around the world. Safety nets help food-insecure households to stabilise their livelihoods and food access by providing predictable food and income, often in exchange for work. In the case of R4, this work is focused on reducing risks posed by weather and climate variability, such as soil and water conservation — the risk reduction component of this initiative.

In addition to risk reduction activities, the R4 approach adds three more risk management tools that enable beneficiary households to go from stabilising income and access to food, to diversifying and building more resilient livelihoods that provide a pathway for these households to achieve food security: insurance (risk transfer), savings (risk reserves), and credit (smart risk-taking).

Risk transfer: Affordable insurance

The R4 approach empowers the poorest farmers to obtain weather insurance by contributing their labour to community risk reduction projects.

Large-scale weather-related shocks, such as drought, can often be beyond the capacity of poor households and their communities to manage. Through R4, cash-poor households can purchase insurance through their own labour: insurance-for-work. When a drought or other weather disaster occurs, insurance payouts are provided through existing safety net programmes, streamlining the process by leveraging established delivery channels: the cash or food-for-work payment mechanisms already in place. This grafting of insurance on to existing mechanisms has been identified as a best practice for scaling up insurance for poor rural households because it provides necessary coverage and incentives for productive investments (Hazell, 2010).

Over the last decade, micro-insurance has increasingly been recognised as a key element in helping the rural poor deal with risk. Affordable risk management products, such as agricultural insurance, reduce the uncertainty and impact of weather-related disasters and the livelihood threats that they pose. With well-designed micro-insurance products, compensation for weather-related losses enables productive assets to be replaced and stimulates faster recovery. The predictability of income can reduce negative risk coping strategies and stimulate rural households to invest in activities and technologies that offer a higher rate of return (Skees, 2008).

Better-off community members are also offered the opportunity to purchase insurance, but by cash, not labour. In Oxfam America's HARITA pilot expansion in Ethiopia in 2010, 27 % of insurance policies were purchased with cash by community members who did not participate in the food and insurance-for-work components of the project.

The development of insurance-for-work as a mechanism to increase the effectiveness of safety nets in the face of weather-related risk is a significant potential outcome of the R4 initiative. Moreover, R4 has the capacity to generate a global market for insurance among poor populations, expanding their access to financial services that fit their needs. If successful, a global market could be generated that would lower the costs of insurance for the poor, and expand access to financial services.

Risk-taking

Beneficiaries are offered increased access to credit: they are empowered to take 'prudent risks' and develop livelihoods that are less exposed to increasing climate risks.

Insurance can unlock credit at better rates, giving farmers the ability to invest in seeds, fertilisers and new technologies to increase their agricultural productivity. Accessing credit and investing in productive assets, such as livestock, is made possible through the guaranteed income provided by food and cash-for-work programmes or, in case of a weather-induced disaster, by the insurance payout. But these investments are still vulnerable to climate and other shocks, including price volatility: in the R4 model, this vulnerability is addressed through risk reduction activities, savings, and insurance.

Risk reserves

The R4 approach helps beneficiaries establish small-scale savings to build 'risk reserves'.

Savings not only allow households to build a stronger financial base for investing in their livelihoods, but also act as a buffer against short-term needs and increase a household's ability to cope with shocks. Group savings can be loaned out to help individual households that have a particular need, acting as a self-insurance mechanism for the community. R4 will work with beneficiaries using proven methods to support household savings, building on Oxfam America's extensive experience in this area.

Current plans foresee reaching 500 000 food insecure and vulnerable households over 5 years in four countries, including Ethiopia and Senegal, with an integrated risk management and food security programme that will augment the capacity of existing safety nets in support to poor rural households.

R4 is recognised by key WFP partners as one of the most promising models for addressing hunger using an integrated risk management approach in line with the current G8 and G20 discussions. USAID has, in fact, already provided USD 8 million to WFP to implement R4 in Senegal.

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6 Index insurance in agriculture — The (re)insurer's perspective

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KEYWORDS: agricultural insurance, index-based agricultural insurance, index insurance, weather index insurance, area-yield insurance, public-private partnership, PPP, remote sensing, crop growth model

SUMMARY

Index insurance has been on the agenda for at least two decades now. Much progress has been achieved in the area of index insurance, especially in product design. Nevertheless, the high expectations placed on index insurance, especially in developing economies, have not been fulfilled. This is mainly due to the fact that the solution was sought at the product level first and foremost, with no appropriate conceptual and institutional framework having been established at the start. The basic element of such a framework is a public-private partnership (PPP) between the state, the farmers, the (re)insurance industry and the banking sector. Furthermore, the potential of weather-triggered policies was overestimated: at farm level, area-yield index products are more feasible. Technological advances will lead to more accurate yield assessments, thus enhancing yield-based insurance solutions. To accelerate this process, research should be focused on the different aspects of yield assessments.

1. INTRODUCTION

Index insurance has been on the agenda for at least two decades now. The objective of index insurance is to design insurance cover based on a predefined trigger which is not directly linked to the real loss in the field, thus eliminating some of the disadvantages of indemnity-based insurance products.

Much progress has been achieved in the area of index insurance, especially in product design (see Table 1).

Table 1: Index insurance products at a glance

Production	Type of index	Perils covered	Application
Crop	Meteorological trigger	One to two selected perils only	India (precipitation), Canada (heat units in corn), pilot projects in several developing economies (cf. Hazell et al., 2010)
	Area yield trigger	All climatic risks as a package	India, USA
	Vegetation index (remote sensing)	Only indirect	Not yet applied for arable crops
	Multiple factors in crop growth model	Selected perils only	Experimental stage
Grassland	Meteorological trigger	One to two selected perils only	Canada, USA
	Vegetation index (remote sensing)	Only indired	Canada, USA, Spain
Livestock	Based on measured livestock mortality	Indirect all risks	Mongolia
	Based on vegetation index	Indirect all risks	Kenya (pilot)

Nevertheless, the high expectations placed on the capacity of index insurance to solve the problem of the lack of risk transfer solutions in developing economies have not been fulfilled. The outreach of index insurance, and its impact on poverty reduction in rural areas in particular, have proved much lower than anticipated. In this paper, the reasons for these developments are investigated and a number of ideas on how to proceed are presented. This analysis is undertaken from the perspective of the risk-taker, the insurer or reinsurer respectively.

2. MISCONCEPTIONS CONCERNING INDEX INSURANCE

2.1. The solution lies in the insurance product

In the process of designing appropriate insurance solutions for agriculture in developing countries, the most prevalent mistake is to look for the solution at the product level first and foremost. The fact that an insurance product alone — either an index-based insurance product or an indemnity-based insurance product — cannot solve the problem of a lack of access to financial services is often ignored.

Each agricultural insurance product needs an appropriate conceptual and institutional framework. Therefore, it is essential to pursue a system-level approach before determining which insurance product is appropriate. In a nutshell: a system approach comes before a product approach.

The elements of a system approach are as follows.

- **Institutional framework in the form of a public-private partnership (PPP)**
  The PPP is made up of the state, the farmers, the (re)insurance industry and the banking sector [(1)]. The basic function of the state lies in setting up the legal framework and providing co-financing of premiums and catastrophe losses. The involvement of all major stakeholders in the agricultural insurance system is essential.

- **Effective organisational set-up**
  For this important element, it is best to pursue a cooperative rather than a competitive approach. A co-insurance pool and a centralised technical entity are successful models that permit combining forces and the limited technical know-how available in developing countries.

- **Response to heterogeneous structures in the agriculture of developing countries**
  The objective of an agricultural insurance system is to provide appropriate insurance solutions for the different social sectors (small, medium and large farms).

- **Efficient marketing channels**
  In order to market the insurance in a cost-effective manner and achieve a reasonable outreach, production credits should be linked with agricultural insurance.

1 For more information on the organisation of the PPP and the functions of the different stakeholders, see Herbold (2010) and Herbold (2012).

2.2. Lower transaction costs for index products?

The argument often advanced and repeated is that index products have lower transaction costs. A closer look, however, reveals the following.

- Development costs are substantially higher for index products, as the product design is complex and the availability and reliability of the data limited. Furthermore, the methodologies used are applicable only to a limited extent to other countries.
- Marketing costs and policy administration costs are at the same level if the premiums charged per area are similar. If the premiums per area are lower, such costs account for a higher percentage of the premium.
- Costs for the loss adjustment in the field are considerably lower in the case of index products, no loss adjustment being necessary in the field.
- Other loss management costs are at the same level.

In conclusion, there is no clear evidence that index products involve lower transaction costs. However, only further research based on the costs of actual operations can answer the question.

2.3. Who are the drivers of index insurance?

Index insurance and weather index insurance in particular are mainly driven by researchers, development agencies, donors and international organisations and not by farmers, the (re) insurance industry, the banking sector and governments. The relevant activities are often triggered by project funds.

3. OVERESTIMATED POTENTIAL OF WEATHER INDEX INSURANCE

In the international discussion, the following shortcomings of weather-triggered policies are often overlooked.

- Relatively low correlation (as low as 60%) between the trigger and the yield actually harvested: implications include a considerable basis risk affecting the individual farmer and a reputational risk for the (re)insurer, especially if crop losses occur but, in accordance with the policy terms, no indemnity is payable.
- Weather stations should cover the entire geographical area. They should be tamper-proof and form a dense network. However, these requirements are often not met.
- Policies are difficult for farmers to understand.

As a consequence of these shortcomings, demand for weather-triggered policies has been much lower than anticipated. Furthermore, scaling-up of pilot projects limited to specific crops or regions to national, sector-wide insurance schemes has proved to be very difficult.

4. WHERE DOES INDEX INSURANCE WORK AND WHERE DOES IT NOT WORK?

4.1. Farm level

For crop production, more potential lies in area-yield products than in weather-triggered policies because they are simpler and more accurate, and the basis risk is lower if the yield is assessed directly instead of being determined on the basis of indirect factors such as precipitation. Yields can be based on the following.

- Official regional production data: this is the standard approach nowadays, but entails the problem of time delays.
- Random sampling of actual yields in the field: it is essential to have a sound methodology for sampling and yield assessment in place.
- Yield assessment by remote-sensing technology and crop growth models in the form of a future application (Section 5.1).

For grassland production, vegetation index insurance based on remote sensing technology and precipitation index insurance are feasible.

An overview of the commercial applications of index-based insurance is given in Table 2.

4.2. Meso level

Table 2: Commercial applications of index insurance in selected countries

Country	Type of production	Index product	Premium [million €]	Liability [million €]	Farmers insured [million]	Area insured [million ha]
India (2009/10)	Crop	Area yield (NAIS)	185		23.7	
	Crop	Meteo trigger (WBCIS)	76		2.3	
USA (2011)	Crop	Area yield (GRP)	333	3879		2.1
	Grassland	Meteo trigger (Precipit)	77	355		12.5
	Grassland	Vegetation index (NDVI)	4	26		1.4
Spain (2010)	Grassland	Vegetation index (NDVI)	13	109		

Sources: AIC (2010), IRDA (2010), RMA, Agroseguro (2010).

On the meso or aggregate level, for example covering a crop credit portfolio or a cooperative, both area-yield and meteorological triggers are feasible, although the advantages of the area-yield triggers referred to above (Section 4.1) apply.

An exemplary credit portfolio cover could be structured in the form of a double trigger using the credit default rate (e.g. greater than 20 %) and an area-yield trigger.

The advantage of the meso-level approach is that the basis risk is pooled. However, the problem of how to distribute the indemnity among the individual beneficiaries, for example lenders or cooperative members, still has to be resolved. It is of the utmost importance that this issue be addressed in the insurance agreement.

5. OUTLOOK ON TECHNOLOGICAL ADVANCES

Technological advances will enhance yield-based insurance solutions for the agricultural sector, facilitate product development and improve loss assessment.

A combination of the technologies mentioned below in the yield assessment process will be vital if further progress is to be made. For example, remote sensing technology is able to deliver input data for advanced crop growth models and achieve more accurate yield assessments. However, the results always have to be calibrated and cross-checked against ground truth yield data. In future, it will be possible to obtain such data from automatic yield recording devices on harvesters and combines.

5.1. Remote sensing

Applications of remote sensing include: plot identification, yield estimations, assessment and monitoring of loss events and vegetation status, insurance products (e.g. based on vegetation indices or area yields).

The challenges for the future are as follows.

- **Identification of crop type**
  It can be expected that this will be possible in the near future for cereals, oilseeds and tuber crops.

- **Assessing yields**
  In the near future, it may be possible to assess regional yields for cereals, oilseeds and tuber crops with sufficient accuracy provided the cultivation structure is homogeneous, with subsequent application to area-yield products.

  It will be much more difficult to assess individual plot yields. The currently available spatial and temporal resolution (both being required simultaneously in high definition) is not sufficient. Therefore, the availability of corresponding satellite technology is the first requirement. Also the size of the plots to be assessed will be crucial.

5.2. Crop growth models

Further progress in yield assessment can be achieved using remote sensing data on vegetation status as additional input parameters for crop growth models. Research should also focus on the following aspects.

- Considering yield variability as a consequence of extreme weather events: current models are inaccurate in reproducing yields in the event of extreme weather hazards occurring.
- Developing yield models with few input parameters in order to facilitate application.
- Determining the variability between regional yields (from official statistics) and site-specific/individual yields. This could vary according to crop and growing conditions.

5.3. Automatic recording of yield

Automatic recording devices are already a widely used form of technology in combines and harvesters in developed countries. Nevertheless, further improvements are necessary, mainly in the following three areas: tamper-proof and fraud-resistant recording, calibration methods, and accuracy

6. CONCLUSIONS

- Index insurance products — like all other agricultural insurance products — need an institutional framework: a system approach goes before a product approach.

- Agricultural insurance systems based on public-private partnerships will lead future development.

- The potential of weather-triggered policies has been overestimated: at farm level, there is more potential in area-yield products.

- Product concepts for the meso level have to overcome the problem of how to distribute potential indemnities to individual beneficiaries.

- New and more accurate technology will lead to advances in yield-based insurance products and loss assessment. Research should focus on the different aspects of yield assessments.

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7 Challenges in structuring and pricing index-based risk transfer products in emerging markets: a reinsurer's perspective

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KEYWORDS: agriculture, food security, index insurance, risk transfer, emerging markets

SUMMARY

As part of risk mitigation strategies, financial risk transfer solutions, for example crop insurance, can help to secure farmers' income and reduce their livelihood risk in case of crop failure. In recent years, index-based agricultural risk transfer products have become increasingly popular in emerging markets, having the relative advantages of fast loss settlement as well as cost-effective and simple administration compared to indemnity-based products. However, with the exception of India, the markets for such index-based risk transfer schemes are still too small to be commercially sustainable. The major challenges for further market development and scaling up of index-based risk transfer solutions in emerging markets are briefly highlighted here. These challenges can be grouped into three areas: (i) data availability and data quality; (ii) basis risk and simplicity of payout definitions; and (iii) effective and efficient distribution.

1. INTRODUCTION

Agriculture is the key mainstay of the economy in most developing countries with a significant part of the population being dependent on subsistence farming. Consequently, food security remains a major concern with crop failure having a devastating impact on people as well as the economy, as recently experienced in the Horn of Africa.

Achieving food security requires actions along the entire agricultural value chain, including access to inputs, storage, transportation, agricultural extension services and credit. In particular, access to production and infrastructure credits is closely linked with access to an adequate financial risk management. Agricultural risk transfer solutions, for example in the form of insurance, are an integral part of farmers' risk mitigation strategies and have contributed to reduce their financial and livelihood risks.

While indemnity-based products are dominant in the global agricultural insurance market, they face various challenges in emerging markets including the lack of adequately trained loss adjusters, high administrative costs, and moral hazard. These issues can generally be overcome by index-based solutions where the payout is defined as a function of an index based on data measured and reported by third parties.

The most commonly used indices are based on weather parameters such as rainfall or on official yield statistics. However, while, in indemnity-based schemes, loss adjusters visit the farmers' fields and estimate their individual losses, the settlement of index-based schemes is determined by pre-agreed payout functions that do not take into consideration farm-specific aspects such as soil quality. The resulting difference between actual losses and the payouts of index-based products is known as basis risk and is often considered a major obstacle for successful scaling up of index-based risk transfer schemes.

It should be noted, though, that for indemnity-based products, there may also be some basis risk as payouts are dependent on the individual loss adjuster's assessment and are possibly biased by sampling errors, even though, through training and experience, the basis risk of such schemes is considered to be minimal.

While index-based products are well known in developed markets for insuring fodder and other non-standard risks, they are the only choice in many emerging markets. An analysis of the major challenges currently faced in the development of index-based risk transfer solutions is, therefore, important and will help to determine the areas which need particular attention and actions in order to reach a commercially sustainable scale.

This review of the major challenges and opportunities of index-based schemes in emerging markets is based on the author's experience in providing the technical support for an estimated 90 % of all index-based insurance schemes in sub-Saharan Africa.

2. CHALLENGES TO SCALING UP INDEX-BASED RISK TRANSFER PRODUCTS

Generally, the major challenges currently faced in index-based risk transfer solutions in emerging markets can be grouped into three areas: data, basis risk, and distribution.

2.1. Data

Considering that the payout is not based on the farmer's actual yield but rather on a proxy index, the data used to construct such an index are of critical importance. As described earlier, the most common data types are weather and (area aggregated) yield data. Independent of the type, market standards as established by risk-takers operating mainly in/out of OEDC countries (Table 1, top row) require data to be of sufficient length (20–30 years for weather, 15–20 years for yield data), quality (few gaps, homogeneous), and availability (costs, timeliness for loss settlement). The reality in emerging markets is often very different from these standards (Table 1, bottom row) making the structuring and pricing of index-based products very challenging or even impossible: weather data are often only available for 10–15 years (even less for yield data) and there are frequently gaps, a lack of information about data history/quality and possible inhomogeneities, for example due to changes in the location, instrumentation or surroundings. Furthermore, as long historical weather time series are often only available from locations remote from the agricultural production areas, new weather stations are occasionally installed closer to the farmers' fields and proposed to be used for settlement. This has, however, the disadvantage that the weather regime of this new site is largely unknown, thus making the accurate structuring and pricing very difficult or even impossible tasks. For yield data, common challenges, though often not limited to emerging markets only, are the non-standardised data collection process and the large inter-annual changes in yield due to, for example the use of fertiliser and other inputs. This makes it very difficult to determine the expected yield which is to be used as reference to assess the farmers' production shortfall.

There exist, however, opportunities to, at least partly, overcome these data issues: for example, the often sparse and short data time series from ground weather stations can be complemented by gridded information from, for example, satellites. Such gridded data could represent a major step forward as they often provide high resolution in both space and time, and generally cover a sufficiently long time such that they can be used in index-based risk transfer products. Recent projects such as, for example, HARITA in Ethiopia have successfully used gridded weather data. To further explore the potential of gridded data collaboration between research institutions, product developers, and risk takers should be intensified.

Table 1: Market standards established by risk-takers in OECD countries

	Data	Basis Risk	Distribution
'OECD-market standard'	• 20-30 years • No gaps • Homogeneous • Near real-time	• Validated • Minimized • Understood by all stakeholders	• Distribution channels dedicated to insurance (e. g. retail insurance agents) • No selling past inception of risk calculation period • Good time management
'Emerging market reality'	• 10-l 5 years • Lots of gaps • Inhomogeneous • Settlement weather station distant from historical weather station	• Not validated • Minimized based on data from similar regions • Not understood by all stakeholders	• Distribution through non-insurance channels • Selling past inception date of risk calculation period • Sub-optimal time management as products are new and/or sales period dictated by marketing of bundled product

2.2. Basis risk

While index-based risk transfer products have the advantage of allowing for an objective, fast, and efficient claim settlement process, they have the limitation of basis risk. Generally, basis risk is considered a larger issue for weather than for yield-based indices with three sources of basis risks commonly being distinguished for weather indices: (i) index-related basis risk, which is introduced as yield losses can be caused by many more factors than those captured by the index; (ii) temporal basis risk, which stems from the mismatch between the calculation periods of the indices and the actual crop growing phases; and (iii) spatial basis risk, which is related to the limited geographical resolution of the index calculation.

To define indices and to quantify and minimise basis risk, historical yield data are needed. As such statistics are often not available, index definitions are based on calibrations between weather data and the yield in other regions; hence, the basis risk inherent to such pilot schemes is not well understood (Table 1).

An additional challenge is the complexity of index definitions: in an attempt to minimise the basis risk, many different parameters are used to design indices for various growing phases, some of which have start dates that are a function of the weather, thus making them increasingly difficult for all the stakeholders, including the local insurance companies and, most importantly, the farmers, to understand and relate to the index.

In order to overcome these basis risk issues, product developers should reserve sufficient time to gather all available written or oral reports of historical yields and aim to design an index that is not only scientifically sound but also practical in the field.

2.3. Distribution

Given the usually small premium per farmer, it is critical to distribute the product in a cost-efficient way and to aggregate risks such that they can be transferred to reinsurers. Both distribution and aggregation need to be done in a commercially sustainable manner and hence, to justify the costs of such processes, projects need to be of sufficient scale.

This is a major challenge in rural areas with an often poor infrastructure. Consequently, already existing rural networks, for example Microfinance Institutions (MFIs) or agricultural input providers, are used to distribute index-based risk transfer products thereby often bundling them with the distributor’s own products such as credit or seeds. While the cooperation with distribution partners is essential to reach scale, their participation can also cause additional challenges, for example when, due to late credit disbursement, the sales period of the index-based risk transfer products might be extended into the calculation period of the insured crop possibly causing adverse selection (Table 1). Furthermore, since many stakeholders (farmers, data providers, product developers, (re)insurers, distributors) are involved in index-based risk transfer schemes, processes at times are so delayed that the partners are unable to sell the product in time for the growing season.

Clearly, distribution is a key factor for a successful scale-up of agricultural risk transfer schemes in emerging markets. While the bundling with credit has been successful in several countries, agricultural lending is still limited. Therefore, alternative distribution channels such as input providers, grain handlers or food processors, if they have contract farming relationships with producers, should be explored. Finally, in order to facilitate the policy administration, innovative technologies such as the M-Pesa mobile phone platform currently used in Kenya by the Kilimo Salama project to collect premiums and issue payments, seem promising.

3. CONCLUSIONS

Index-based risk transfer solutions are considered an important contribution to agricultural risk mitigation strategies in emerging markets with several pilot projects having been launched in the last few years. However, with the exception of India where the success has also been driven by regulatory actions such as subsidies and mandatory risk-taker involvement in rural areas, index-based risk transfer products are still mostly in their pilot phase and have not yet reached a commercially sustainable scale. The major challenges which need to be addressed concern the data availability and quality, basis risk and the practicability of the indices, and the successful and timely distribution through channels which are often not dedicated to only selling insurance. Clearly, multi-stakeholder initiatives are needed in order to overcome these issues.

Besides these more technical issues, actions are also needed for building local capacity in the areas of underwriting, product development, distribution, and policy administration as well as for the set-up of a legal and regulatory framework for index-based risk transfer products.

In conclusion, considering the large number of jurisdictions where pilot projects are currently being implemented as well as the challenges related to the design and marketing of index-based agricultural risk transfer schemes, scaling is unlikely to be as fast as is being experienced in India. However, in many markets, such schemes are the only feasible solution and, hence, worth further development.

National experiences

8 Using weather index insurance to combat food insecurity: Malawi Case

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KEYWORDS: **Malawi, food security, weather index insurance, credit, groundnut, tobacco**

SUMMARY

The effects of climate change have not spared the Malawian farmer but rather exacerbated the food insecurity challenge. Dry spells, drought, excess rainfall and floods are becoming the order of the day making it difficult for a peasant farmer to feed his family. Recently, weather index-based insurance, has proved to be a solution to the weather challenge. Farmers' livelihoods have been improved through weather index insurance and several households have been saved from food insecurity.

1. INTRODUCTION

1.1. Malawi's social economical background

Malawi ranks among the world's most densely populated and least developed countries. The economy is predominately agricultural with about 80 % of the population living in rural areas. Agriculture, which has benefited from fertiliser subsidies since 2006, accounts for one third of GDP and 90 % of export revenues [(1)].

Malawi is highly vulnerable to impacts of climate change, particularly as it relates to agriculture and rural livelihoods (AfDB, 2011). The country has traditionally been vulnerable to natural disasters because of its unique geo-climatic conditions. In view of the country's high vulnerability profile, the recurrent phenomena in the form of hydro-meteorological hazards affect millions across the country leaving behind a trail of losses in the form of lives, property

1 http://www.indexmundi.com/malawi/economy_profile.html

and livelihoods. In part of the country, disaster losses tend to outweigh the development gains. The economic and social losses because of droughts and floods continue to mount year after year (RMSI, 2010). Only 19 % of the Malawi's population is banked and less than 3 % is insured (FinScope, 2008).

1.2. Major challenges faced by the farmers

The Malawian smallholder farmer is surrounded with many challenges, the major ones include: lack of access to inputs and finances; lack of extension services; lack of access to market and market information; and bad weather.

1.3. Weather risk in Malawi

The nature and pattern of weather-related risks is shifting and becoming unpredictable, increasing in frequency, intensity and magnitude as a result of climate change. Over the past 10 years, there have been three major droughts and seven floods of significant proportions. Recurrent and prolonged dry spells have been persistent in many parts of the country even in the absence of pronounced droughts. Dry spells are blamed for between 20 % and 30 % of crop loss yield per hectare when such events occur during the critical periods of crop development. The 2009 nationwide Comprehensive Food Security and Vulnerability Assessment (CFSVA, 2010) found that 18–80 % of households assessed reported drought as the main shock experienced during the 2008/09 crop season. These adverse climatic conditions represent shocks that have led to food insecurity and malnutrition for affected households [2].

1.4. The poverty trap

Food insecurity issues are exacerbated with weather risks and poor households suffer most because they lack risk-transfer technologies. Better-off households are able to move more quickly out of shock because they have better cushions in the form of savings, livestock and other non-financial assets which can be liquidated in times of crises. The opposite is true for poor households who have little or nothing to lean on when catastrophic events hit their households. It takes much longer time for a poor household to recover from weather shocks and, in many cases, the households are pushed below the poverty threshold and do not recover at all.

1.5. Weather index insurance in Malawi

The concept of weather index insurance was first introduced in Malawi in 2005 by the World Bank. Different stakeholders were involved in the pilot study: the National Smallholder Farmers Association of Malawi (NASFAM) a farmer-based association; Opportunity International

2 WFP Malawi Country Strategy 2012–16.

Bank of Malawi and Malawi Rural Financing Company (financing Institutions); Insurance Association of Malawi (an umbrella body for insurance companies); and the Malawi Meteorological Department (which provided historical data and daily rainfall readings). MicroEnsure successfully coordinated the implementation of the project with technical and financial support from the World Bank from 2005 to 2009.

The Insurance Association of Malawi was invited to participate in the project; however, this being an area in which it had no expertise, it was involved as a risk-taker but to a very small extent as the rest of the portfolio was reinsured overseas.

The pilot programme started in Malawi in 2005 with groundnut farmers under NASFAM. Groundnut was chosen because of its sensitivity to drought and marketability. A total of 892 farmers were recruited for the project. A total sum of USD 37 000 and USD 12 000 was insured for Opportunity International Bank of Malawi and Malawi Rural Finance Company (MRFC), respectively. Side selling took centre stage and affected the success of the programme. The weather index insurance project was taken as an *ex ante* solution to the drought that caused food insecurity in Malawi.

2. FOOD SECURITY AND WEATHER INDEX INSURANCE

2.1. Coping strategies

People have different coping strategies when drought hits. Research conducted by Kakota showed that coping strategies for shortages of food due to less rainfall, dry spells and droughts included: skipping meals or reducing the number of meals per day so that food lasts longer; reducing the quantity of food; substituting usual meals (maize flour, or *nsima*) with less preferred meals such as vegetables, fruits, porridge and locally diluted drinks. In the case of reduced water and firewood resources, households cope by using water sparingly and using energy-saving technologies for cooking. Other strategies such as selling livestock and other assets, food for work, finding alternative livelihoods such as selling charcoal and off-farm employment also provide temporary relief for households (Kakota et al., 2011).

The 2005/06 pilot did not directly address food security issues as only groundnut (a commercial crop) was piloted. However, during the following season (2006/07), maize was included. The number of farmers increased from 892 to 1 800 and the sums insured increased from USD 37 000 to USD 80 000 for Opportunity International Bank of Malawi while MRFC did not participate due to credit management issues. Generally, farmers bought the premiums because they were presented as bundled products (credit and insurance). However, this cropping combination of maize and groundnuts proved to be ideal for farmers as they had food and cash crops both covered with weather index insurance.

The pilot worked to the advantage of farmers as payouts adding up to USD 1 245 were made at the end of the season. These payouts were triggered as a result of dry spells in Lilongwe District.

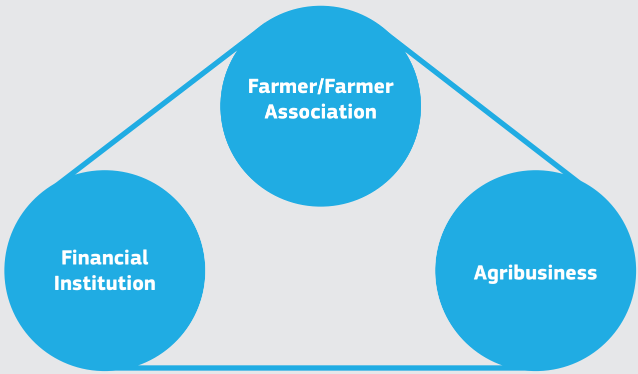
2.2. The success of weather index insurance

Although the 2006/07 weather index insurance model included maize, it was not a success for the financial institutions because maize and groundnut have open markets and it is difficult for any lending institution to recoup money loaned to farmers. Maize, again, is a political crop where the government controls the price to ensure that consumers are able to afford the staple food. Therefore, this made it necessary to change the lending model.

In the 2007/08 growing season, a tripartite lending model was introduced in the weather index insurance to address side selling issues and give leverage to the financial institutions to recoup their funds. In this model, the financial institutions worked with farmer associations who were on out-grower schemes or contract arrangements with an agribusiness company. The latter provided extension services and guaranteed a market while the bank provided financial resources for inputs. Farmers accessed the loan in kind through inputs which they obtained through the agribusiness and they sold their crops at an agreed price to the agribusiness which paid the farmers through the bank. Through this arrangement, the bank was able to deduct the loan before remitting the balance to the farmer.

In this model, groundnut was replaced with tobacco, mainly because tobacco is well regulated and has a structured market. Because of its attractiveness to the industry, the sum insured increased from USD 80 000 to USD 310 000 and eventually to USD 2 402 804 in 2008 and 2009, respectively, covering 2 533 farmers.

Figure 1: Agribusiness lending model



The weather index insurance programme in Malawi did not only address the food security issue but it proved to be a livelihood solution as farmers have had access to farm loans which translated to food on their tables and cash in their pockets from tobacco sales (Figure 1).

3. CHALLENGES FACED IN THE IMPLEMENTATION OF WEATHER INDEX INSURANCE

3.1. How to communicate insurance concepts to farmers?

Although the weather index insurance project has resulted in combating food insecurity in Malawi, it has had its own challenges; the key issues among these many challenges are discussed in this section. The first is the fact that insurance is a new concept in Malawi and the word does not exist in any of the local languages. This makes it a challenge to explain the complex issues of weather index insurance to farmers in a way that is easily understood by them.

3.2. How to sell insurance to the farmer?

In Malawi, people do not talk in public about future eventualities. Culturally, talking about future catastrophes such as accidents, funerals, burglary, and disasters is not acceptable by many. On the other hand, farmers think the only benefit of insurance is when they receive the payout. One farmer in Chiwamba EPA asked the awareness team: “What if drought does not happen? Where will my money go?”

3.3. Microclimatic conditions and basis risk

Within the same locality, climatic conditions differ and since the index takes measurements from the weather stations only, it leads to basis risk.

3.4. Limited number of automated weather stations

The country has only 26 automated weather stations and this is not enough to cover many farmers bearing in mind that one weather station covers a radius of 20 km. In some cases, the weather stations are far away from farming communities — because most of them were built for aviation purposes.

3.5. Financial institutions are only interested in cash crops and not food crops

Banks in Malawi are not very interested in financing food crops, preferring cash crops, so farmers are encouraged to grow a combination of cash and food crops.

3.6. Farmers are interested in the credit facility as opposed to insurance

Research has shown that although there is a huge appetite for weather index insurance, farmers are only interested because it is bundled with a credit. So it is the credit that motivates the farmers however farmers are now able to access that credit because the weather risk is covered.

4. CONCLUSIONS

The success of weather index insurance in combating food insecurity is better captured at different levels of the value chain.

For farmers, weather index insurance is important because it has helped them access loans for cash and food crop production. In return, this brings food security and income from crop sales.

For financial institutions, the weather index insurance helps them cover their portfolio from weather risk and, for insurance companies, a profitable business case with a low loss ratio is what they call a successful programme.

All in all, although the weather index insurance is not a panacea but it has proved to be a livelihood solution to the Malawian farmers in combating food insecurity.

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9 Insuring the poor: the experience of catastrophic agricultural insurance in Peru

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KEYWORDS: crop insurance, agriculture, index insurance, catastrophic insurance

SUMMARY

Agriculture is the main economic activity that generates employment in Peru, but it is an activity that suffers from a wide range of both climatic and non-climatic risks. There is a high probability of negative impacts on households' incomes and assets, especially among the most vulnerable fringe of the population living in rural areas. In 2007, the Gobierno Nacional (National Government) created the Fondo de Garantía para el Campo y del Seguro Agropecuario (Guarantee Field Fund and Agricultural Insurance) to finance agricultural insurance mechanisms. It is offered through the insurance system, designed to reduce the exposure of farmers (such as rural communities, and native, small and medium farmers) to climate risk and the impact of pests that negatively affect production and profitability. Since the beginning of the catastrophic agricultural insurance programme (2009–10, 2010–11 and 2011–12 seasons), La Positiva Seguros has compensated almost 116 000 people in the Regions of Cajamarca, Huanuco, Pasco, Ayacucho and Puno. The payouts were mainly made through the Banco de la Nación (National Bank). The accumulated loss ratio of La Positiva Seguros after the three mentioned agricultural campaigns is 66 %, which is equivalent to USD 13 349 661 and represents more than 70 % of the payouts of this national programme.

1. INTRODUCTION

Agriculture in Peru suffers from a wide range of both climatic and non-climatic hazards, with a high probability of negative impacts on households' incomes and assets. This especially affects the most vulnerable in rural areas who practice subsistence agriculture and cultivate less than 0.250 ha. Almost 66 % of the agriculture depends on rain and the production of 15 000 ha of various crops is lost every year because of climate variability.

Agriculture is the main economic activity that generates employment. Even though most of the people engaged in agriculture live in conditions of poverty or extreme poverty, they generate more than 7.5 % of the GDP and constitute more than 23 % of the economically active population and 65 % of the rural economically active population.

Law 28939 that created the Fondo de Garantía para el Campo [(1)] with a capital of USD 31 036 623 was published on 22 December 2006. On 1 April 2007, its scope was expanded and its name changed to Fondo de Garantía para el Campo y del Seguro Agropecuario [(2)] and on 21 July of the same year, its capital was reduced to USD 12 670 256 by Law 29064. The implementation and operation of this Fund is governed by Law 29148 of 13 July 2007.

The transfer mechanisms of the capital from the Fund were specified by the Decreto de Urgencia [(3)] 030-2008 (5 July 2008). Almost one month later, on 20 August, the general and special conditions of the agriculture insurance were approved. The operational regulation of the Fund was ruled by the Decreto Supremo [(4)] 019-2008-AG (21 September) to enable it to be used in a trust [(5)]. Six months later (19 March 2009), the trust contract between the Ministerio de Agricultura [(6)] (MINAG) and COFIDE [(7)] was approved with the Decreto Supremo 008-2009. Finally, on 8 July 2009, the co-financing scheme was approved for the payment of the agriculture insurance premium for the agricultural period from August 2009 to July 2010. This financing scheme has also been approved for the agricultural periods from August 2010 to July 2011 and August 2011 to July 2012.

Agricultural insurance in Peru is a financial instrument regulated by Law 26702, which covers risks for agricultural production and livestock production. Its purpose is to finance agricultural insurance mechanisms, offered through the insurance system, designed to reduce the exposure of farmers, such as rural communities, and native, small and medium farmers, to climate risk and the impact of pests that harm production and profitability.

Traditional, multi-peril crop insurance, common in developed countries, determines payouts through loss assessments performed through costly and time-consuming individual farm visits that evaluate the damage of a weather event on a farmer's field. In developing countries, the costs associated with these types of assessments can be very high, due to small farm sizes and the condition of the transport infrastructure (Bryla and Siroka, 2007).

1 Guarantee Field Fund.

2 Guarantee Field Fund and Agricultural Insurance.

3 Urgent Decree.

4 Supreme Decree.

5 A Trust is the transmission of one or more assets, amounts of money or rights, present or future, to a natural or legal person called trust, to be managed or invested pursuant to a contract, on behalf of himself or a recipient.

6 Ministry of Agriculture.

7 COFIDE is a Peruvian development bank (http://www.cofide.com.pe/).

Index insurances are linked to an index, such as the level of precipitation, temperature, moisture and crop yields, rather than to actual loss. The approach provides a solution to some of the problems that limit the application of crop insurance in rural areas of developing countries.

La Positiva Seguros is the third company of the Peruvian insurance market with more than 4 million people insured. It has more than 75 years of experience in developing innovative products for new markets such as:

(i) the first area-yield index insurance for cotton producers;
(ii) the first life micro-insurance for farmers and their families;
(iii) the first index insurance for El Niño; and
(iv) more than 280 000 ha of subsistence agriculture insured by the catastrophic agricultural insurance next to the traditional agricultural insurance

2. CATASTROPHIC AGRICULTURAL INSURANCE

This scheme was designed by an international consultant appointed by the MINAG in the form of an area-yield index insurance that uses as a trigger the 40 % of the mean yield of the crop insured in a region: in this case, the statistical sector of a district [(8)]. the gobierno nacional [(9)] subsidises 100 % of the premium's cost. This scheme of insurance protects farmers, mainly the poor and extremely poor, in the presence of a catastrophic risk, where 'catastrophic' means that the regional impact results in the complete or almost complete loss of crops insured within the statistical sector.

This kind of insurance does not cover the cost of production. It is aid from the Gobierno Nacional (i.e. MINAG) for the agricultural producers at subsistence level, the poor and extremely poor.

The risks covered by this insurance are climatic hazards such as drought, hail, freezing periods, variations in air temperature, excess of humidity, strong winds and floods. Because it is oriented to the poor and extremely poor, it also covers biological risks like crop diseases, pests and predators.

The characteristics of this insurance are:

(i) **it is comprehensive** (i.e. all the producers of the Gobierno Regional [(10)] (GORE) and crops selected by the MINAG are insured);
(ii) it is **catastrophic** (i.e. it pays compensation when the yield of a crop insured within the statistical sector is less than 40 % of the mean yield); and
(iii) **which crops are insured** is defined by the MINAG and the GORE.

8 The political and administrative divisions of Peru are the region, province and district. The division of statistical sector within the district is used by the MINAG in order to compile the agricultural statistics. The statistical sector is composed of agricultural and non-farm land within the district, bounded by natural and cultural elements (channels, ditches, roads, railways, etc.) for easy identification, represented in cartographic documents in digitised form provided by the MINAG.

9 National government, central government.

10 Regional government — the plural is Gobiernos Regionales (GOREs).

There are five actors in this scheme.

(i) The **Gobierno Nacional** that pays 100 % of the premium and defines the technical parameters of the insurance.

(ii) **Fondo de Garantía para el Campo y del Seguro Agropecuario**, composed of three members: one member from the MINAG, one from the Ministerio de Economía y Finanzas [11] and one from the Presidencia del Consejo de Ministros [12]. They have the responsibility of approving the request of this insurance.

(iii) The **GORE**, which signs the contracts and appear in the policy as the insured.

(iv) La **Positiva Seguros**, which takes the risk and pays compensation if required.

(v) **The producers**, those who receive the compensation.

At the beginning of this insurance scheme in 2009–10, seven regions were selected by the Gobierno Nacional: Cajamarca, Huanuco, Huancavelica, Ayacucho, Apurimac, Cusco and Puno. The criteria used were that they are the poorest ones. La Positiva Seguros had four regions of this portfolio. In 2010–11, one more region was included by the Gobierno Nacional and La Positiva Seguros had five regions in this portfolio and four in 2011–12.

This scheme works in four main steps (illustrated in Figure 1):

(i) if a catastrophic event occurs, farmers inform the MINAG;

(ii) the MINAG informs La Positiva Seguros;

(iii) La Positiva Seguros then sends experts to evaluate the area;

(iv) if the evaluation shows that there was, indeed, a catastrophic event that is insured, La Positiva Seguros pays compensation to the GORE.

Figure 1: The four principal steps of the catastrophic agricultural insurance scheme

11 Ministry of Economics and Finance.

12 Presidency of the Council of Ministers.

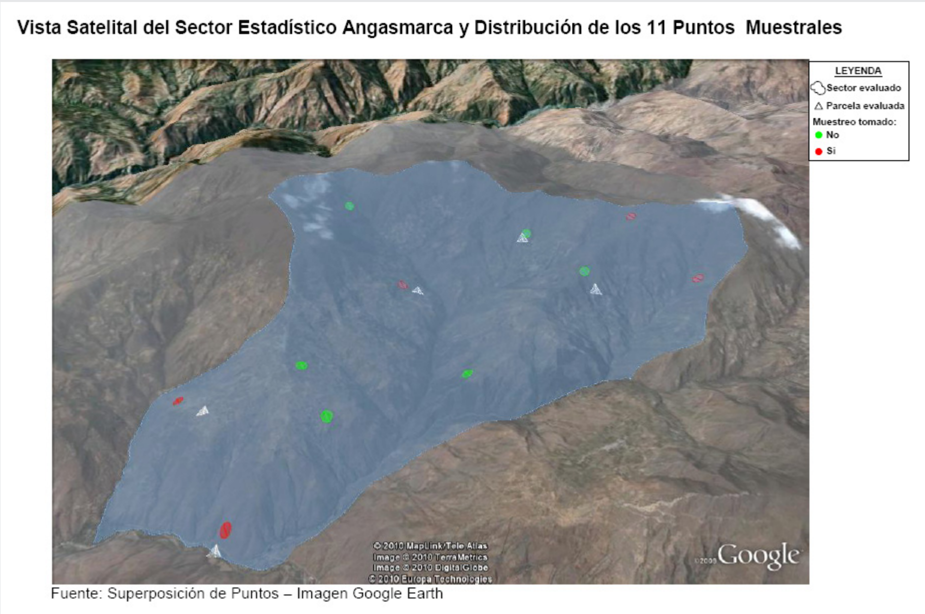
To assess whether or not a reported event is catastrophic (i.e. covered by the contract, Steps 3 and 4) three sub-steps have to be followed.

(i) Using random numbers and a table of factors (Kendall and Babington-Smith, 1938), 11 points are chosen in every statistical sector that was identified by the MINAG. Figure 2 shows an example of the distribution of the points within the statistical sector.

(ii) The crop yield is calculated at each of the 11 points, as well as mean yield of the statistical sector.

(iii) If the mean crop yield of the statistical sector is less than 40 % of the historical mean yield, then a catastrophe has occurred and La Positiva Seguros has to pay the compensation that is in the contract to the GORE. This process is valid for all ensured crops.

Figure 2: Distribution of the eleven points within the Angasmarca Statistical Sector (Huánuco)



There are two ways to hand over the compensation to the GORE.

(i) The entire amount is given to the GORE and then it pays the compensation to the producers. The GORE is required to submit detailed accounts of the producers who are compensated, including the given compensation. La Positiva Seguros pays the costs incurred for the elaboration of the producers' account.

(ii) La Positiva Seguros pays the compensation directly to the producers through the Banco de la Nación [13], or other financial institution. The GORE is required to send a detailed account of the producers to be compensated together with the given compensation. The costs incurred for the elaboration of the producers' accounts and the fees charged by the Banco de la Nación, or other financial institution, for the transaction are covered by La Positiva Seguros.

Even though the cost of the preparation of the producers' accounts and the fees charged by the Banco de la Nación, or other financial institution, for the transactions were not included in the contract or premium, La Positiva Seguros pays these charges because this is a transparent way to be sure that farmers receive their compensation. Finally, after three years of this scheme, La Positiva General Insurances has made arrangements to create savings accounts at the Banco de la Nación for all the farmers that are going to receive compensation; the MINAG and the Banco de la Nación will enter into a contract to in order to benefit from cheaper transactions fees. This is a positive step in direction of the introduction of special financial products to rural farmers.

At the beginning of this scheme, the Gobierno Nacional selected the crops that were insured (the most common in most areas are potato and maize — amilaceo). One of the GOREs disagreed with this procedure because one of the selected crops was not a regional priority. Based on this experience, in the following campaigns, the crops to be insured were selected by the GOREs.

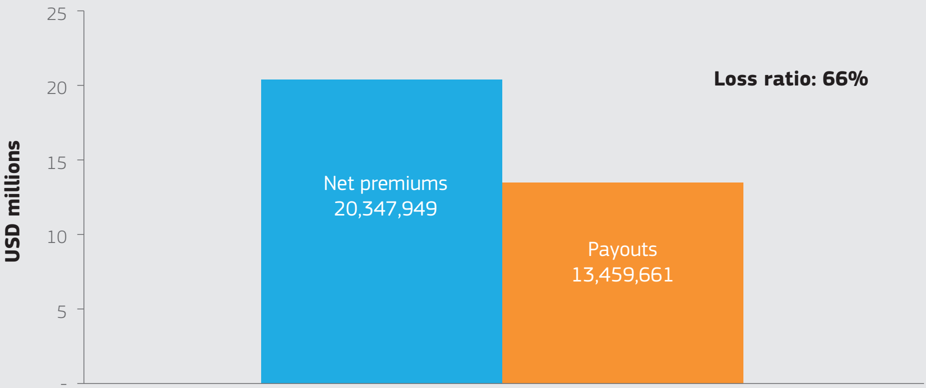
Another important improvement is that the Gobierno Nacional and GOREs have agreed that the crops that have to be insured are the main crops of the region (because some GOREs insured as many as 87 different crops, making the evaluation process very difficult).

The total land areas that have been insured are: 271 804 ha in 2009–10; 280 978 ha in 2010–11; and 193 810 ha in 2011–12.

13 National Bank.

3. RESULTS OF THE CATASTROPHIC AGRICULTURAL INSURANCE PORTFOLIO OF LA POSITIVA SEGUROS

Figure 3: Accumulated loss ratio of La Positiva General Insurance's Portfolio (payouts include the cost of adjustments)



The accumulated loss ratio after three agricultural campaigns (2009–10, 2010–11 and 2011–12) is 66 % as shown in Figure 3. This is equivalent to USD 13 349 661 and represents more than 70 % of the payouts of this national programme. The accumulated loss ratio in 2009–10 was 42 %, 106 % in 2010–11, and 41 % in 2011–12.

In 2010–11, La Niña increased the rain in many regions of the highlands; the most affected was Ayacucho, where the rain in the period January–March was the greatest of the last 15 years, followed by Puno, as shown in Figure 4.

These payouts were made through the Banco de la Nación and a micro-insurance institution, Caja Nuestra Gente. In 2009–10, there were 25 228 producers who received compensation according to the local branches of these institutions. In 2010–11, the number of producers was 77 502 and there were about 16 000 producers in 2011–12. So, since the beginning of this programme 118 730 producers have received compensation from the catastrophic agricultural insurance. Only the region of Pasco decided to pay the producers directly.

The characteristics of the producers that have received compensation are:

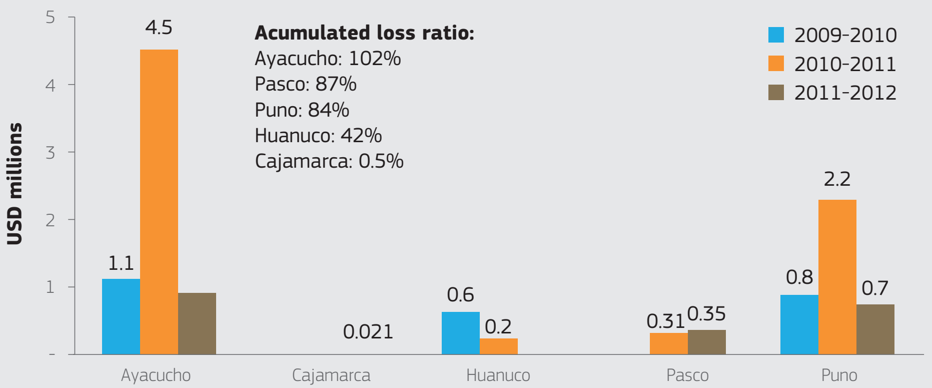
(i) they have almost 8 years of basic education (in Ayacucho and Puno), although they should have 11 years;
(ii) 88 % are poor and 74 % extremely poor;

(iii) most do not have access to financial services;
(iv) most reinvested their compensation in agriculture;
(v) some pooled their compensation to repair irrigation channels; and
(vi) for some, it was the first time they had visited a financial institution.

After three years of operation of the catastrophic agricultural insurance the following challenges can be identified.

(i) The assignation of the money to the Fondo de Garantía para el Campo y del Seguro Agropecuario to buy insurance has to be on time. This was the case only in 2009–10, when the funds were available in October; during the following two years, the money was made available when the season was more than 50 % over, in February (2010–11) and in May (2011–12).
(ii) Even though La Positiva Seguros has made some progress in trying to create a culture of insurance in rural areas, explaining how this product works to the people of the insured regions (employees of the MINAG Regional [14], local leaders and authorities) is not enough; the Gobierno Nacional should have a more determinant role in this.
(iii) Some groups of the Gobierno Nacional and GORE do not understand that this mechanism of risk transfer is just one part of the management of disaster risk reduction and climate change adaptation, not the 100% solution.
(iv) Crop yield information, even though the area insured is the statistical sector, most of the official data from the MINAG Regional is provided by district and it is assumed to be representative for the whole of the statistical sector. On the other hand, as this scheme is purely technical, it's inducing the MINAG to improve statistics.

Figure 4: Payouts of La Positiva General Insurance's Portfolio by agricultural campaign: Pasco was included in the scheme from 2010–2011; Huanuco was not insured by La Positiva Seguros in 2011–12



14 Regional Ministry of Agriculture.

4. CONCLUSIONS

Some 116 000 producers from Cajamarca, Huanuco, Pasco, Ayacucho and Puno have received compensation in the three years of operation of the catastrophic agricultural insurance in Peru: all of them were insured by La Positiva Seguros.

The payouts were mainly made through the Banco de la Nación. The costs incurred in the elaboration of the producers' accounts and the fees charged by the Banco de la Nación, and other financial institutions, for the transactions were paid by La Positiva Seguros.

La Positiva Seguros has made arrangements to set up savings accounts at the Banco de la Nación for all the farmers that are going to receive compensation. The MINAG and the Banco de la Nación will enter into a contract in order to benefit from cheaper transaction fees. This is progress on the way to introducing special financial products to rural farmers.

The accumulated loss ratio of the catastrophic agricultural insurance of the portfolio of La Positiva Seguros after three agricultural campaigns (2009–10, 2010–11 and 2011–12) is 66 %. This is equivalent to USD 13 349 661 and represents more than 70 % of the payouts of this national programme.

The characteristics of the producers that have received compensation are:

- they have almost 8 years of basic education (Ayacucho and Puno), although they should normally have 11 years;
- 88 % are poor and 74 % extremely poor;
- most do not have access to financial services;
- most reinvested the compensation in agriculture;
- some pooled their compensation to repair irrigation channels; and
- most insured producers visited a financial institution for the first time when they collected their compensation.

There are some challenges to be overcome in order to make the programme better.

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10 Evaluation of the existing rainfall index insurance experience in Ethiopia's Nyala Insurance Company (NISCO), Ethiopia

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KEYWORDS: market-based risk transfer, weather index crop insurance, *post ante*, scalability

SUMMARY

Agriculture is the dominant sector in the Ethiopian economy: 83 % of the population earns its livelihood from agriculture and more than 43 % of the GDP and 87 % of the export earnings are generated from agriculture. However, this sector is characterised by subsistence rain-fed farming dominated by smallholders (with less than 1 ha holding) who account for 90 % of the agricultural undertaking.

These smallholder farmers are highly susceptible to frequent and severe climate risks mainly deficit rainfall (drought).

Existing climate risk mitigation mechanisms among the rural community in the country rely mostly on traditional (informal) ways of risk sharing and risk smoothing; they are not suitable for dealing with climate risks with a very high covariant nature such as drought. Hence, when farmers are exposed to a climate calamity, they usually resort to selling their productive assets including animals for survival; this, in turn, entails its own impetus for perpetual poverty.

1 This summary was prepared by Biniam Tadesse with some input from Shukri Ahmed, FAO. Demelash Birara attended, and delivered the presentation at the meeting.

Reliance on government [2] and external emergency aid is also another *post ante* way out in place. In both cases, until recently, there was no market-based risk transfer mechanism.

To this effect, Nyala Insurance — one of the leading private insurers in Ethiopia — introduced two innovative insurance products: Double Trigger Multi-peril Crop Insurance (DTMPCI) in 2007 and Weather Index Crop Insurance (WII) in 2009. The former uses weather data as a trigger and a benchmark plot based loss assessment for indemnification; the latter relies solely on the weather data to decide payouts.

The insurance scheme is primarily deemed to protect the livelihoods of smallholders by lessening their vulnerability to catastrophic weather risks. It is also expected to bring about a productivity increase by boosting the confidence of smallholders to take the risk of investing in improved inputs. Above all, the scheme is believed to enhance smallholders' access to agricultural credit by impacting lenders' hesitation to extend credit to smallholders vulnerable to climate risk.

Over the last 5 years, close to 28 000 farmers were insured via farmers' cooperative unions, micro-finance institutes and other social organisations locally called *Idder* and *Iqub* [3]. WII cover was provided for crops identified as vital in respective localities: teff, wheat, barley, beans, maize and some others can be mentioned in this connection.

The major challenge in scaling up the WII service in Ethiopia includes (but is not limited to) the following:

- limited availability and poor quality of infrastructure especially weather stations;
- poor quality of weather data;
- financial illiteracy among the rural community;
- inaccessibility of reinsurance facilities and
- limited technical know-how and capacity on the insurers' side.

Amidst the above mentioned challenges, there exist immense opportunities for scaling up due to the sizeable potential demand for WII: climate risk is perceived as a credible threat among the rural community and there is room for productivity improvement through the enhancement of agricultural credit and input use.

Needless to say, diversification of insurance products and government support is essential to establish and strengthen the Ethiopian farm insurance market.

2 Government actions mainly include safety net programmes and other measures addressed via the Disaster Risk Management and Food Security Sector (DRMFSS) of the Ministry of Agriculture.

3 Funeral Service and Savings Association, respectively.

11 Index-based crop insurance in Senegal and West Africa: some concerns based on ongoing experiments

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KEYWORDS: insurance, index, climate, agriculture, basis risk, Senegal, West Africa

SUMMARY

Agricultural insurance is just starting in West Africa (WA) with the recent launch of some index-based insurance pilot projects. However, it is already possible to stress some important issues based on those experiments and also considering previous knowledge on climate and agriculture in WA. As regards climate issues, the main problem is the basis risk due to the huge spatio-temporal variability of rainfall. This reality pleads for the development of remote sensing methods. Other important issues are the local rainfall gradients and the recent trend of increasing rainfall. Climatic issues also stress the question of the fair management of the level of protection and cost of premiums. The only way to ensure equity between farmers is to use subsidies of different values in order to provide the same protection for the same price to all farmers. That is the case in Senegal but it is the only country where the government provides subsidies for insurance. The main issue to be solved will be to find an acceptable solution with all the stakeholders to the trade-off between 'protection' and 'premium cost'. While people in Mali and Burkina Faso have accepted, so far, the purchase of very cheap insurance policies, without knowing how it protects them, we faced a totally opposite situation in Senegal where farmers' organisations analysed the indices in detail and asked for good protection at a low price. Major efforts will be necessary everywhere to allow stakeholders to analyse insurance issues together and decide which kind of system will be more appropriate.

1. INTRODUCTION

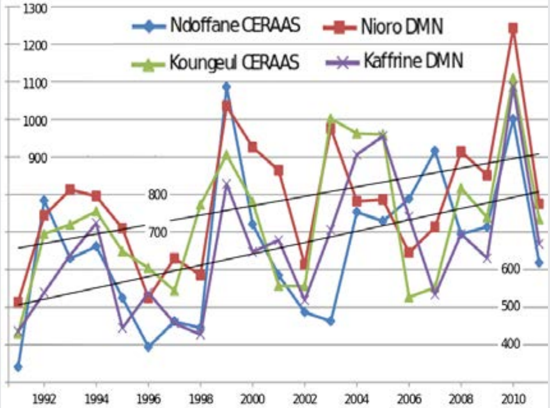


Figure 1: Evolution of annual rainfall (mm) in the centre of Senegal in the 1990–2011 period; the trend lines correspond to Nioro (top) and Kaffrine (bottom) and show an annual rainfall increase of about 150 mm in just 10 years.

Agricultural insurance is just starting in West Africa (WA) with the recent launch of some index-based insurance pilot projects, in Mali (cotton, corn), Burkina Faso (cotton, corn), Benin (corn) and Senegal (groundnut, corn). In these insurance systems, yield losses are not directly measured in the fields of insured farmers but indirectly assessed through the value of an index, that is a mathematical equation or model which uses reference measured parameters, for example rainfall or other climatic variables or official regional statistical yields (World Bank, 2009; Hazell et al., 2010). Although projects started very recently (2011 and 2012), it is already possible to stress some important issues based on the ongoing experiments and also considering previous knowledge on climate and agriculture in WA. We will focus here on rainfall index-based insurance.

2. HOW TO DEAL WITH CLIMATE FEATURES

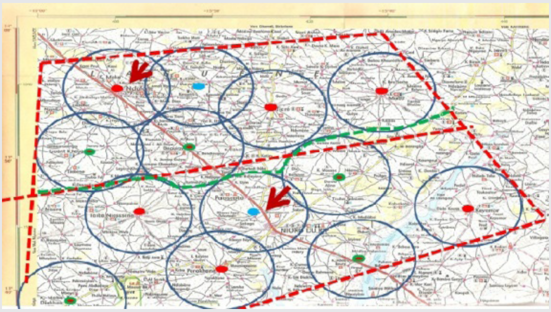
The main feature of the climate in Sudano-Sahelian areas is the huge spatio-temporal variability of rainfall, probably the largest in the world. Farmers are very aware of this. As a consequence, basis risk probability is important for rainfall-based insurance. That is the main concern for index insurance development.

Remote sensing technologies seem, logically, to be the solution to cope with this problem since they potentially allow the assessment of weather data and crop situation everywhere, depending, of course, on pixel size. They appear also to be the solution for index-based insurance since it seems unrealistic to install meteorological equipment everywhere. Yet, even with those techniques, basis risk is not totally eliminated since data are assessed as an average at pixel level. Moreover, the accuracy of those technologies must be assessed and improved. Approaches, including both remote sensing and ground observations, will probably be the best solutions. In Senegal, pilot projects are based on rainfall: a quite dense network of automatic rain gauges network was installed in the project area around Nioro. In the other countries, the index data used are dekadal relative evapotranspiration assessed from METEOSAT [(1)] information.

An important issue is that rainfall has shown a marked increase in WA over the last 15 years (Figure 1), and farmers are well aware of it. This observation raises the question of which historical series of data must be considered to calibrate insurance systems? Considering a classical 30-year data time series seems to not be fair for farmers. For example, in Senegal, the cost of the premium of an insurance system varies from FCFA [(2)] 14 000 when considering only the last 15 years, to FCFA 20 000 when considering the last 30 years. But who knows what the rainfall pattern will be in the next 10 years?

Another important issue is the south-north gradient of precipitation in WA. It can be very steep in some places: for example, 130 mm in 25 km in the area of Nioro in Senegal. The question is: What kind of zoning is the most appropriate to handle gradients? Yet, it is not possible to calibrate specific parameters for index-based systems for all sites within a same agricultural region, nor for each pixel of a grid. This will be time-consuming, expensive to solve and to manage, and not easy to explain to farmers. In the Nioro area, we divided the region into two and considered, for each zone, a reference station located in the North (i.e. in the drier part of each zone) (Figure 2).

Figure 2: Subdivision of Nioro-Ndofane region into two sub-zones: red arrows indicate reference sites used to calibrate parameters of indexes; coloured points indicate reference automatic rain gauges installed for the insurance project; and circles indicate areas covered by rain gauges.



1 http://www.esa.int/SPECIALS/MSG/

2 The CFA franc is the euro-backed currency of several WA countries. At the end of 2012, the exchange rate was about 500 FCFA 500 to USD 1, FCFA 656 to EUR 1.

Last but not least, the issues just mentioned also pose the question of the fair management of protection and premium within and area: the same level of protection will be costed differently according to rainfall features (premiums will be more expensive when going north). Thus, the choice is between selling insurance contracts having the same premium, but offering less protection to the farmers in the northern sites, or selling insurance contracts offering the same protection but being more expensive in the northern latitudes. This is a very critical point. The only way to manage it with equity between farmers is to use subsidies of different values, the result of which is that the same level of protection is obtained for the same price by all farmers and that is the way things have been managed in Senegal — the government pays more subsidies in the north. Up to now, Senegal is the only WA country where the government provides subsidies for insurance.

Another complex question will be raised in the future: How to integrate climatic forecasts in insurance systems?

3. HOW TO SOLVE THE TRADE-OFFS BETWEEN LEVEL OF PROTECTION AND COST OF PREMIUM

The farmers who invest in their crops, using purchased inputs (fertiliser, improved seeds), and aim to earn money from their production, are the only ones who could be interested in paying for insurance. Moreover, crop insurance can correctly develop only if the other development factors (credit, access to inputs, technical support) function well. Yet, the role of insurance is only to manage the non-controllable risks. Thus, insurance seems to be compatible only with a certain level of intensification, trade circuit and general organisation where, ideally, all the stakeholders work together in an intelligent way.

In Senegal, farmers have shown interest in insurance because they consider insurance will help them to have easier access to credit and to improve credit conditions by securing their credit and protecting them in the bad years, by strengthening credit systems, and by contributing to credit rate decreases and general credit development. This is the hope of farmers and other stakeholders such as farmers' organisations, banks and credit institutions.

Senegalese farmers also appeared to be very professional and curious about index-based insurance. In focus groups and meetings, farmers always asked very precise questions such as: Will the index take into account rainfall distribution over crop phases? Where will reference rain gauges be installed (they are aware of rainfall variability and understand basis risk issue)? How will their fields be linked to reference rain gauges? What about hazards other than drought? How will credit and insurance be linked? When must premiums be paid? Will insurance premiums decrease after a few years if there was no indemnification? Is it safe to trust the insurance company? What will be the cost?

Thus, it can be said that actors are very professional and this must be considered as a very positive and favourable context for insurance development.

However, the main farmers' organisations have not yet accepted the proposed index insurance since they consider (i) it will offer insufficient protection to the farmers, and (ii) it is too expensive even considering subsidies! Obviously, they are fulfilling their role when they defend farmers' interests, but it has been difficult so far to find a solution to this situation. Stakeholders must understand that due to large risk probabilities, it will be impossible, even considering subsidies, to offer a significant level of protection for a low price.

Thus, additional work is still necessary in Senegal to allow all stakeholders to jointly analyse insurance issues and decide which kind of system will be more appropriate.

In Mali, Burkina Faso and Benin, the situation has been totally different so far. Farmers and other stakeholders have accepted the insurance systems elaborated by Planet Guarantee (PG [3] despite the fact that they are based on remote sensing data, which nobody can understand, and despite not knowing in detail how they protect them. Moreover, since the developed indices are based on a purely statistical approach, they are not calibrated according to crop status and/or yields losses, they do not take in account sensitive phases of the crops, and they also induce unfair differences in protection level between areas.

But, Planet Guarantee succeeded in selling thousands of contracts. The first reason is that the premiums were very low (since they offer low protection). The second reason is the ability and 'commercial skill' of Planet Guarantee. The third is the large demand for credit of the farmers. As a matter of fact, farmers explain that 'they trust their credit institution' and credit institutions explain that 'they trust Planet Guarantee and insurance companies'. We, personally, doubt that this 'kind of black-box' system will be sustainable in the long run.

These two opposite situations stress the problem of the prevalence of drought in Sudano-Sahelian areas and the difficulty in developing insurance in such a context. The key question is how to solve the trade-off between 'protection' and 'cost of premium'. The Senegal experience indicates that serious stakeholders of the agricultural sector will not easily accept insurance.

4. FIRST CONCLUSIONS

The main problem is the basis risk due to the huge spatio-temporal variability of precipitation. This reality pleads for the development of remote sensing methods, probably coupled with grounds measurements (rainfall and yields). Other important climatic issues are: (i) local rainfall gradients, which raise the question of the zoning approach; and (ii) the recent upward trend of rainfall, which must normally also be considered.

The climatic issues also raise the question of the fair management of protection and premium; the only way to manage this very critical question fairly between farmers is to use differential subsidies in order to provide the same protection for the same price to all farmers.

3 http://www.planetguarantee.com/

This is the case in Senegal, but Senegal is the only country where the government provides subsidies for insurance.

The other main issue to be solved is to find a pertinent solution with all the stakeholders to the trade-off between 'protection' and 'premium cost'. People in Mali and Burkina Faso have accepted, so far, the purchase of very cheap insurance, without knowing how it protects them. We faced the opposite situation in Senegal where farmers' organisations analysed the indices in detail and asked for good protection for a low price.

A lot of work will be necessary everywhere to allow stakeholders to analyse insurance issues and jointly decide which kind of system will be more appropriate.

Our hypothesis is that in the future insurance systems will probably be calibrated to protect only against severe climatic hazards, in order to stabilise credit systems while remaining affordable. Moreover, we also consider that insurance systems should focus on global portfolios of credit institutions, without being managed at farmer level.

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12 Protecting pastoralists against drought-related livestock mortality: the Index-Based Livestock Insurance project (IBLI) in Northern Kenya

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KEYWORDS: livestock, mortality, arid lands, insurance, index, NDVI

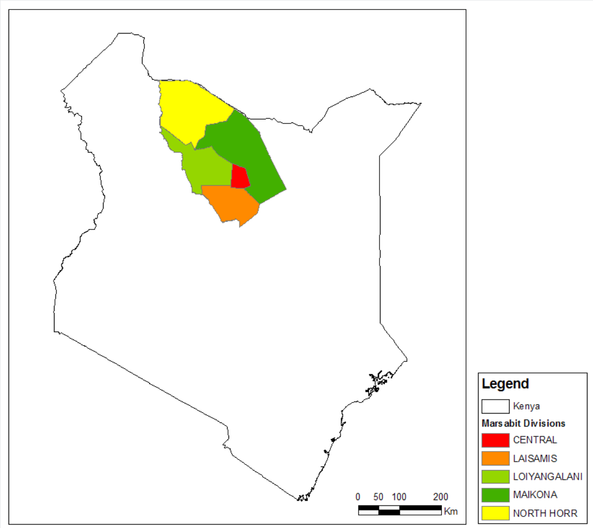
SUMMARY

The International Livestock Research Institute (ILRI)'s Index-Based Livestock Insurance project (IBLI) is a project aiming to deliver an index-based insurance product that covers drought-related livestock mortality to pastoralists in arid and semi-arid lands. In this project, which was first commercially launched in Marsabit District, northern Kenya, in January 2010, livestock mortality is predicted using freely available Normalised Difference Vegetation Index (NDVI) data, which represent the amount and vigour of vegetation that will be grazed by livestock. The implementation of such insurance programmes is vital in those regions since poor household rely mainly on livestock as a source of livelihood. Severe droughts are the major cause of livestock mortality: they occur as covariate shocks and cause large losses to many households at the same time. In the framework of our research, we use the IBLI index as a basis for developing a generic livestock mortality index from Earth Observation data for arid and semi-arid lands.

1. INTRODUCTION

Northern Kenya is characterised by a dry climate with bimodal rainfall pattern (one short rainy and short dry season, or SRSD, from October to February and one long dry and long rain, or LRLD, from March to September) (Chantarat et al., 2012). As in the other arid and semi-arid lands (ASALs), Northern Kenya regularly faces severe droughts. Within the last

Figure 1: Marsabit District and the five divisions covered by the IBLI contract



100 years, 28 major droughts have been recorded in that area, and four of them have occurred in the last 10 years (Adow, 2008).

In ASALs, poor households rely mainly on livestock as a source of livelihood (Mude et al., 2010). In these regions, drought is the predominant cause of livestock mortality. Livestock losses due to drought can be particularly high during drier seasons (severe weather shocks), such as during the extremely poor rainfall period in 2000 (Mude et al., 2010). In regions characterised by rain-fed agriculture and livestock-based economies, people are highly vulnerable to extreme weather events (UNDESA, 2007). In the event of an intense weather shock, households without risk transfer mechanisms are more likely to be driven into permanent poverty (Barrett et al., 2006). It is therefore vital for them to be able to protect their assets and income with suitable risk transfer mechanisms and insurance programmes.

The Index-Based Livestock Insurance (IBLI) is a livestock insurance programme designed by the International Livestock Research Institute (IRLI) in order to cover livestock (cattle, camels, sheep and goats) mortality due to forage scarcity caused by dry meteorological conditions. IBLI contracts were first sold in Marsabit District, Northern Kenya (Figure 1) in January and February 2010 and the first compensation was paid in October 2011 as the result of the dramatic drought that was experienced in the whole of the Horn of Africa region in the year 2011.

In the following sections, we will present the predictive mortality index and the insurance contract (Sections 2.1 and 2.2). We will then finish with the perspectives this project offers by describing the research project (Section 2.3).

2. THE INDEX-BASED LIVESTOCK INSURANCE

2.1. The predictive mortality index

In the IBLI contract, the index that triggers payment is based on freely available NDVI data. Livestock mortality is calculated using NASA's MODerate resolution Imaging Spectrometer (MODIS) NDVI data (Chantarat et al., 2012).

The predictive index takes the form of a linear regression involving different variables derived from division averaged NDVI. The livestock mortality, expressed as a percentage of the total number of animals, is calculated by the following equation:

$$\mathbf{M(\%) = a * CZNDVI_{pre} + b * CZNDVI_{n} + c * CZNDVI_{p} + d}$$

where the CZNDVI variables represent the cumulative values of the standardised (z-score) NDVI over different periods (Figure 2).

The coefficients (a, b, c, d), presented in Table 1, depend on:

- the cluster in which the division is located (upper cluster for North Horr and Maikona divisions, lower cluster for Laisamis, Loiyangalani and Central and Gadamoji divisions); and

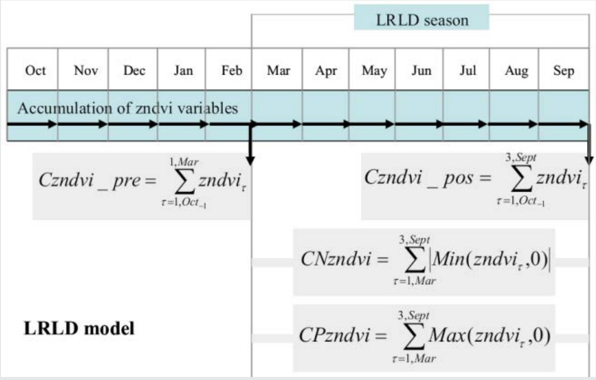
- the vegetation regime: 'good' if the accumulated value of division averaged ZNDVI over the year ($CZNDVI_{pos}$, Figure 2) is ≥ 2.5 and 'bad' if it is < 2.5.

The linear regression was computed using household-level mortality data obtained from Kenya's Arid Land Resource Management Project (ALRMP) and USAID's Global Livestock Collaborative Research Support Programme Pastoral Risk Management (PARIMA) (Chantarat et al., 2012).

Table 1: IBLI Mortality index regression coefficients

		UPPER MARSABIT		LOWER MARSABIT	
a	Good regime	-0.00104		0.00128	
	Bad regime	-0.01366		-0.01619	
b	Good regime	0.00926		0.00177	
	Bad regime	0.01521		0.01970	
c	Good regime	0.00064		0.00199	
	Bad regime	-0.01878		-0.01008	
d	Good regime	0.00000	0.02452	0.00000	0.00533
	Bad regime	0.00000	0.11922	0.00000	-0.00963
		LRLD	SRSD	LRLD	SRSD

Figure 2: IBLI vegetation regressors (CZNDVIs) — example for the Long Rain-Long Dry (LRLD) season (March to September) (Chantarat et al., 2012)



This regime-switching model is characterised by adjusted R^2 of 52 % and 61 % for upper and lower clusters, respectively, in the case of a 'bad' climate regime (CZNDVI_pos < 2.5) while in the case of a 'good' climate, no statistically significant relationship could be observed between livestock mortality and any of the vegetation regressors. In that case, adjusted R^2 for the linear regression was very low. This result is consistent with the fact that variations in the range of good vegetation conditions should not have a systematic impact on livestock (Chantarat et al., 2012).

2.2. The insurance contract

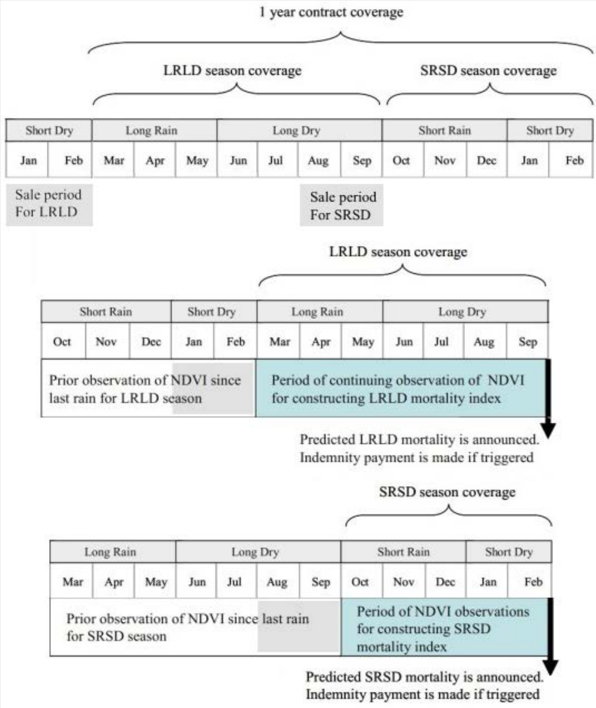
The index-based livestock insurance contract covers pastoralists from Marsabit District against livestock mortality due to forage scarcity. As mentioned above, the animals that can be insured are cattle, camels, sheep and goats. The contract covers two seasons, the Long Rain-Long Dry (LRLD), from March to September and Short Rain-Short Dry (SRSD), from October to February. The contract can be purchased during the sales period before each season: livestock is then covered for the next two seasons. The contract temporal coverage and sales periods are shown in Figure 3.

Indemnities are paid to pastoralists who purchased the insurance if the predicted mortality researches the threshold value of 15 % at the end of the season (losses inferior to 15 % are at the charge of the pastoralist).

2.3. Perspectives

In the framework or our research, we will use ILRI's Index-based livestock insurance project as a basis for the design of a predictive drought-related livestock mortality index from Earth Observation data in arid and semi-arid lands. Such an index could be used in various contexts such as livestock index insurance but also famine early warnings, food security programmes, etc.

Figure 3: Index-based livestock insurance contract temporal coverage (Chantarat et al., 2012)



Our research will focus on two main objectives. Firstly, the improvement of the current livestock mortality predictive index and, secondly, the generalisation of the index to regions presenting similar agro-climatic characteristics and the development of a tool for pastoral insurance and other livestock and forage availability studies. This will mainly be achieved by considering other remotely sensed data (vegetation indicators from other sensors), meteorological data, land cover data, water hole-related data, and by improving the statistical treatment of these data (non-linear relationships, spatial econometrics methods, etc.).

3. CONCLUSIONS

The Index-based livestock insurance project has shown that remotely sensed NDVI can be used to assess drought-related livestock mortality and that this indicator suits the need for operational mortality indices that will, when included in insurance programmes, help reduce the risk that pastoralists of arid and semi-arid lands are facing.

This project has illustrated the feasibility of predicting drought-related livestock mortality from remote sensing data in general and opens up new horizons in this field of research.

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13 Weather index-based insurance in a cash crop regulated sector: *ex ante* evaluation for cotton producers in Cameroon

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KEYWORDS: **agriculture, index-based insurance, cotton, Cameroon**

SUMMARY

In the Sudano-Sahelian region, which includes northern Cameroon, the inter-annual variability of the rainy season is high and irrigation is scarce. As a consequence, bad rainy seasons have a massive impact on crop yield and regularly entail food crises. Traditional insurance based on crop damage assessment is not available because of asymmetric information and high transaction costs compared to the value of production. Moreover, the important spatial variability of the weather creates room for pooling the impact of bad weather using index-based insurance products. We assess the risk mitigation capacity of an alternative form of insurance which has been implemented in India since 2003: insurance based on a weather index. We compare the capacity of various weather indices from different sources (daily rainfall, temperatures and satellite imagery) to increase the expected usefulness to a representative risk-averse farmer. We show that using observed sowing dates increases the pooling capacity of the index in the case of daily rainfall. We also show that calibrating parameters in subregions avoids non-negligible balancing out between distinct geographical zones, even within a relatively bounded area. We finally explore whether such contracts are worth implementing in the case of a cash crop, the revenue of which largely depends upon international price levels.

1. INTRODUCTION

Cotton is the major cash crop of Cameroon; however, even if it represents a quarter of agricultural exports it only accounts for about 6 % of total exports (Gergerly, 2009). The cotton society, Sodecoton (Société de Développement du Coton du Cameroun) and its Malian counterpart are still monopolies (Delpeuch and Leblois, 2011a). These parastatals are thus the only agents in each country to buy cotton from producers at pan-seasonally and territorially fixed prices.

Cotton represents the major income source (monetary income in particular) for growers of the northern provinces (north and extreme north, Folefack et al., 2011). It is grown by smallholders with about 0.6 ha per farmer dedicated to cotton production on average in the whole area (Gergerly, 2009). Some 346 661 growers cultivated 231 993 ha in 2005 at its peak, while, in 2010, the number of grower dropped to 206 123 growers and the area cultivated with cotton shrank to 142 912 ha. Profits in cotton-growing activities are quite limited given the need for costly inputs and are thus highly dependent on input and cotton prices [1].

Cameroon, however, has suffered a decreasing trend in yields since the end of the 1980s. A trend reversal, succeeding with the increase of cotton yields in the 1960s and the 1970s, can be observed in most of the major African producing countries (Vitale et al., 2011). The recent decrease in production level has mostly been explained by two major issues, which almost every cotton-producing country in West and Central Africa suffers: institutional issues linked to country specific sector management [2] as well as by high fertiliser prices (Crétenet, 2010). Credit default is thus a major source of risk since it can produce heavy losses for Sodecoton. Even if some of those losses are caused by smuggling across national boundaries [3] (Nigeria and Chad), reducing the yield risk for farmers could limit input credit default rate. The sector, however, also suffers from several geographic and climatic challenges: isolation of the north of the country and decline in soil fertility due to increasing land pressure.

Moreover, cotton is rain-fed in almost all sub-Saharan African producing countries, and largely depends on rainfall availability. The impact of a potential modification of rainfall distribution during the season or the reduction of its length has been found to be of particular importance (Blanc et al., 2008; Sultan et al., 2010) and could even be higher under global warming. The very low surface grown with cotton per farmer added to the very low cash saving capacity makes the sector particularly dependent on exogenous shocks due to rainfall. When growers are not able

1 Input prices are linked to energy prices due to an increase in production of energy, under upward pressure since 2000; cotton prices are linked to euro/dollar exchange rates that have dramatically increased since 2002.

2 Including side selling in borderland areas to countries where price are higher — Nigeria in the case of Cameroon — or where the cotton sector has been liberalised which means it is possible to avoid input credit reimbursement (cf. Aurojo-Bonjean et al., 2003; Delpeuch and Leblois, 2011b). A major part of the input credit is, indeed, reimbursed after harvest when the national cotton society buys seed cotton from producers. Credit default in Cameroon did not exceed 5 % until 2005, but reached 10 % after 2006. However, side selling always existed in Cameroon. For example, in 1989, Sodecoton's annual brief reports large amounts of cotton going to Nigeria.

3 According to Kaminsky et al. (2011), the buying prices in Nigeria could have reached three times as much as the Cameroonian price in recent years. Smuggling, particularly in the north-west of the cotton zone, creates a potential loss of about 16 % of the national production (authors' estimate).

to reimburse their input credit at the harvest [4], they are not allowed to take a credit the next year. Falling into a situation of unpaid debt is very painful for those cotton growers, especially when little livestock is owned by the family (Folefack et al., 2011).

This paper, therefore, aims at calibrating weather index-based insurance (WII) contracts in order to shelter cotton growers against drought risk (either defined on the basis of rainfall, air temperature or satellite imagery). Insurance indemnities are triggered by low values of the index supposed to explain yield variation. It allows the pooling of risk across time and space in order to limit the impact of meteorological shock (and only meteorological) on producers' income. Such insurance can be supplied either through a private (with an underlying loading factor for both risk and administrative costs) or a public scheme.

Traditional agricultural insurance, based on damage assessment cannot efficiently shelter farmers because of the information asymmetry between the farmer and the insurer, especially moral hazard, and from the cost of damage assessment. An emerging alternative is insurance based on a weather index, which is used as a proxy for crop yield (Berg et al., 2009). In such a scheme, the farmer, in a given geographic area, pays an insurance premium every year, and receives an indemnity if the weather index of this area falls below a determined level (the strike).

Index-based insurance is not subject to the two shortcomings mentioned above: the weather index provides an objective, and relatively inexpensive, proxy of crop damages. However, its weakness is the basis risk (i.e. the imperfect correlation between the weather index and the yields of farmers contracting the insurance). The basis risk can be considered as the sum of three risks: (i) the risk resulting from the index not being a perfect predictor of yield in general (the model basis risk); (ii) the spatial basis risk (the index may not capture the weather effectively experienced by the farmer — all the more so if the farmer is far from the weather station(s) that provide data on which index is calculated); (iii) the heterogeneities among farmers, for example due to their practices or soil conditions, are often found to be quite high in developing countries.

The fact that the cotton sector is operated by a single national company offering input credit, makes area-yield or WII easier to implement. Moreover, yields are highly dependent on costly input use, which tends to potential bundling of WII with input credit. WII is also a 'corruption-free' incentive to grow cotton.

We thus examine the potential for such pooling tool to increase the certainty equivalent income for farmers in the region. We first describe the cotton sector and the data and we then discuss the methods used before calibrating and estimating weather index-based insurance outcome.

4 The standing crop is used as the only collateral and credit reimbursement is automatically deducted from growers' revenue when the national company buys the cotton, cf. Section 2.2 for further descriptions.

2. DATA AND METHODS

2.1. Data

Yield-time series are available at the Sector [5] level from 1977 to 2010, provided by Sodecoton, but show an attrition rate of 18 %. We matched it to unique meteorological (daily rainfall and temperatures: minimum, maximum and average) data from different sources (IRD and Sodecoton's high density network of rain gauges), with at least one rainfall station per sector (Figure 1).

We interpolated, for each sector, temperature data from 10 IRD and GHCN [6] meteorological stations in the region (including six in Cameroon and four in Chad and Nigeria). We used a simple Inverse Distance Weighting (IDW) interpolation technique, each station being weighted by the inverse of its squared distance to the sector considered applying a reduction proportional to 6.5 °C per 1 000 m altitude. The average annual cumulative rainfall over the whole producing zone is about 950 mm, hiding much of the heterogeneity we explore in the next section.

The agronomical data of the sectors are matched to rainfall data using the nearest station that is, on average, a distance of 10 km with a maximum distance of 20 km. The location of sectors are the average GPS coordinates of every Sodecoton producers group (PG) within the sector, which represent about 900 km^2 on average.

Finally, we used online GIMMS AVRHH data [7] of the NDVI index, available for a 25-year period spanning from 1981 to 2006. This vegetation index is a relative measure of the spectral difference between visible (red) and near-infrared regions and is thus directly related to green plants biomass.

2.2. Method

2.2.1. Agroecological and rainfall zones

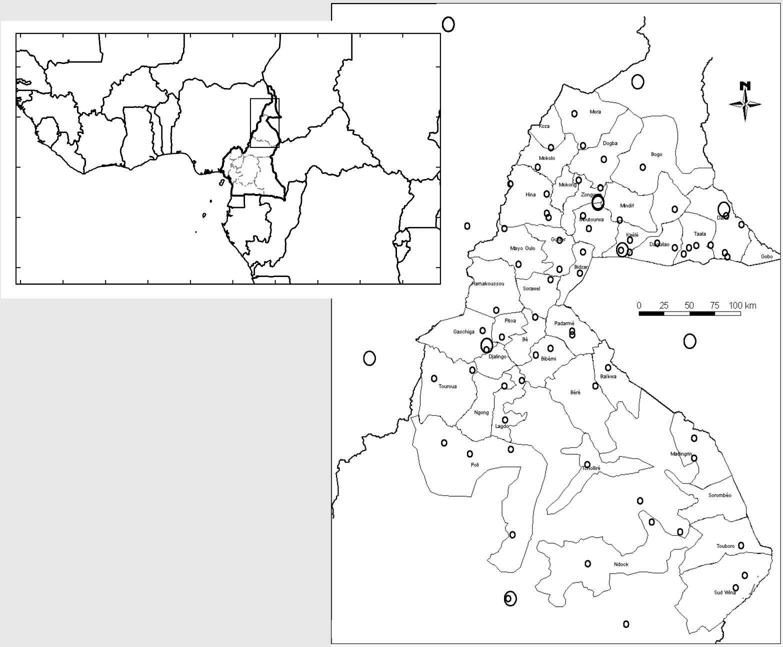
In Mali, the definition of agroecological and rainfall zones (Debock et al., 2010) justifies the use of different zones across the Malian cotton sector in order to insure yields. Pooling yields across heterogeneous sectors in terms of average yields indeed leads to subsidisation in sectors characterised by low yields.

5 The country is subdivided into cotton growing areas known as 'sectors'.

6 http://www7.ncdc.noaa.gov

7 http://www.glcf.umd.edu/data/gimms

Figure 1: Network of meteorological stations (large circles) and rainfall stations (small circles) of the region and centres (average of Producers' Group locations) of sectors.



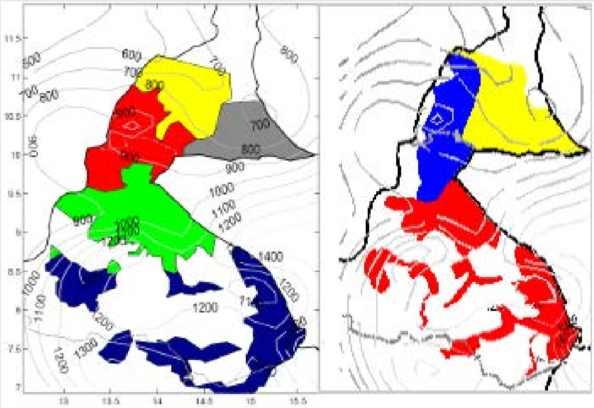
Sources: SODECOTON, IRD and GHCN (NOAA).

Moreover, considering different areas associated with a heterogeneous climate would also lead to subsidisation in drier areas in the context of a drought index-based insurance framework.

Average annual cumulative rainfall varies between 600 mm and 1 200 mm in the cotton producing area characterised by a Sudano-Sahelian climate (Sudanian in the south and Sahelian in the north).

We grouped seven agroecological zones in three distinct groups in order to obtain a significant sample of matched yield and meteorological data in each of them. The initial agroecological zoning borrowed from Adoum Yaouba (2009) also matches socio-economic indicators used by Kenga et al. (2005). It is used together with agro-climatic ones in order to characterise farming systems in the region. The first zone is the north-east, mostly situated above the 800 mm isohyet (meaning it benefits from less than 800 mm of rainfall per year, Figure 2, right-hand side), and is characterised by a semi-arid climate. The second groups the centre of the cotton-producing zone and the north-west: these areas are more rainy than the north-east, due to

Figure 2: Rainfall zones (left), agroecological zones (right) and isohyets (grey lines)



the topography (the presence of the Mandara Mountains. The third is the southern part of the zone and is more humid (i.e. benefiting from about 1 000 mm rain per year or more).

We finally defined five zones only following the rainfall levels of each sector (referred to as 'rainfall zones' below), sorting them by average annual cumulative rainfall over the whole period and grouping them in order to get a significant sample. The zoning is shown in Figure 2 (left-hand side). There is still a huge difference between observed and simulated cropping cycles. Moreover, we can see, apart from the fact that yield is very sensitive to the planting date (the major determinant of growing season), that the two northern rainfall zones are sowed (and emerge) 10 to 15 days later.

2.2.2. Indemnity schedule

We define the indemnity (I) as a stepwise linear function of the index with three parameters:

- the strike (S) (i.e. the threshold triggering indemnity);
- the maximum indemnity (M);
- and λ, the slope-related parameter.

When λ = 1, the indemnity is either M (when the index falls below the strike level) or 0. The strike represents the level at which the meteorological factor becomes limiting. We thus have the following indemnification function depending on x, the meteorological index realisation:

$$I(S, M, \lambda, x) = \begin{cases} M & \text{if} \quad x \leq \lambda S \\ \frac{S-x}{(1-\lambda)S} & \text{if} \quad \lambda S < x < S \\ 0 & \text{if} \quad x \geq S \end{cases} \qquad (1)$$

2.2.3. Insurance parameter calibration

We use different objective functions in order to test the relative robustness of each. We consider the three following objective functions, respectively the semi-standard deviation (equation 2), a negative exponential (CARA) utility function (equation 3) and, finally, a CRRA utility function (equation 4):

$$(2) \quad CEI_{ssd}(\tilde{Y}) = E(\tilde{Y}) - \phi \times \sum_{i=1}^{N} (max(E(Y) - Y_i, 0)), \qquad \tilde{Y} = \{Y_1, ..., Y_N\}$$

$$(3) \quad CEI_{cara}(\tilde{Y}) = -\psi \times \ln\left(\sum_{i=1}^{N} 1 - \exp(-\psi \times (Y_i + W))\right), \qquad \tilde{Y} = \{Y_1, ..., Y_N\}$$

$$(4) \quad CEI_{crra}(\tilde{Y}) = \left((1-\rho) \times \sum_{i=1}^{N}\left[\frac{(Y_i + W)^{(1-\rho)}}{(1-\rho)}\right]\right)^{\frac{1}{1-\rho}} - W, \qquad \tilde{Y} = \{Y_1, ..., Y_N\}$$

where:

Y is the vector of growers' income;
N the number of observations; and
W the average non-cotton related income.

The first function is simply capturing the income 'downside' variability (i.e. variations are considered only when yield is inferior to the average yield considered to be particularly harmful). The second term represents the average downside loss, loss being defined as yield inferior to average of yield distribution among the calibration sample (whole sample, AEZ or rainfall zone). It represents about one third of average yield (with very little change when considering different samples), this objective function is then tested for ρ = (0.5, 1, 1.5).

The second and third objective functions are quite standard in the economic literature; we added an initial income level, following Gray et al. (2004). Given that we use the aversion to wealth (and not transitory income) in both cases, we can assume that $\psi = \rho/W$, according to Lien and Hardaker, 2001. The profit after indemnification is as follows:

$$(5) \quad \Pi_i^I = \Pi(x) - P(S^*, M^*, \lambda^*, x) + I(S^*, M^*, \lambda^*, x)$$

$$(6) \quad P = \frac{1}{N}\left[(1+\beta) \times \sum_{i=1}^{N} I_i(S^*, M^*, \lambda^*, x_i) + C \times \sum_{i=1}^{N} F_i\right], \quad \text{with} \quad F_i = \begin{cases} 1 & \text{if} \quad I_i > 0 \\ 0 & \text{if} \quad I_i = 0 \end{cases}$$

The loading factor is defined as a percentage of total indemnifications on the whole period (β fixed at 10 % of total indemnification) plus a transaction cost (C) for each indemnification. C is fixed exogenously to 1 % of the average yield.

We finally optimise the three insurance parameters in order to maximise certain equivalent income and look at the gain it can bring depending on the index and the calibration sample.

3. PRELIMINARY RESULTS

3.1. Whole cotton area

When testing different indices on the whole sample, we observe that there is no particular index that seems to perform better than the others. The utility gains also vary with the objective function choice, the CARA utility function showing a much higher gain in percentage. Looking at the certain equivalent income (CEI) in a utility framework allows a comparison of the gains (reduction in the variability and amplitude of bad yield occurrence) to the cost of the insurance in terms of reduction of average income (corresponding to the insurers' profit or administrative costs).

We show that it is not worth considering satellite imagery. The date of the emergence, conditioning the availability of early rainfall, seems to be driving a large part of yield levels: the index defined as the percentage of area where cotton had emerged at 30 June is a good predictor of yields. As a consequence, the observation of sowing dates seems to condition the use of rainfall indices. It, however, poses some moral hazard issues that probably could be overcome by sowing date monitoring by the cotton companies. The revelation of sowing dates at low costs is, indeed, possible in many WCA countries, were the cotton company still plays a large role in cotton cultivation campaigns.

3.2. Specific AEZ and rainfall zones

We then computed the CEI gain when optimising insurance parameters in each agroecological zone and each rainfall zone according to each of the three above mentioned objective functions. We found very heterogeneous results depending on the choice of the zone and the indices. Some zones seem to have better potential for index insurance than others (rainfall zones 1, 2 and 5), where very little risk hedging is found with the rainfall indices. The third (Mandara Mountains) and the fourth (Benoue River watershed) do not show significant gain for index insurance. We, thus, show that the identification of different zones for parameter calibration influences the outcome of index-based insurance, since many indices are very efficient in reducing the risk when parameters are calibrated on different rainfall zones, while they are not when doing so on agroecological zoning. It seems, indeed, of primary importance to underline the fact that calibrating rainfall insurance parameters on one specific area, often leads to subsidisation of the driest parts of this area at the detriment of those that are more humid.

3.3. Prices

Finally, we show that the implicit price insurance offered by the cotton company by announcing the cotton purchasing price before sowing has a major impact on cotton profit variability. The intra-annual variations of cotton international prices are high and the stabilisation offered by the company showed higher gains in CEI than the index-based insurance tested.

4. CONCLUSIONS

Firstly, we show that considering a large area, with potentially different agroecological zones, leads, in our case, to significant cross subsidisation. It underlines the need for precise calibration fitting local climate characteristics, even for a single crop and in a bounded area. Cutting the cotton-growing zone into smaller units, of about 1 decimal degree according to annual rainfall levels, shows that the southern part of the zone will benefit much less from such an insurance scheme.

Secondly, in accordance with the agronomic literature, we underline the critical role of observed sowing dates in rainfall index calculations.

Lastly, we found that the gain from index-based insurances was lower than that from implicit insurance, against intra-annual variations in the cotton international price, offered by the national company by announcing the purchasing price before sowing.

We have shown that there is a non-negligible potential to pool yield risk using meteorological indices, through the calibration of the parameters of a simple insurance contract. There are, however, several limitations, which emphasises the need for further research.

As already mentioned in Leblois et al. (2011) and Norton et al. (2012), spatial basis risk is significant and in-sample calibration thus tends to overestimate insurance gains. We will also use broader sets of individual yield data to compute the estimates of the potential of index-based insurances at grower level. Leblois et al. (2011), indeed, show that considering average yield for a given (and even very limited area) leads to an overestimation of the potential of pooling of shocks: this is because intra-village yield variation is often found to be very high, even more so at the sector level.

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14 Forecasting the major crops for Australia and crop yield insurance: an integrated climate, biophysical and remote sensing approach

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SUMMARY

Since early settlement, the existence of most rural communities in Australia has depended on agriculture. Dryland cropping has been one of the main activities contributing towards the long-term viability and sustainability of these communities. This is still true today. However, the operating environment of producers has become more challenging. Food producers are increasingly exposed to variability and change in world markets, commodity prices and climate, thus increasing their vulnerability and threatening their livelihoods. Advance knowledge of the associated risk in crop production, however, can mitigate some of the impacts of such factors. Hence, easily accessible, near real-time, objective and accurate crop production information is becoming increasingly valuable in decision-making for agricultural industry and government agencies. To date, industry and crop forecasters have had a good idea of the potential crop yield for a specific season, but advance, accurate, timely and objective information on crop area for a shire or region has been mostly unavailable. Here, we present

a holistic approach to bridging the information gap, which is exacerbated by the lack of accurate and timely information and a projected increase in market and climate volatility within Australia and globally. In addition, the hedging of production risk against highly volatile climate and marketing environments is incorporated through a new crop insurance product called YieldShield™, which is also discussed.

1. INTRODUCTION

Australia has one of the most variable climates in the world with a consequent impact on the productivity and sustainability of natural ecosystems and agriculture. Major droughts, usually associated with El Niño events, affect mainly the eastern half of the continent every 3–7 years. This has important impacts on farmers' incomes, regional communities, and the Australian economy overall (Allan, 2000). For example, the drought associated to the 2002 El Niño event reduced Australia's gross domestic product by 0.75 % (Penm, 2002) and the floods and cyclones associated with the La Niña event of 2010/11 reduced economic growth by 0.5 % (Zachariahs, 2011).

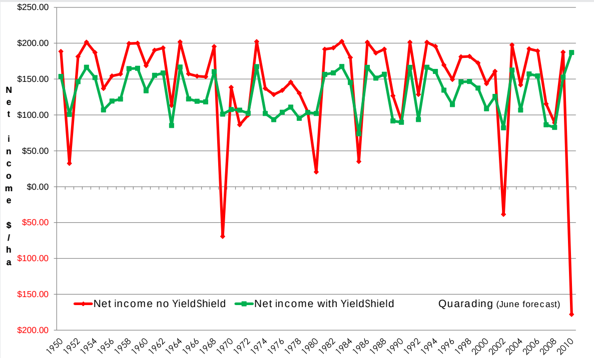
El Niño (EN) and La Niña (LN) are opposite modes of the El Niño Southern Oscillation (ENSO) phenomenon and are categorised by the meteorological community according to predefined thresholds of sea surface temperature anomalies in the equatorial region of the Eastern Pacific [1]. However, there are many different types of EN events, which have significant differences in terms of impacts on agriculture (Potgieter et al., 2005). Often, El Niño-like events that do not 'qualify' according to climatological rules still have major impacts on Australian rainfall (e.g. the drought of 1937/38 [2]). Such El Niño-like (as well as LN) events are likely to increase in magnitude and frequency with progressing climate change (IPCC, 2007). Furthermore, global climate models (GCM) indicate that Australia and, in particular, north-eastern Australia is likely to become hotter and drier under most climate change scenarios (IPCC 2001, 2007). This is likely to affect the long-term production of agricultural systems across Australia. Although there are considerable uncertainties about the magnitude and spatial extent of these changes, it is important to assess how a range of expected climates are likely to affect crop yield if no adaptation actions are taken.

During the late 20th century, most regional crop production (i.e. area x yield) estimation frameworks in Australia were based on local knowledge from local experts (e.g. extension officers, farmers, grain traders, etc.), and were thus heavily dependent on how well these experts knew their regions. Yield estimates were often derived from historical regional, state and national level statistics that were, and continue to be, collated by the Australian Bureau of Statistics (ABS) via an agricultural census/survey at the shire (statistical local area) scale. This approach forms the basis on which various government bodies (e.g. the Australian Government and the Queensland Government) make various policy decisions with large impacts on the viability of regional communities, such as which districts should be classified as drought stricken during drought years.

1 http://www.esrl.noaa.gov/

2 http://www.bom.gov.au

Figure 1: Net income per hectare both with and without YieldShield™ for one hectare of land in the shire of Quarading over the past 60 years assuming a constant production cost, insurance cost and value per tonne for wheat. The red line is without YieldShield™ and the green line with YieldShield™. The net income is calculated from a gross margin analysis from the Western Australian Department of Agriculture and assuming a 50 % equity level on land worth AUD 1 500 per hectare with mortgage and overdraft interest rates at 9 %. The shortcomings in the calculation are the fixed per hectare production costs regardless of the seasonal forecast and that it does not allow for the development of the loss cost over time.



In the late 1990s, the ABS census was changed to a yearly survey and a 5-year census, which further confounded the availability of accurate crop information. In addition, the statistics collated during survey years, such as the 2002 season, were aggregated and disseminated at a coarser statistical division level (group of shires or districts) (Lester, 2008). The lack of more detailed, shire-scale information during four out of five years further emphasises the need for alternative near real-time accurate and objective crop production estimates to assist government and industry decision-making at regional scales. This has especially been the case recently, particularly during the severe drought of 2002, which reduced the economic growth of the Australian economy by approximately 0.75 percentage points (Penm, 2002).

The Regional Commodity Forecasting System (RCFS), which is used operationally by the QAAFI to predict shire-scale wheat and sorghum yield on a monthly basis [3], is an example of the type of system being used to deliver objective information to industry in a timely manner. The RCFS generates a yield forecast distribution of wheat and sorghum on a monthly basis through the integration of a parsimonious biophysical model (Potgieter et al., 2005; Potgieter et al., 2006; Stephens and Lyons, 1998) with the El Niño Southern Oscillation (ENSO) climate forecast system generally known as the Southern Oscillation

3 http://www.dpi.qld.gov.au/fieldcrops

Index (SOI) phase system (Stone et al., 1996). This is run for each month throughout the crop-growing season (winter and summer) over the main crop-producing districts in Australia to generate updated yield forecasts as the season unfolds. A shortcoming of this system, however, is that it generates an estimate of yield per unit area without any estimates of crop area. This estimate is used by decision-makers in conjunction with subjective knowledge of total area planted at the shire or broader scale to calculate total production. In order to generate accurate total production predictions, real-time estimates of crop area planted is needed along with yields per unit area. This is necessary for determining near real-time production figures and updating supply chain information at the regional, state and national levels. In addition, the application of such technology in the insurance industry for Australia is discussed.

2. APPROACH, RESULTS AND DISCUSSION

2.1. Biophysical agro-climatic crop models

The seasonal wheat outlook is based on the integration of:

- (i) a simple agro-climatic wheat stress index model (Oz-Wheat) (i.e. bare fallow routine) (Ritchie, 1972); wheat stress index model adapted from previous research (Fitzpatrick and Nix, 1969; Nix and Fitzpatrick, 1969), which is sensitive to water deficit or excess during the growing season;
- (ii) actual climate data up to the forecasting date; and
- (iii) projected climate data (reference distribution) after that date.

These projected data are drawn from historical analogue years (forecast distribution) based on similarity to the prevailing phase of the Southern Oscillation Index (SOI) (Stone et al., 1996). The Oz-Wheat (Oz-Sorghum) model is run from 1 October the year before sowing in order to account for the influence of the summer fallow (winter fallow for sorghum) on starting soil moisture conditions. The model input parameters for each shire (i.e. potential available water content, planting rain and stress index period) have been selected based on the best fit when calibrated against actual shire wheat yields from the Australian Bureau of Statistics (ABS) for the period 1975–99. Spatial correlation when predicting the shire wheat yields for the 2000 season, which was independent of the training period, was 0.8 (0.9) across all main wheat (sorghum) producing shires in Australia (245 and 31 for wheat and sorghum, respectively) (Potgieter et al., 2005; Potgieter et al., 2006).

2.2. Creating of the forecast distributions

Both the reference and forecast distributions were derived from trajectories generated from the commodity simulation analysis depicted for wheat and sorghum on a monthly basis. Climate data plumes were created for each year for each forecast month by integrating the actual climate up to the time of the forecast with climate for each year of the historical record after the time of the forecast. A crop model was then run using each of these climate data plumes as input to generate a set of crop condition trajectories. Using the SOI phase (Stone et al., 1996) available at the time of the forecast, the trajectories were segregated into a forecast set (i.e. SOI phase analogue years) and a reference set (i.e. the remaining trajectories). Hence, the forecast distribution, which was derived from the analogues, was independent of the reference distribution, which was derived from the remaining sequences (Potgieter et al., 2003).

2.3. Smoothing out of volatility: YieldShield™

The insurance of agricultural risks in Australia is relatively undeveloped when compared to most European countries. There are a variety of reasons for this and no definitive answer but, apart from many factors that are often quoted, one of the main causalities of the low level of product development is that there is no government support/subsidy for crop insurance in Australia. Traditional insurance does not address the biggest yield limiting factor for wheat in water-limited regions such as Australia, where insufficient or excessive rainfall accounts for up to 90 % of yield variability on wheat. Recently, a Sydney-based insurance company (Primacy Pty. Ltd.) has developed a crop yield insurance product, YieldShield™, for farmers to hedge their risk against crop losses due to in-season water stress — a first in the developed world.

The main attributes of this product are:

- (i) a tool to transfer the risk of a growing season not reaching its reasonable expectation;
- (ii) uses simulated yields from Oz-Wheat/Oz-Sorghum models incorporating seasonal rainfall forecasts;
- (iii) Start of Season (SOS) simulated yield forecast v End of Season (EOS) simulated yield value; and
- (iv) SOS as early as May and EOS around November/December.

Figure 1 shows that there would have been a definite reduction in the variability in net income (AUD/ha) for crop yield in the Quairading Shire (Western Australia) if farmers had made use of the YieldShield™ product in this shire/district during the last 60 years. Variability reduced from as low as –AUD 178/ha (loss) in 2010 to not lower than AUD 75/ha (1985) if risk was hedged against the YieldShield™ product during that time. Net income per hectare would have dropped below equity on three occasions if no crop insurance was taken out by farmers for that region during the last 60 years. Over this period, the policy would have responded to a loss percentage greater than 10 % on 16 occasions. Thus, this smoothing effect allows the farmer to plant crops again in the following season and meet their debt servicing requirements, and thus stay in business. Currently, we are investigating better and smarter ways to help elucidate the impact of crop losses due to water stress at a field/farm level utilising Landsat Thematic Mapper (TM) and MODIS satellite imagery over time. This is likely to address the lack of uptake of this product by incorporating metrics of crop losses due to water stress at a local level.

2.4. Multi-temporal remotely sensed approach to determine crop area estimates

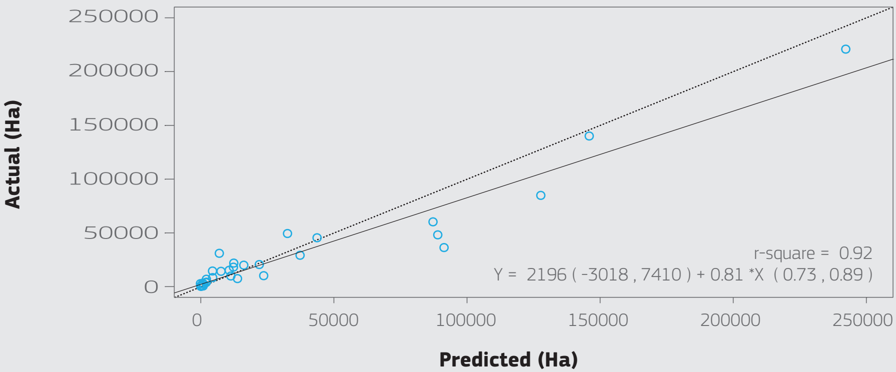
The prediction of the end-of-season crop areas was done using the harmonic analysis of time series (HANTS) approach similar to that implemented in a previous case study for Queensland (Potgieter et al., 2007). The HANTS method (Verhoef et al., 1996) was applied to discriminate between areas for wheat, barley, chickpea and non-crop areas across all subregions for the 2005 and 2006 seasons (Figure 2). The accuracy when using all ground truth training samples to discriminate between pixels classified as wheat, barley, chickpea or non-crop for the entire cropping region was high with percentage correctly classified (PCC) values of 99 % and 98 % for the 2005 and 2006 seasons, respectively. At a regional scale, high accuracy was evident when contrasting predicted shire-scale crop area estimates against actual shire-scale area estimates for total and specific crops in 2005. The predicted area estimate was highly correlated with the actual total winter crop area estimates and not significantly different from the 1:1 relationship for the 2005 season across Queensland. The percentages of variance in observed area explained by end-of-season area estimates using a multi-temporal approach (Potgieter et al., 2011) explained 92 % (Figure 3) of the total variation of the actual observed ABS winter crop area estimate across all shires for 2005, which suggests appreciable value in application for industry.

2.5. Bridging the information gap

Advance knowledge of crop yield and production has become increasingly sought by groups within the industry such as government agencies, bulk handlers of grain, financial institutions, insurance companies and farmer groups (to name a few) over the last decade (Hammer et al., 2001). The need for such information has been accelerated even further, not only domestically but also internationally, by the observed change in global climate and its impact on cropping systems and ensuing food production, now and in the future (IPCC, 2007). Although effective systems have been developed to deliver advance knowledge of yield likelihood (Mueller, 2009; Potgieter et al., 2005; Potgieter et al., 2006), information on early-season production estimates was less available due to the absence of accurate and timely estimates of crop area. Another likely reason is the high costs associated with acquiring agricultural statistics via crop surveys or censuses. This further contributes to the widening of the information gap and highlights the need for advance, accurate and transparent crop production estimates at a regional scale.

Figure 2: Final area estimates for specific winter crops for the 2005 (a) and 2006 (b) seasons for Queensland, Australia (Potgieter et al., 2011)

Figure 3: Scatter plot of the end-of-season total winter crop area estimate for each shire (HANTS). The portion of variance explained is given as the r-square. Lower (ll) and upper (ul) 95 % confidence intervals (CI) are included in brackets for each coefficient in the equation: Y = a (llCI, ulCI) + b*X (llCI, ulCI). The 1:1 line is shown as a stippled line, while the solid black line is the fitted regression line and a represents the intercept and b the slope.



Knowing the likely production volume and its geographical distribution helps decision-makers to make more informed decisions, for example: (i) with forward buying or selling of grain; (ii) shifting resources from one region to another (depending on supply and demand structures); and (iii) hedging risk by buying insurance against crop loss well before harvest. The latter is specifically designed to smooth on-farm crop loss volatility due to water stress measured at a shire/district level and, therefore, enhancing the farmer's adaptive capacity to extreme fluctuations in climate, prices and markets. Therefore, having access to advance knowledge of the likely crop size will lead to more informed decisions, which will reduce the associated risk and thus increase the economic viability of industry over the long term.

The availability of early-season and ensuing end-of-season crop area estimates at shire scale, when combined with yield estimates, provides the means to *bridge* the information gap. Reliable, timely and detailed production estimates underpin industry decisions on commodity handling logistics and commodity marketing. Furthermore, they provide a transparent basis for government decisions in relation to exceptional circumstances policy associated with extreme events or potential supply shortfalls to industry.

The application of such technologies in food insecure countries, where livelihoods are more at risk, is likely to mitigate the impact that climate variability and change have on strategic and long-term decision-making processes in support of policy at country level. It is anticipated that such a framework, in conjunction with targeted agricultural management practices tailored to specific climate forecasts, will lead to improved crop outcomes at household and regional levels, thus enhancing food security across large regions. However, further research is necessary to determine the impact, utility and value at a local and regional scale across most developing countries that are currently facing some of the most severe droughts in history and where projected future climate is likely to have an exacerbating effect on food security.

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Index philosophy

15 Combining multiple sources of climate information to guide the design of weather index insurance

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KEYWORDS: climate models, index insurance, Bayesian networks, uncertainty

SUMMARY

The successful design of weather index insurance products depends, in part, on the availability and quality of meteorological data to derive premiums that reflect the underlying risk. In a changing climate, an over-reliance on historic meteorological data to calculate threshold exceedance probabilities may lead to substantial losses for insurers or result in unfair premiums for policyholders. Furthermore, while insurance can act to mitigate the impacts of climate change on vulnerable populations, it is equally important to consider the impact of climate change on the long-term viability of weather index insurance products. A method is presented to incorporate multiple sources of climate information to test the sensitivity of pricing assumptions. The methodology employs Bayesian networks that are developed in the context of a hypothetical example of rice crop micro-insurance in Kolhapur, India. Challenges in the use of different types of climate information to price index insurance are discussed and the case to consider climate model output is made whilst acknowledging the limitations in the current generation of climate models.

1. INTRODUCTION

Calculating an appropriate premium for a weather index insurance (WII) product requires an assessment of the likelihood of a meteorological threshold being surpassed, over a specified future time period at a given location. This likelihood can be determined by estimating the probability distribution function (PDF) for the meteorological variable of interest. A conventional WII product design utilises available observed data, typically from weather stations, to estimate the PDF but there are shortcomings in approaches which rely solely on observations.

To insure crops against drought risk, WII products are designed using observations of cumulative rainfall over the period or season in which the crop is most sensitive to deficit rainfall. Rain gauge data is the primary data source used in WII design but remote sensing data, especially from satellites, is receiving increasing attention (Rosema, 2010). However, by limiting the design of WII products to incorporate observed data only, insurers are making the assumption that past weather is representative of the expected distribution of weather over some future period. The past observed record is only one of many plausible time series of observations which could have been realised. Indeed, if the state of the atmosphere-ocean system was perturbed at some previous date, the subsequent evolution of the system would be different. In the absence of a perfect model of the climate system, it is, therefore, impossible to know whether or not the trajectory of past weather is adequately representative of the PDF which describes the climate: the expectation of weather at a given spatial scale.

Modes of internal climate variability and changes in external forcings (such as solar fluctuations or increasing greenhouse gas concentrations) influence the likelihood of experienced weather. The probability of a meteorological drought event, for example, changes as the climate system evolves. Indeed, a drought which may appear to be a one-in-thirty-years' event, having occurred only once in a 30-year time series, may be considerably more or less than a one-in-thirty **probability** event in reality. When pricing risk based on return periods of low frequency events, it is prudent to consider alternative plausible time series of past weather. Moreover, given the known influence of internal modes of climatic variability (e.g. ENSO) in addition to systematic changes in climate, it may be wise to consult climate model forecasts to inform the pricing and viability of WII products.

2. INCORPORATING CLIMATE MODEL OUTPUT

Can climate models be used to improve loss estimates in the design phase of WII products and avoid crude approximations to premium loading as a result of ambiguity and uncertainty? This question is becoming increasingly relevant to WII as the sector matures and expands into new markets. To ensure that premium prices reflect the uncertainty in the probability of a particular meteorological threshold being exceeded, model output may provide useful additional information to inform insurers and provide fairer products to policyholders.

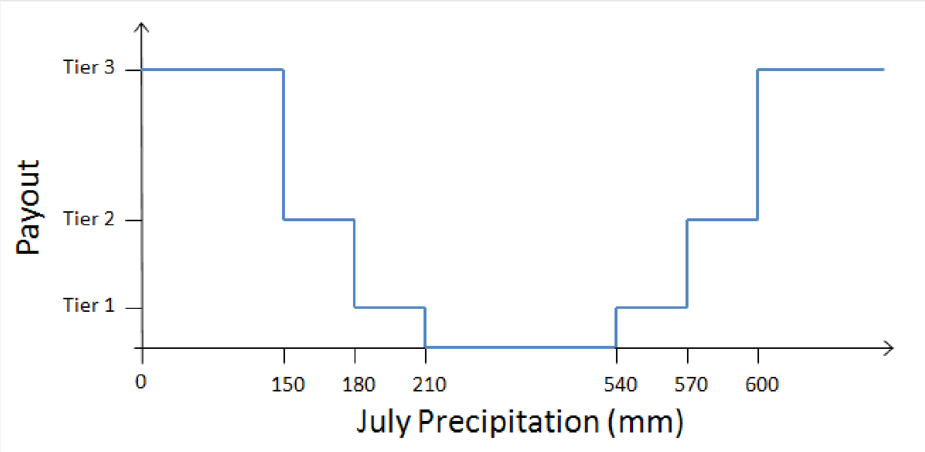
Because of computational constraints, Global Circulation Models (GCMs), used to simulate the climate over long time periods, are unable to resolve the state of the atmosphere-ocean system at very high spatial resolutions and must, therefore, incorporate subgrid-scale parameterisations of key system processes. As a consequence, numerical climate models are not isomorphic with the climate system and often contain large errors and systematic biases (Smith, 2002). Nonetheless, they provide a means of testing hypotheses and exploring the impact of altered forcings on the evolution of the climate system. Comparing the output of multiple models and multiple realisations from a single model (by perturbing parameters or using different initial conditions) allows practitioners to develop an appreciation of how models project the behaviour of the climate system and where agreement between models (or model versions) is strong or weak. Furthermore, comparing the output of models with observed data, from meteorological observing stations and/or remote sensing data, may help insurers to identify regions in which products are particularly sensitive to the uncertainties associated with climate variability and change. Here, a formal approach to compare model output with observational data is presented in the context of WII product design to address specific decisions on pricing of WII premiums.

3. RESULTS OF CASE STUDY

A Bayesian Network (BN) is a graphical model with an underlying probabilistic framework, which characterises and quantifies an outcome of interest, the relevant variables and the causative interactions (Donald et el., 2009). Using a BN framework, a case study was developed to estimate potential losses from drought and excess rainfall cover for rice farmers in Kolhapur, India, using both observational and model forecast data as inputs. Kolhapur was selected because of the recent emergence of WII in the region and the climatologically sensitive nature of the location, being situated at the edge of the core monsoon region (IITM, 2011).

The rice crop in Kolhapur is a Kharif crop and is therefore dependent on the summer monsoon rains. An illustrative payout profile (Figure 1) shows the payouts (as a percentage of total coverage) for a series of triggers attached to an idealised WII product for the period of July: the cumulative precipitation in July is particularly important for the success of the rice crop in Kolhapur. Each meteorological trigger corresponds to a different payout tier. The

Figure 1: Payout profile for a hypothetical rice crop index insurance product triggered by rainfall deficit and excess rainfall: Payouts: Tier 1 = 100 %; Tier 2 = 40 %; Tier 3 = 15 % (percentage of total insured coverage)



precipitation values used are informed by a number of studies linked to crop production in the Indian monsoon region (Bhuiyan, 1992; Veeramani et al., 2005; Rajagopolan, 2009) though actual triggers would likely vary depending on consumer preferences.

Using observed precipitation from the APHRODITE project (Yatagai, 2009) and the payout profile shown in Figure 1, a BN was constructed to show the expected losses associated with the observed precipitation data. The BNs were developed using the software Netica and the images presented here are taken from the user interface (Norsys, 1998). Figure 2 includes four *nodes* to show how WII losses might be estimated using a BN with observed data only. The parent node is the observed July precipitation, from 1961 to 2004, and it has two child nodes which propagate the continuous data to show the probability of exceeding specific thresholds for rainfall deficit and excess rainfall. The final node, at the bottom of Figure 2, shows the combined probabilities of triggering losses at the specified tiers shown in Figure 1. The value in this node, 11.7 ± 27, is the expected loss and the standard deviation based on the probabilistic information in the BN. The expected loss can be used to calculate an appropriate premium. Assuming expenses and loading of 3 %, a necessary minimum premium to ensure profits over a sustained period would be 14.7 %.

The BN in Figure 2 can be extended to include multiple sources of data. Figure 3 shows a simplified version of a BN (node names only) incorporating additional data from downscaled regional climate model (RCM) projections and seasonal forecast data. The RCM data was extracted from the output of the HadRM3 model driven by two GCMs, HadCM3 and ECHAM5, while the seasonal forecast data was created for illustrative purposes only.

The BN developed allows users to examine the influence of different sources of climate information on the expected loss for a particular pricing structure. The *Climate Information Choice* node provides the means for selecting, or weighting, the different sources of data. Numerous methods have been developed to establish different metrics and measures of skill to weight models (Tebaldi et al., 2005; Greene et al., 2006; Tebaldi and Knutti, 2007). However, the decision to weight models based on their ability to capture past observations and key climatic processes is questionable (Weigel et al., 2010). Rather than weight each information source, one can use the BN to determine the sensitivities by selecting each source separately.

Figure 2: Bayesian network of WII losses for hypothetical product including observed rainfall data only

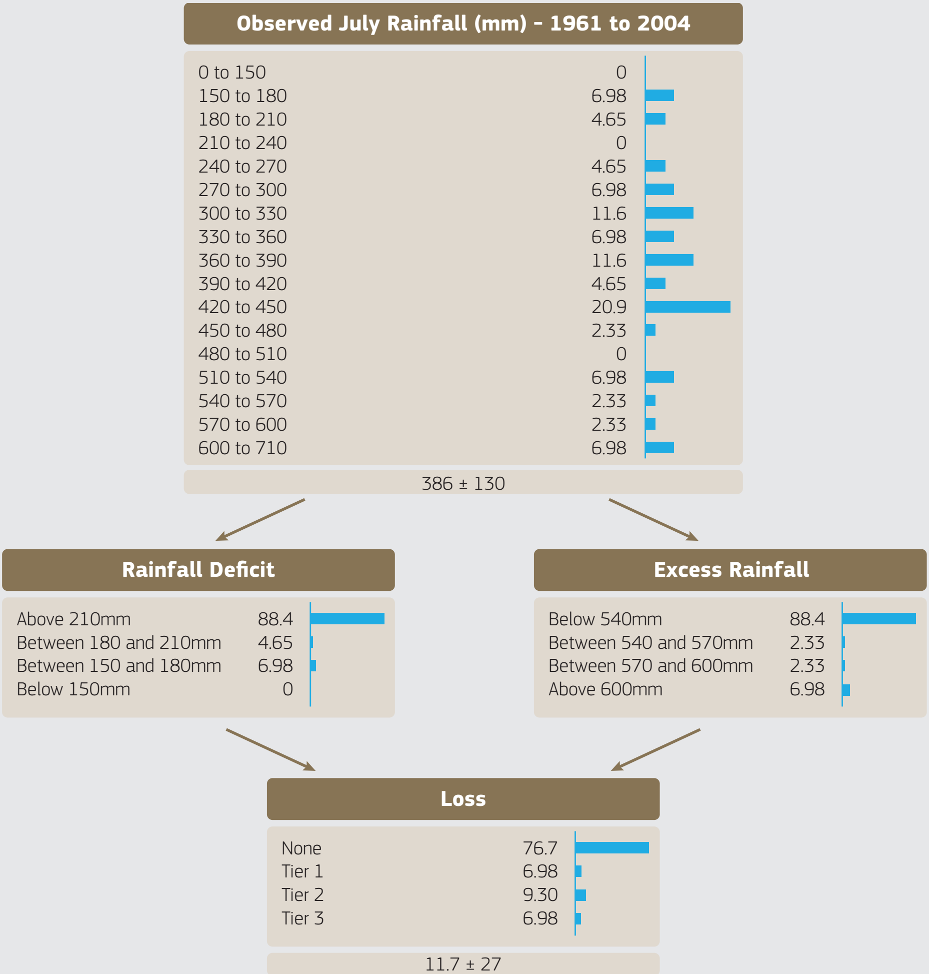


Figure 3: Bayesian network of WII losses combining multiple sources of climate information (node names only)

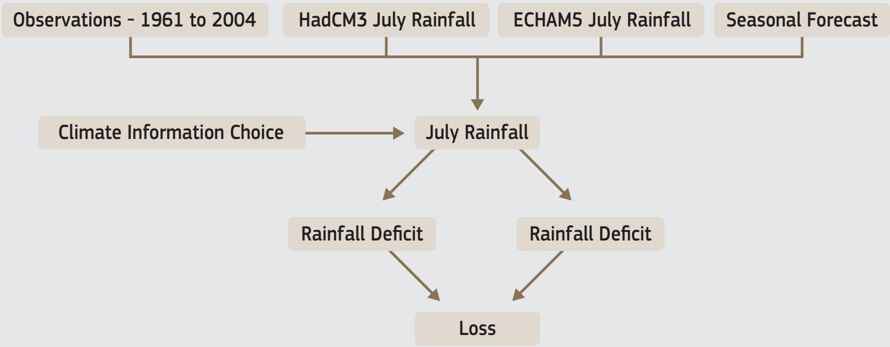


Table 1 contains the expected loss and corresponding standard deviation for each data source for the past and the period 2020 to 2049. The results show that the expected loss from the observations, seasonal forecast and HadCM3-driven RCM results are similar but the ECHAM5-driven RCM results suggest substantial losses, both under past conditions and over 2020 to 2049. Closer inspection of the data reveals that the ECHAM5-driven output (and, to a lesser extent, the HadCM3-driven output) significantly underestimates the cumulative precipitation for the monsoon months in Kolhapur, thereby increasing the frequency of years with deficit rainfall. It is possible to apply bias corrections to the raw model output, which will reduce the estimated losses, but the statistical manipulation of the data needs to be consistent with physical reasoning. Irrespective of the different methods used to correct, or weight data, the BN approach offers a framework for comparing and assessing the value of various sources of climate information in a transparent manner.

Table 1: Expected losses for the rice crop weather index product in Kolhapur, India given different climate information sources

Time period	Information source	Expected loss (%)	Standard deviation (%)
Past	Observations	11.7	27
	Seasonal forecast	9.5	18
	HadRM3/HadCM3	10.4	22
	HadRM3/ECHAM5	88.5	29
2020 to 2049	HadRM3/HadCM3	7.76	20
	HadRM3/ECHAM5	87.7	31

4. CONCLUDING REMARKS

One of the key components of WII product design is the estimation of reliable index variable PDFs. An over-reliance on observed data may lead to inappropriate pricing of contracts, inflating premiums charged to policyholders or risking significant losses to insurers. As the WII sector matures, it may be possible and, indeed, desirable to incorporate climate model output into the design of policies to improve the quality of WII products. Combining information from climate models with observed data from meteorological observing stations and/or remote sensing data requires the interpretation of multiple sources of quantitative data. The BN method explored here presents one way in which alternative sources of data may be combined and compared to estimate the probability of exceeding meteorological thresholds. The case study developed shows how this framework might be used to test the sensitivity of a pricing structure to different data inputs, in the context of rainfall deficit and excess rainfall payouts to rice farmers in Kolhapur. While there are dangers in misusing the BN approach to provide optimal pricing solutions, the tool might be beneficial in aiding the development of suitable WII policy structures.

Perhaps the primary issue facing the WII sector regarding the uptake of model forecasts is the reliability of climate models in simulating the behaviour of the climate system. Model inadequacies and limited computational capacity dictate that model projections are imperfect and contain erroneous information. Assessing climate model reliability and suitability is a nontrivial task. In addition, the legal and regulatory implications of using model forecasts as a basis for WII pricing needs to be carefully considered in the context of insurer responsibilities and policyholder requirements. Nevertheless, such concerns need not delay research on the applied use of model forecasts in WII. Observations of meteorological variables remain uncertain and changing climatic conditions mean that WII practitioners cannot ignore the limitations inherent in relying on observed data. In order for the index insurance community to scale index products in the context of a changing climate, it would be unwise to dismiss the potential value of climate model output in improving loss estimates and providing more robust and fair WII products.

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16 From information to actionable knowledge: Hotspots of food insecurity in Eastern Africa

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KEYWORDS: food insecurity, yield gap, agriculture, cluster analysis, hotspots, scaling out

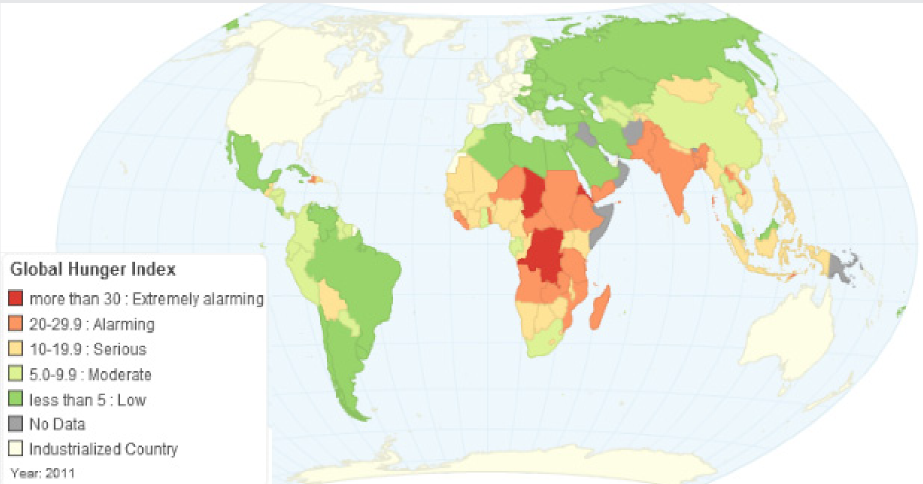
SUMMARY

Even though around 12 million fewer people went hungry during 2010 in sub-Saharan countries, food insecurity remains at levels higher than before the global financial crisis, which threatens the achievement of the World Food Summit and Millennium Development Goal Target 1 (FAO, 2010). Although, at national level, aggregated information on food security is usually available, this is not usually the case at the regional, subregional and local levels. Indices that combine regional information on the severity of food insecurity and potential improvements in production (i.e. yield gap) with indices of the potential return from intervention could help direct governments and donors. In this study, we explored the use of a range of spatial information layers to derive a multidimensional index to determine the potential return from intervention as a function of food insecurity and yield gap, thus informing options for research, development and extension (R, D & E) across five countries of eastern and southern Africa. Outputs from the analysis include: (i) highly vulnerable regions across eastern Africa; and (ii) a list of relevant and actionable issues of potentially high impact for research, development and extension that will help to inform policy and increase investment.

1. INTRODUCTION

As one of the most vulnerable regions in the world to the projected impacts of climate change, Sub-Saharan Africa (SSA) faces many challenges. Uncertain rainfall and the exposure to unmitigated climate risks (IPCC, 2007), the degradation of soil fertility, and the rapid growth in population are major threats to food security. In addition, food insecurity is the most prevalence in SSA with more than one in three people (265 million) suffering chronic hunger and more than 400 million living in extreme poverty (FAO, 2008). For most of the continent, hunger is concentrated in the east, central and southern regions of Africa (Figure 1). Across eastern and southern Africa, maize is the major component of food security for the region and for a majority of the rural households. As the most important staple crop, maize is mostly grown by resource-poor farmers in complex and risky farming systems, alongside legumes, oilseeds and livestock — while it is also the basic staple food for the majority of urban poor. In this south-eastern region, the population exceeds 300 million, of which over 75 % depend on farming (FAO, 2008). With growth in the population and incomes, the demand for maize is projected to increase by approximately 3–4 % annually over the next 10 years, leading to a requirement of 50 % more maize by 2018. In addition, currently, more than 50 % of the south-eastern region depends on maize for food security. This is, however, compounded by the huge volatility in maize production across the SSA region (Koo, 2010).

Figure 1: Hunger is a prominent factor for many living in, especially, SSA and the impact and extent of projected climate change and variability is likely to exacerbate food security across most of that region [(1)].



1 http://www.ifpri.org/publication/2010-global-hunger-index

Africans, together with the developed world, have started taking action and a number of important investments are being made to improve input-output value chains, access to training, and to improve agricultural practices. The Australian Centre for International Agricultural Research (ACIAR) funded the SIMLESA (Sustainable Intensification of Maize Legume Systems in Eastern and Southern Africa) project which is an example of a more integrative approach to improve crop management practices and household livelihoods. However, the task is complex. This is because the problems are multi-causal and solutions might involve trade-offs between conflicting and important goals. This study aimed to provide a first attempt at answering the question: What and where is the problem of food security and poverty in southern and eastern Africa? This information could help bridge the gap between what Africa could be and what Africa can be.

The answers to these questions are expected to provide ideals, facts, and more relevant actions required to solve this complex problem. Here, we utilised local geographical data layers and traditional statistics to determine a multifaceted food insecurity index that can assist in generating relevant and actionable scientific knowledge to help direct investment towards areas likely to have the best possible chance in enhancing food security.

2. APPROACH, RESULTS & DISCUSSION

2.1. Determining the food insecurity index and likely scaling out of technologies

A number of data sets on food production, population growth, and yield gap (HarvestChoice, 2009) were combined using GIS (geographic information system) techniques to derive maps of high likely impact from intervention and investment. Hotspots (equation 1) for intervention were then created by integrating a theoretical measure of food shortages and a measure of yield gap (equation 2). Estimates of yield gap (YG) were used as a measure of potential for improvement in the yield of crops. The number of people without food was used as a measure of potential impact of improvement in food security. Here, people without food were defined in a Food Insecurity Index (FII). The most critical regions would be those having the largest (negative) values of FII and the highest (positive) values of YG.

Thus, hotspots were expressed as:

$$\text{Hotspots} = f[\text{FII}, \text{YG}] \quad [1]$$

$$\text{FII} = [P - \text{PoP}*\text{GR}]/\text{GR} \quad [2]$$

where:

P is grain production (yield x area);
PoP is population; and
GR represents the grain requirement/person/year.

The value of FII then encompasses the human impact of shifting relationships between production and population consumption (Funk and Brown, 2009). Negative values of FII represent areas where the demand for food consumption is higher than its actual availability (supply), while positive values are the opposite. The food insecurity index is then a function of the population, its grain requirement, and available production at a specific location and time.

Gridded production allocation totals (1999 to 2001) for maize, sorghum, rice, wheat, cassava, soybeans, beans and millet were downloaded from HarvestChoice [(2)]. Collectively, these are the most important crops in SSA contributing between 60 % and 80 % of the total calorie intake (Lobell et al., 2008).

Gridded population statistics were extracted for the year 2000 census [(3)]. Only grid cells (approximately 9 km x 9 km) with more than 2 people/km^2 and less than 1 000 people/km^2 were selected. Grid cells having fewer than 2 people/km^2 were considered to be self-reliant, and cells with more than 1 000 people/km^2 were classified as highly densely populated areas (Lobell et al., 2008; FAO, 2008 (http://sedac.ciesin.columbia.edu/gpw/global.jsp)).

Regionally, grain requirements range between 115 kg and 400 kg grain/year/person. In cases of missing data, we used a minimum grain requirement per person of 190 kg/grain/year assuming a caloric requirement of 1 900 calories/day and a typical caloric content of 3 600 calories/kg of grain (Liu et al., 2008).

As maize is the main staple in the region, the yield gap for the maize crop was used as an index of the potential for agronomic improvements in grain yields. Here, yield gap was calculated as the difference between maize yields simulated using low technology inputs (LI) (manure, manual labour, etc.), and the maize yields simulated using high technology inputs (HI) (fertiliser, machinery, etc.), expressed as a percentage ratio (http://www.harvestchoice.org). Negative values indicate areas, which are likely to improve in maize production.

$$YG = (YieldLI – YieldHI) / YieldLI * 100 \qquad [3]$$

In order to identify areas having similar rankings for FII and YG within and across the five countries, a traditional k-means clustering analysis was run. The cluster analysis was customised to identify 10 classes based on minimising the variance within groups and maximising the variance between groups. As the scale and magnitudes in the data varied between countries, the analysis was run for each country individually.

Scaling out technologies across region and neighbouring countries was also investigated by determining regions having similar climates (i.e. 75 % significance level, Figure 4: p-value > 0.75), using Homologue™ software (Homologue™ CIAT, Centro Internacional de Agricultura Tropical, Cali, Colombia, 2004). Homologue™ uses monthly rainfall totals, monthly average temperatures, and monthly average diurnal temperature range (maximum minus minimum) to calculate

2 http://www.harvestchoice.org

3 http://www. sedac.ciesin.columbia.edu

36 variables in the analysis. The climate data layers were interpolated from the WorldClim [4] data set at a maximum of 10 minutes of arc (about 18 km) grid cell size for the 1960 to 1990 period.

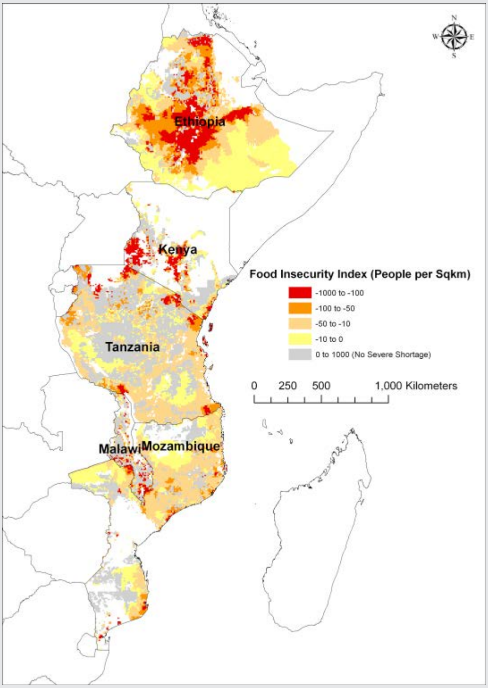
2.2. Hotspots of food insecurity and yield gap

The largest negative FII values were found in Ethiopia and Kenya followed by Malawi, Tanzania and Mozambique. The FII was smallest in Malawi with most areas falling in the class very little or no food shortages, and thus a secure food supply (Figure 2). Combining FII and YG through a cluster analysis delineated regions of high likely return from investment in research, development and extension (Figure 3, red indicates most severe hotspots).

2.3. Scaling out of technologies

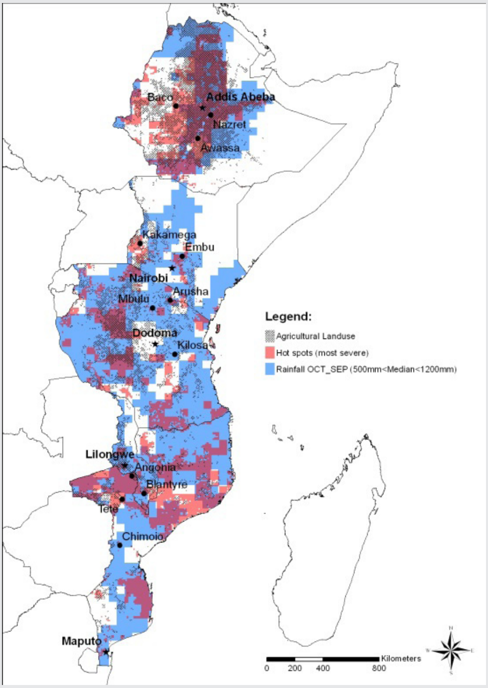
Figure 4 shows the regions that have similar rainfall and temperature closeness and shape for each of the selected SIMLESA locations. Tanzania and Ethiopia showed the largest areas with similar climate homologues while Balaka in Malawi had the largest area of similarity across the

Figure 2: Human impact of shifts in the relationship between production and food consumption.



4 http://www.worldclim.org/current

Figure 3: The most severe hotspot areas (red) superimposed on annual rainfall (> 600 m for October to September) and main dry land agricultural areas. The final selected target sites of the SIMLESA project are overlaid in Figure 3.

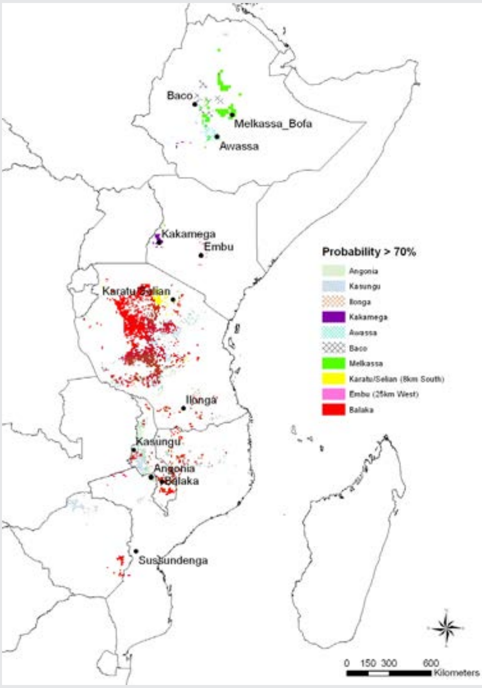


SIMLESA region. Areas of similar colour are likely to have analogue climates and are, thus, the areas to target when extrapolating farming systems technologies such as crop management practices from one region to another. Thus increasing the likely return of investment through enhanced research efficacy and thus having the maximum impact at reducing food insecurity.

2.4. Can we do better?

Farmers are currently experiencing poor crops in about 25 % of years in some parts of Ethiopia and Kenya. This exacerbates the complexities they are facing within a volatile environment. Therefore, targeted agricultural research (e.g. that currently executed in the SIMLESA project) is critical to devise solutions for farmers who produce maize under highly risky conditions —for maize itself, but also to determine more clearly when, and how, legumes can be incorporated into the system, and to devise sustainable management approaches that increase soil fertility and rainfall harvesting. Such research needs to be designed and conducted in the context of household livelihood systems and local institutional settings. In particular, the value chains for input supply and produce marketing are crucial; they also convey knowledge and buffer risk. Such research should be oriented to whole farm-household systems and needs to be undertaken in close cooperation with male and female farmers as

Figure 4: Climate homologue areas for SIMLESA sites



well as local input supply and marketing institutions, in order to produce technologies that are relevant to the social context of households and particularly meet the needs of female farmers. Furthermore, the use of climate forecasting systems and the role that micro-insurance can play in mitigating the impact of climate variability at the regional and household level should not be underestimated. It is anticipated that micro-insurance products will be transferable between regions that have similar climate homologues. Further research would, however, be necessary to determine the value of such systems at a regional level.

3. CONCLUSIONS

This analysis has elucidated that the integration of spatial information layers such as population, production, simulated yield gap, and grain requirement per person in a cluster analysis, can successfully be used as a diagnostic tool to aid in identifying areas for potential investment in research, development, and institutional investment projects across eastern Africa. Clustering of population density, grain requirement and yield gap layers within each country showed areas where food security are most likely to be a problem. Furthermore, similarity domains, based on climate homologues, can be used to identify regions where targeted research, development and extension investment would have maximum impact at reducing food insecurity. This approach has shown that spatial information can be used to generate relevant and actionable scientific knowledge to help direct investments towards areas likely to have the best possible chance in shifting the boundaries from a state of hunger towards a more food secure state.

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17 Demand for drought insurance in Ethiopia

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KEYWORDS: **Ethiopia, weather index insurance, choice experiment, insurance for work, econometrics**

SUMMARY

Although food-for-work or cash-for-work programmes are popular in many developing countries, the idea of 'work for insurance' is new. Using a choice experiment approach in the Southern Nations, Nationalities, and Peoples' Region (SNNPR) and Oromia Region of Ethiopia, we found that smallholders are interested in these types of insurance products and insurance premium payment vehicles, and that most of them are willing to participate in the insurance-for-work programme at lower daily wage rates than those commonly found in food-for-work or cash-for-work safety net programmes. However, most are financially restricted to paying premiums in cash unless subsidised.

1. INTRODUCTION

One in every six countries in the developing world faces food shortages because of droughts (Liu et al., 2008). In recent years, the introduction of weather index insurance schemes has received increasing interest due to new ways of controlling moral hazard and growing concerns about increasing climate risks due to global warming. Despite the various benefits of weather index insurance in agricultural risk transfer and mitigation, results from various pilot studies indicate that the uptake of weather index insurance products by smallholder farmers is below expectation (Dercon, 2002; Suarez and Linnerooth-Bayer, 2010; Giné et al., 2008). High premiums have been one of the key factors negatively influencing the demand for weather index insurance in low-income countries (Carter, 2009). Although price is an important factor affecting demand, it is not the only factor (Cole, 2012). Product design, basis risk, trust and perception of insurance principles by the poor are equally important (Cole, 2012; Carter, 2009).

The existence of social networks, government subsidised post-disaster management strategies such as food-for-work or cash- for-work programmes may affect the demand for weather index insurance. This is because the above strategies may be cheaper for the poor as long as the strategies are accessible. Unfortunately, the use of informal risk management strategies and that of government post-disaster management are often costly. This is because such strategies often arrive after households have sold their assets and, therefore, recovery would be difficult.

In this regard, provision of low cost weather index insurance (based on records of local rainfall station) is expected to enhance product uptake despite some of its inherent problems such as basis risk. In this study, we allow households the possibility of paying their insurance premium in the form of labour, a combination of labour and cash, and cash only to determine households' willingness to pay for drought insurance. Payment with labour has previously been possible in food-for-work programmes, while work for insurance is a new idea originally suggested in Tadesse and Victor (2008).

2. EXPERIMENTAL DESIGN

Households were asked to choose between three insurance schemes and a 'none-of-these' option. The insurance schemes were described by three attributes: work, cash, and payout. To secure identification of the attributes we used the design software Ngene [(3)] to create fractional factorial design with three factors: work, cash, and payout rate. We analysed the choice data using a mixed logit model where we allowed the parameters of all three attributes in the choice experiment to be random parameters with a normal distribution. To capture how previous events related to food shortages, access to safety nets and risk attitude affects the willingness to buy insurance, we added three dummy variables as interaction terms to the two payment variables: work and cash.

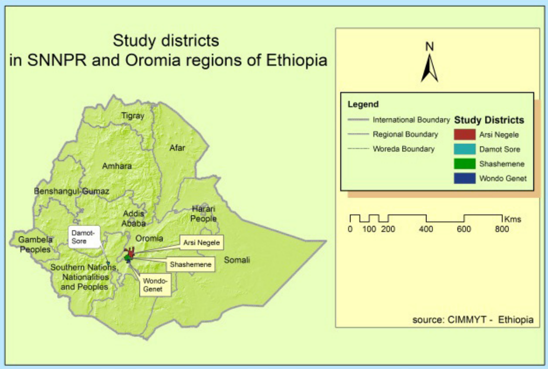
The work attribute was the number of days per year the participants had to work to buy the insurance in a work-for- insurance programme. The cash attribute was the amount per year the participants had to pay to buy the insurance. The payout was the amount of money the participants would receive if there is as little rain (based on a nearby rainfall station record) as is typical every fourth year. The expected yearly payout would, therefore, be 25 % of the payout. Each attribute has five levels in the choice experiment.

3 http://www.choice-metrics.com/features.html

3. DATA AND RESULTS

This study was conducted in two districts in the Southern Nations, Nationalities, and Peoples' Region (SNNPR) (Damot Sore and Wondo Genet) and two districts in the Oromia Region (Sashemene and Arsi Negele) of Ethiopia (Figure 1).

Figure 1: four districts in SNNP (Southern nation's nationalities and peoples: Damot Sore and Wondo Genet) and Oromia (Sashemene and Arsi Negele)



These districts represent different agroecologies, production potential and access to markets. A total of 576 randomly sampled households were used for our choice experiments and answered six or eight choices each. This makes our total number of choice observations 4 103. In addition to the information on drought insurance, other information including exposure to shocks, access to Productive Safety Net Programmes (PSNP), potential risks and coping mechanisms was collected.

A typical farmer in the most densely populated areas (Damot Sore District) has an average farm size of 0.5 ha to support a family of five persons. Only a handful of farmers in Wondo Genet District use irrigation, otherwise the majority of our farmers use rain for crop and livestock production. Hence, the effect of drought is very significant in these farming systems.

Participants familiar with micro-finance and *iddir* (a funeral society) quickly recognise the inherent merits of insurance, while participants who had no experience of these institutions struggled at the outset of the focus group discussions to grasp the concept of formal risk transfer (about 37 % of the sample farmers had not previous heard of insurance). When asked whether they would demand their premium be refunded in periods of no loss based on a weather station record not necessarily on their farm, the majority stated that they would not demand a refund (63 %) but 5 % stated that they would demand their premium back.

About 87 % of the sample households considered the possibility of contributing their labour in tree planting or other development activities to receive insurance cover as a win-win approach.

This is because tree planting in itself helps to conserve soils that could help increase crop productivity and allowing labour as payment for insurance premiums also helps transfer risk to the third party (insurers). About 75 % of households experienced food shortages within the last four years. Both late arrival and early end of the rain are commonly mentioned as the major problem compared to a totally dry spell.

Some of the findings from our mixed logit model indicated that respondents, on average, were subject to the same disutility from working one day as from paying ETB 2.43 [(4)], and that they are willing to pay ETB 0.81 for an expected yearly payout of ETB 1. We note two things: firstly, the implicit wage rates are much lower than the current wage rates from food-for-work programmes in Ethiopia; secondly, the average participants need a subsidy to pay cash for insurance since their willingness to pay is less than the expected cost of the insurance for an insurance company.

4. CONCLUSIONS

This paper uses a choice experiment to elicit smallholders' willingness to pay for weather index insurance in the highlands of Ethiopia. Although food-for-work or cash-for-work programmes are popular in many developing countries, the idea of work for insurance is new.

Using a choice experiment approach in the SNNP and Oromia Regions of Ethiopia, we find that smallholders are interested in these types of insurance products and insurance premium payment vehicles, and that most of them are willing to participate in the insurance-for-work programme at lower daily wage rates than those commonly found in food-for-work or cash-for-work safety net programmes. However, most are financially restricted and are not willing to buy insurance with cash unless the insurance is subsidised.

Households exposed to food shortages in previous seasons are more willing to work for insurance than those that have not experienced food shortages; however, they are not willing to pay more in cash. Hence, interlinking traditional risk management practices (such as PSNP) with insurance will provide a win-win outcome. This is because even in those periods with no payout, farmers may still benefit from the trees planted/soils conserved. Insurance providers are also benefiting from the premium collected in this non-drought period. Furthermore, as smallholders are interested in working for insurance certificates at lower wage rates than the current PSNP rate, this means that the difference in wage rates could be used for insurance subsidies with no additional cost to donors or the government to subsidise the premiums.

4 ETB (birr) is the Ethiopian currency: UDS 1 = ETB 17.96, 2 October 2012.

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6. ACKNOWLEDGEMENT

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18 Demand for index-based insurance by smallholders in light of existing rural institutions in Africa

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KEYWORDS: weather index insurance, interlinking credit with insurance, demand for index insurance

SUMMARY

Income risk in smallholder agriculture in developing countries is very large, and farmers have developed several ways to mitigate these risks. Nevertheless, considerable risks remain that cannot be insured either individually or within the wider village community. Systematic risks are notorious for their difficulty to insure. Weather index insurance is a promising solution to some of the largest smallholder risks, and there have been several pilot projects. However, demand for standalone index insurance appears to be low, and this calls for further investigations and real-world experimentation.

1. BACKGROUND AND MOTIVATION

Small and medium-sized agricultural producers face many income and non-income risks. The major income-related risks are caused by idiosyncratic shocks (i.e. affecting only the individual farmer), such as illness, or covariate shocks (i.e. affecting everyone in a given location), such as weather variations. Farmers the world over have developed individual risk management and risk coping strategies to deal with these risks, but such strategies may be detrimental to income growth as they lead to low return, low risk activities. Research has shown that in rural areas of developing countries, despite the various risk management and coping strategies, considerable residual income risk and vulnerability remains. In that context, the issue is whether there is a demand for additional price and weather-related income insurance in light of individual existing risk management strategies. Related questions are:

Can index insurance crowd in credit and how? What is the rationale for market-based or publicly supported price and weather-based safety nets? What are the appropriate institutional structures conducive to combining index insurance with credit?

2. THE MAGNITUDE OF THE PROBLEM

Income risk in developing countries can be enormous, with the coefficients of income variation of farmers in many developing countries often higher than 40 %. The major worry is that the impact of shocks creates large negative fluctuations in consumption, and especially food consumption and nutrition. Income shocks also lead farmers to draw down their productive assets, such as animals and land, becoming destitute and being stuck in a poverty trap. Furthermore, the tendency of farmers to allocate their production into lower paying, but lower risk activities and similarly for their investments, leads to underinvestment in agricultural inputs, technology, and education, and can lead to permanent poverty traps.

Research has shown that small farmers are not excessively risk averse, with their coefficients of absolute or relative risk aversion being around 1 or less. Risk aversion seems only slightly higher for the poor than for the 'rich', but internal discount rates are often enormous, especially for the poor. This suggests that liquidity and credit constraints may be more important determinants of behaviour than risk aversion.

Credit constraints are important for a variety of reasons. The poor, typically, can only borrow small amounts for short periods (or in linked transactions) because they may be too poor to be reliable borrowers, and have no credible collateral. Formal credit in rural areas is much more constrained than in urban areas because of heterogeneity of areas, plots of land, and the seasons, because of moral hazard, seasonality, and covariance of risk. Furthermore, rural banking requires very high reserve ratios, or has to be provided by banks with urban business: microfinance has not overcome these problems.

Rural financial markets are underdeveloped in most developing countries for the following reasons: the costs of acquiring and transmitting information are high; there are strong informational asymmetries; and there are multiple sources of risk, many of which are correlated across individuals. These features result in endogenous market failures that militate against smallholders. The market failure implies absence of conventional insurance contracts, supply-side portfolio restrictions for agricultural loans; contractual restrictions because of relatively high collateral requirements, which imply quantity rationing of loans; and risk rationing, namely demand-side restrictions.

In this context, farmers find it very difficult to insure their crops because of heterogeneity of areas, plots of land, and the seasons, moral hazard, covariance of risk, and low correlation between weather and income. For these reasons also, it is very difficult to use stand-alone crop insurance to secure the credit to farmers.

Nevertheless, farmers do adjust to shocks. *Ex post* strategies involve the following: drawing down stocks and savings; increasing labour supply; borrowing; exchanging gifts and interest free loans; selling livestock; selling land; temporary migration. *Ex ante* strategies involve, among others: crop and enterprise diversification; build-up of stocks, savings and assets; diversification of assets; using fewer purchased inputs; social sharing arrangements.

However, because of risk, a large share of assets is held in liquid form (food stocks, cash). Rich farm households tend to hold well-diversified portfolios. However, poorer households are not able to hold profit-maximising levels of liquid assets and animals, as they must sell animals to finance consumption in poor years. The attendant loss in profits can be large, of the order of 25–35 % for the poorest. Nevertheless, poor households have higher rates of return on their assets than the rich, which implies that they have good investment opportunities, if they could get the appropriate capital.

The upshot is that, in rural smallholder agriculture, individual consumption is fairly well insured, but only partially so, and better for the 'rich' than for the poor. Furthermore, food consumption is better insured than non-food consumption. However, consumption is not insured against systemic shocks or when social networks break down. Insurance varies a lot by wealth, with the poor poorly insured, while the 'rich' may be fully insured against individual and systemic shocks. In high-risk environments, the profit/loss from adjustment to risks by the poor is likely to be high. But covariant risks are much more difficult to insure at individual level.

In that context, the focus of policy should be on systemic risks, such as weather, prices. Policymakers should not worry so much about impact of risk on agricultural supply because those who supply the most (the larger and richer farmers) are already well insured. Rather, policy should focus on risk reduction and mitigation for the poor, including, of course, famines.

3. THE DEMAND FOR INDEX INSURANCE

Considerable effort has been dedicated to creating and providing pilot index rainfall insurance products, to alleviate income risks. The advantage of index insurance is that it avoids the standard agricultural insurance problems of moral hazard and adverse selection, and it involves an objectively and transparently observed indicator, on the basis of which indemnities are paid. The biggest problem, however, is basis risk, namely the low correlation between the rainfall at the location of the rainfall gage, and the farmers' fields.

Theory has shown that the demand for rainfall insurance is likely to be affected by the following variables (sign of expected effect in parenthesis): the price of the insurance (−); the degree of risk aversion (+); the degree of consumption smoothing (−); household vulnerability to poverty (±); the degree of unpredictability (variability) of future prices or incomes (+); the variance of returns to the insurance contract (−) and; the correlation between returns to insurance and future income (−). Empirical research based on a priori estimations, on the basis of contingent valuation surveys, has found most of these predictions to be true.

Furthermore, it has been found that a priori demand for rainfall index insurance appears to be considerable.

Nevertheless, the demand for actual rainfall insurance, when offered to poor rural households in pilot projects, has been rather low. The main reasons that have been proposed in the literature for this include, among others: high risk aversion; basis risk; time inconsistency (i.e. high personal rates of time discount, which imply desire for consumption earlier rather than later); and ambiguity aversion (i.e. the tendency to not adopt strategies whose outcomes are poorly known).

4. THE INTERLINKING SOLUTION

Since the core source of correlated farm risk is weather, and since credit and liquidity constraints are omnipresent, and poverty trap inducing, index insurance used as a collateral substitute to insure farm credit seems to provide a natural way to resolve this problem. There are several a priori advantages: the provision of insurance to lenders means that they can take on the risk of lending to agriculture; the provision of insurance to farmers means that farmers can afford to take on the risk of using and borrowing for inputs; and the simultaneous provision of credit and insurance allows the creation of 'state-contingent loans'. In other words, farmers receive inputs on credit; then, if the weather is bad, the farmer pays nothing back; if the weather is good, the farmer pays the loan and the premium and interest on both.

There have been no applications of this principle in real settings. A current pilot application in rural Ethiopia is testing this product via a randomised control trial, and is expected to produce some results by 2013.

19 An insight on farmers' willingness to pay for insurance premium in South India: hindrances and challenges

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KEYWORDS: **weather-based crop insurance scheme, agriculture insurance, double bounded dichotomous model, willingness to pay**

SUMMARY

Farmers are vulnerable to substantial weather risks in many parts of the country. In recent years, weather-based crop insurance has been promoted in India for rain-fed crops to provide insurance against risks and losses in crop yields resulting from adverse weather. Farmers, in general, are not aware of the details of weather-based crop insurance policies and the premium calculations. This study focuses on farmers' preferences towards the weather insurance of paddy crop, one of the major irrigated crops in India and highly vulnerable to extreme weather. We analyse the mean willingness to pay for weather-based crop insurance using the double bounded dichotomous model of contingent valuation method. Farmers' willingness to pay was about 2.5 % of gross income with the condition of timely payout for crop losses, creating awareness of the compensation packages and simple documentation. The insurance premium can also be referred to as a risk-adjusted management input in agricultural production.

1. INTRODUCTION

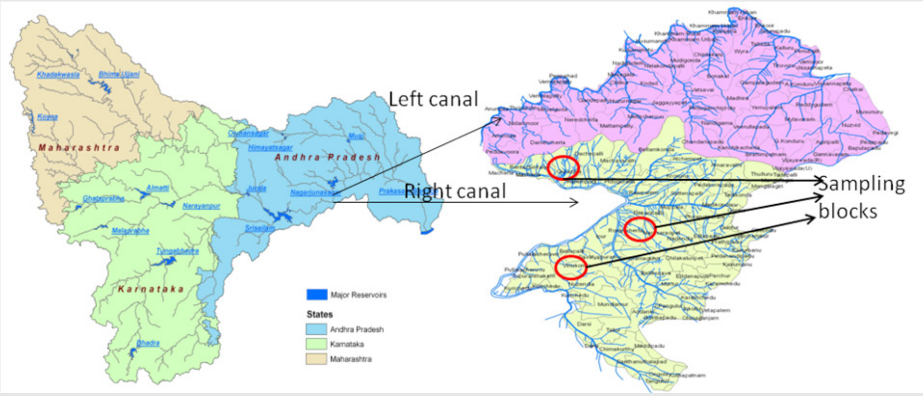
Agriculture is prone to various risks due to production, weather, technological and market uncertainties. Losses arising out of these risks have to be mostly borne by farmers. The majority of Indian farmers operate on a small scale, and often find it difficult to adjust to uncertainties, especially the risks from extreme weather events and variability in climate. Some 65 % of Indian agriculture is heavily dependent on natural factors, particularly rainfall. Studies have reported that rainfall variations account for more than 50 % of variability in crop yields (Agricultural Insurance Company of India Limited, 2005) and a high degree of correlation exists between the rainfall and agricultural production (Gadgil, 2003). Studies on inter-annual and long-term variability of monsoon rainfall have also indicated that variation in rainfall for the subcontinent has a statistically significant (Thapliyal and Kulshrestha, 1991; Srivastava et al., 1992) impact on agricultural production and the national economy.

Farmers in India normally make several adaptations to the changing rainfall pattern, starting from changes in the cropping pattern, delaying sowing time, keeping the land fallow and investment in bore wells. However, government departments also help farmers to cope with risks and weather uncertainties on an ad hoc basis, through subsidies on inputs, waiver of crop loan repayments and crop insurance to compensate the losses. The Government of India has been promoting the crop insurance schemes in association with the state governments since the 1970s. However, due to various institutional constraints, the schemes have not been very popular amongst farmers.

Looking at the overall insurance system, there has been a continuous change in approach for loss assessment and indemnity payments since crop insurance was introduced. The crop insurance business is expanding in terms of the number of crops covered, the number of farmers covered, the premium amounts collected and the premium rates, the amount paid for settling claims, etc. The National Agricultural Insurance Scheme (NAIS) initiated in 1999–2000 was adopted by 23 states and two union territories. The scheme is available for all loanee and non-loanee farmers irrespective of the size of holding. The NAIS covers all the food crops (cereals, millets and pulses) exposed to risks such as drought, excess rainfall, flood, hail, and pest infestation. The NAIS scheme covered more than 110 million farmers and 11.42 million hectares of cropped area in 2008. The scheme is based on the historical yield data of 10 years. Basis risk is high due to the difference between the yield of the area (block) and the individual farmers, high loss assessment costs and delays in processing claims.

The better accessibility to weather data, higher accuracy of weather forecasts and the expansion of meteorological network have recently led to another insurance approach, the Weather-Based Crop Insurance Scheme (WBCIS). The WBCIS operates on the concept of 'Area Approach' (i.e. for the purpose of compensation, a Reference Unit Area (RUA) is deemed to be a homogeneous unit of insurance). The state government notifies all the insured cultivators in a particular RUA of the insured crops before the commencement of the season. Each RUA is linked to a reference weather station. The WBCIS has been implemented in selected states of India on a pilot basis since 2003, providing compensation for adverse conditions of relative humidity, unseasonal rains, and heat. The WBCIS was extended to 20 states at the end of 2009. The WBCIS was implemented for selected crops such as groundnut, maize, cotton, chillies, tomato, brinjal and selected plantation crops, but not irrigated paddy crop.

Figure 1: Krishna River basin and the Nagarjuna Sagar project with left canal and right canal



Nonetheless, a number of these policies or measures are ad hoc and, in most situations, farmers neither get timely information to claim the losses, nor compensation. There are still some difficulties in implementation, linked to premium rates for different crops, farmers' unawareness of the use of WBCIS, etc. These difficulties entail lower insurance interest on the farmers' side. At present, index insurance is deemed to work if there is a sustained demand for it, which depends on farmers' understanding of the true value of insurance.

To this end, the present study was designed to address farmers' willingness to pay for the irrigated paddy crop in the Nagarjuna Sagar Project (NSP) located in the Krishna River basin in Andhra Pradesh. This would help the policymakers and the insurance companies to better understand the insurance of paddy crop under WBCIS and develop the relevant payouts. The study also focuses on the constraints in adapting the crop insurance, the perceptions of farmers to climate change and, particularly, rainfall variability.

2. METHODOLOGY

2.1. Study area

The Nagarjuna Sagar Project (NSP) from Krishna River basin in Andhra Pradesh was selected for the study. This is a multi-purpose project with irrigation, hydropower and flood control components. The major NSP canals, the right and left canals cover five districts, namely Guntur, Prakasam, Nalgonda, Krishna and Khammam, with a 0.82 million hectare command area (Figure 1).

The Guntur District has the highest command area of 0.28 million hectare. Some 240 paddy farmers were randomly interviewed during the 2010 Rabi season from the head, middle and tail ends of Nagarjuna Sagar project right canal area in Guntur District covering six villages from three mandals (blocks). Data related to the household characteristics, their perceptions of the crop insurance and their willingness to pay for weather-based crop insurance for paddy crop was collected. In addition, Agricultural Insurance Company of India Limited (AIC) officials were also interviewed on the constraints of the crop insurance implementation.

2.2. Analytical tools

To elicit farmers' willingness to pay for weather-based crop insurance, the double bounded dichotomous model of contingent valuation (DB-DCV) method was employed as it has been the most popular method for assessing the value of any non-market goods during recent times (Haripriya, 2003; Herriges and Shogren, 1994; Pinuccia and Elisabetta, 2000; World Bank Institute, 2002). The DB-DCV method is superior to an open-ended format as it confronts respondents with a more market-like situation (Bateman et al., 2002) and is statistically more efficient than conventional single bound contingent valuation method in reducing anchoring bias, 'yea-saying' bias, standard error of parameter estimates and confidence interval to willingness to pay estimates (Hanemann et al., 1991).

To obtain realistic willingness to pay estimates in CV studies, the reference (status quo) and target levels of each attribute of interest should be clearly described to the respondents (Bateman et al., 2002). The weather-based crop insurance policy was explained in detail to all farmers, before they were asked whether they would be willing to pay for weather-based crop insurance policy at a certain price level. The exact wording of the question posed to farmers was: 'Suppose new weather-based crop insurance is coming into the market, which is effective in compensating farmer losses based on the cost of cultivation and deviation of pre-fixed weather parameter from its normal level in your locality. There will not be any yield loss estimation survey or crop-cutting experiments for assessing yield loss. In this case, would you like to take the crop insurance? If "Yes", would you pay INR XXX per hectare as a premium for insurance policy which would provide a compensation of INR YYY per hectare if the insured event occurs?'

Depending on the response to first bid, the second bid was prsented: for 'Yes' respondents, the second bid was higher and for 'No' respondents, it was lower than the first bid. The amount of the second bid was also assigned randomly across all interview schedules. Farmers were told that weather-based crop insurance pays out only if the concerned weather parameter (rainfall or other) deviates from a pre-fixed trigger level in both directions (i.e. deficient or excess). If the farmer refuses to pay any bid amount, he was asked to mention the reason for non-willingness to pay for weather-based crop insurance or any suggestions or modification they have other than those mentioned in the weather insurance product presented to him.

Relevancy rating was employed to evaluate the importance of different constraints faced in the implementation of an insurance scheme in the study area. The farmers and AIC officials were asked to rate the constraints in a five-point relevancy continuum, namely 'Very highly relevant', 'Most relevant', 'Relevant', 'Less relevant' and 'Not relevant' (Manojkumar et al., 2003).

Furthermore, to evaluate the farmers' perceptions about the climate change, the Henry Garrett Ranking Technique was used (Garrett and Woodworth, 1971). In this method, farmers were asked to assign ranks to seven prominent climate change phenomena depending on their observations. The order of merit given by the farmers was converted into ranks.

3. RESULTS AND DISCUSSION

The sample farmers interviewed were cultivating paddy as a major crop on their farms. Other major crops include chilli and cotton, and tobacco to some extent. All farmers were using canal water as a major source of irrigation for the cultivation of paddy crop. The average age of farmers from the sampled data was 44 years, where most of them (45 %) were primary educated (1–4 standard). The majority of these farmers (59 %) observed considerable variability in the weather over the past 10 years, while 31 % observed little variability in weather. Farmers were very much concerned too about climate change (47 %).

Farmers' perception on climate change shows that 'irregular weather' holds the highest mean score in the first Henry Garrett Ranking which indicates that farmers have frequently observed irregularities in the climatic phenomena over the last 10 years. 'Untimely rains, storms and floods' held second position in the Henry Garrett Ranking and 'persistent drought', third position. The 'temperature fluctuation high or low' was at the bottom of the list bearing lowest mean score. All these ranks indicate that farmers are well aware of the climate changes over the years and the risks from such climate variability or change to crops and their livelihoods. These perceptions, perhaps, would have some bearing on their willingness to take a crop insurance policy. However, there are other constraints that influence farmers' interest in the crop insurance policy as observed in the study.

The constraint bearing highest relevance coefficient (RC) is 'Scheme does not indemnify even if I suffer loss' which bears the highest RC (0.74), followed by 'Payouts are not made in time' (0.71). This raises concern about small farmers because if compensation is not made on time, small farmers are unable to continue production during the next season due to lack of money to purchase inputs. This may affect the total production of paddy in the district as farmers may not take risk in spending more money on inputs such as fertilisers and chemicals during water scarcity periods. On the other hand, AIC officials revealed that frequent relief assistance by the government to farmers in event of natural calamity and high claims to premium ratio reduces the financial viability of the insurance scheme RC (1). Furthermore, loosely laid compensation frameworks, particularly in estimating and confirming the crop losses, makes the payment difficult and time-consuming.

Studies on the factors affecting willingness to pay for the WBCIS are scarcer; such findings would be useful in the development of premium products and policy recommendations. The log-likelihood analysis in the study show that the farmers' age was negatively significant implying farmers' willingness to pay for the WBCIS will decrease with increase in their age. Increase in the farmers' age reduced the log-likelihood of their willingness to pay by – INR 24.48 which was significant at 1 % level (Table 1). Furthermore, old farmers were comparatively illiterate and had difficulties in understanding the insurance concept. The result was in contrast to Seyed et al. (2010), who stated that farmer's age was positively related to the adoption of crop insurance by Iranian farmers. This may be due to differences in socio-economic features of the farmers of India and Khuzestan Province of Iran.

Farmer's education was found to be positively significant with the willingness to pay. As the farmers' educational level increases, their willingness to pay for WBCIS also increases by INR 39.35, which is significant at 1 % level. This result was in compliance with the result obtained by Seyed et al. (2010) who stated that farmer literacy level was positively related to their adoption of crop insurance. Farm size was found to be positively significant with the willingness to pay. As the farm size increased, farmers' willingness to pay for the WBCIS also increased. The marginal effect of farm size on farmers' willingness to pay was INR 38.78 which was significant at 5 % level of significance.

Table 1: Results of the log-likelihood model for DB-DCV

Variables	Coefficient (Std. Error)	Z value	P > | z |
Farmer age (years)	– 24.48** (8.15)	– 2.64	0.008
Farmer education (years)	39.35** (15.12)	2.60	0.009
Farm size (ha)	38.78* (17.21)	2.25	0.024
Farming experience (years)	11.28 (8.35)	1.85	0.052
Annual income (INR)	0.0013* (0.0005)	2.23	0.026
Awareness about crop insurance (Yes/No)	77.97* (31.7)	2.46	0.014
Institutional credit access (Yes/No)	2.77 (132.62)	0.02	0.98
Constant	716.48* (293.12)	2.44	0.015
ln σ	6.27 (0.11)	56.92	0.00
σ	528.15 (58.17)	—	—
Log-likelihood	– 202.30	—	—
Chi-square (χ^2)	53.99	—	—
Estimated mean willingness to pay (INR ha^{-1})	1 421	—	—

The other important factor playing key role in the farmers' willingness to pay was the awareness programme on the WBCIS. The marginal effect of the awareness programme on farmers' willingness to pay was INR 77, and significant at 5 %. The mean willingness to pay for paddy WBCIS was INR 1 421/ha, which is about 4.7 % of the maximum compensation offered (INR 30 000/ha). In other words, the farmers are willing to pay up to INR 4.7 for compensation of INR 100 during the critical climatic conditions.

It is worth mentioning that the mean willingness to pay for the WBCIS is comparatively higher than the premium rate of NAIS (2.5 %) for paddy crop. The farmers are also willing to pay on the conditions of timely payout for crop losses, sufficient awareness about the compensation packages, and of ease of documentation and the compensation process. The estimated mean willingness to pay for the WBCIS is about 2.5 % of the gross income (INR 56 840/ha), 0.6 times of seed cost (INR 950/ha) and about 0.5 times of the irrigation cost INR 650/ha). Hence, insurance premiums can also be considered a small portion of the input cost and can also be viewed as a risk adjustment management input instead of a separate cost of cultivation. As the insurance premium is comparatively less, it can be encouraged to be adopted by all farmers.

4. CONCLUSIONS

Compared to conventional crop insurance, weather-based crop insurance schemes are expected to provide significant weather risk reduction in the agricultural sector. The latter is currently being tested in most of the states in India on various crops and through subsidies by the state and central governments. Hence, it is important to create more awareness of the farmers of the insurance schemes in order to ensure their financial security in the event of heavy loss due to unmanageable adverse weather events such as floods, droughts, etc.

The major factor which may increase the farmers' willingness to pay for the WBCIS is the large-scale awareness programme: it was also found to be significantly influencing the farmers' willingness to pay. The AIC could run intensive awareness campaigns for farmers through different programmes such as Rachabanda and Polambadi, or displaying pictorial flexies showing the benefits of the WBCIS at Grampanchayat offices, farmers' meeting places, village libraries and temples, and through different mass media such as agricultural periodicals, newspapers and television. AIC representatives should visit villages to provide in-depth awareness about the WBCIS. Bankers can quote numerical facts to farmers about similar schemes, if any, which are being implemented in any other region. The AIC could ask for help from the local agriculture extension officers to arrange awareness programmes.

The state governments have decided to use mandal (block)wise automatic weather stations for the forecast and the WBCIS. The private services can also emerge in the market for providing weather data for forecasting and scale-up weather-indexed insurance. The private insurance companies such as BASIX and ICICI Lombard, which are already in the field of indexed insurance can intensify the awareness programmes by providing forecast information to the farmers and developing the new insurance products according to the local climatic conditions.

The forecast information would have a large impact on weather-indexed insurance for irrigated crops (like paddy) and, already in some states, automatic weather station networks are being set up. Researchers can also play a key role in bringing out the socio-economic issues and farmers' perceptions on the insurance index. Further research can focus on the development of payouts for the RUA based on their cost of cultivation and weather parameters. Working out different premium and compensation packages will provide more opportunities to accept the World Bank Institute as a viable risk-bearing strategy. The premium can also be considered as an input (management) cost, thus making it justifiable for its inclusion in future crop production programmes.

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20 Designing and implementing weather indices: towards resolving the challenges of weather-based indices for Agro Risk

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SUMMARY

Agricultural insurance in Asia, Africa, and, in general, in the developing countries is high on the public policy agenda. There have been great efforts by the FAO, World Bank, regional banks, NGOs and others to launch a number of weather index-based schemes for agricultural insurance (covering the cost of production) based on the ease of administering these programmes, and fast payouts. Basis risk and its asymmetrical distribution are major issues with the highest impacts being on individual policies and primary layers and much smaller impacts on the higher reinsurance layers. Without acceptance from the stakeholders on the ground, these programmes will not be sustainable or scalable, despite the fact that the global reinsurance may be willing to provide capacity for reinsurance covers. This paper summarises the approaches and issues in pricing index-based agriculture insurance contracts and the associated diverse issues using a recent project for illustration. Proposals are made to alleviate some of the well-recognised issues.

1. INTRODUCTION

Agricultural insurance in developing countries has been supported and promoted in various ways for many years, as a means to assist farmers in protecting their livelihoods from the impact of primarily weather-related losses. The goal has also been to ensure stable and less volatile food production in these countries. Agriculture in most of the developing countries is based on small to very small (a few hectares or less) land holdings, rain-fed crops, insufficient access to capital, and mostly self-sustenance production. At the same time, the poor farmers in these countries make up a significant part of the population and are large contributors to the national GDP.

Rural development policies are aimed at improving the living conditions and earning power of the farmers. In this context, agricultural risk insurance (mostly limited to cost of production) could play a significant role towards achieving the development goals of many developing countries. However, the nature of the agro-production in these countries creates significant challenges. Traditional distribution channels and traditional indemnity insurance cannot be sustained due to the limited farmers' ability to pay the market premium, lack of risk awareness and low developed insurance markets, complex and exclusion-driven policies, as well as time-consuming claim settlement processes and associated moral hazards. Under these circumstances, weather-based parametric trigger insurance has been seen as a solution due to simple and understandable policies, quick settlement of claims based on well-defined indices, very low moral hazard without claims adjustment processes and, overall, much lower distribution costs of the insurance programmes. As a result, many pilot projects of this kind have been launched (Hazell et al., 2010). However, they have faced some significant challenges — efficient and sustainable delivery channels, complex modelling requirements necessary for development of weather-based indices and, in general, difficulties in scaling up the programmes to a sustainable and commercially viable levels for all stakeholders (farmers, governments, primaries, and reinsurers).

There are many challenges to agro-insurance development. One obvious one is the willingness of farmers to participate in a voluntary insurance programme. Contrary to a credit programme in which the farmer obtains capital money upfront and must repay over time, the farmer needs to pay upfront into an insurance scheme with the expectation of receiving money in the future should they incur losses.

In the event that the insurance trigger does not activate (pay out) when there are, indeed, losses, the insurance programme will lose credibility and farmers will not subscribe to it. This is what is called 'Basis Risk'. Of course, the opposite could occur; the farmers could receive payouts from the insurers although no losses were sustained.

Parametric trigger-based risk transfer programmes have performed well within the context of catastrophe bonds used for risk diversification of large insured portfolios. While basis risk is unavoidable, in such cases, it has been within acceptable levels and disclosed and articulated in the prospectus of these securities. In the case of individual weather-based polices, the basis risk could be relatively very high despite the fact that it could be within reasonable bounds for larger aggregations of policies (portfolios) at country, region, or province level. Individual farmers are 'happy' when they gain from the peculiarities of the basis risk, and distrustful when they do not get paid for their losses due to the triggers being not activated. Parametric weather-based insurance for them becomes 'intangible good that offers stochastic benefits' (Carter, 2009).

The basis risk is an issue for the risk-takers (e.g. insurance and reinsurance), but it is relatively small and can be dealt with through conservative risk pricing and risk selection. However, this asymmetry in the impact of basis risk to the farmers and the financial sectors is not sustainable since the insurance solutions, intended to protect and assist the farmers, are not seen as such and are not embraced by the farmers.

We point to several issues in this note that are frequently encountered and present some thoughts on how basis risk could be tackled and made acceptable from the farmers' perspective.

2. RISK QUANTIFICATION

2.1. Different perspectives

It is worthwhile looking at weather-based index crop insurance from the perspectives of the insured (farmers), insurers/reinsurers, and modellers (both 'statistical' and 'agro-climate' profiles) to better understand the issues concerning feasibility and sustainability of the solutions being promoted.

Due to the relative high frequency of adverse weather conditions, premiums reflecting the risk are greater than the 10–15 % range of the sums insured, which is the threshold above which the poor farmers will not participate voluntarily into insurance schemes. This makes premium subsidies by the government necessary; the government, in turn, would look on the success of the insurance programmes in terms of how much the farmers have been paid back. From their perspective, a successful underwriting year for insurers/reinsurers is not a measure of market success.

From farmers' perspective, they can retain a small part of the risk and manage it through various community-based solutions: their main concern is to be quickly compensated for losses seriously impacting their livelihoods.

Commercial insurers and reinsurers always have the option to select only the risks they understand and can quantify, and avoid other risks. They have the option to spread and diversify their portfolios, as well as to price the risks based on the technical risk pricing, risk margins, CAT loading, and administrative costs.

Modellers, who are tasked with quantifying the risk and verifying the feasibility and sustainability of the risk transfer products, have significant challenges. 'Statistical' modellers need sufficiently long time series of yield and agrometeorological data to properly capture the variance in crop yields with respect to weather indices. Basic indices (e.g. deficit/excess rainfall, temperature) have been developed and tried in many pilots, but more complex indices (e.g. crop disease-related) generally lack data to correlate yields and weather variables in developing countries. 'Agro-climate' modellers with their background in crop modelling and crop yield forecasting attempt to overcome the shortcomings of the short and incomplete historical data. This approach, typically, requires more time and effort in order to properly calibrate the crop and forecasting models.

A unifying theme across the different perspectives is that the lack of sufficient data has to be dealt with, and calibration methods used need to be insurance-oriented.

2.2. Weather-based index and area-yield policies

A typical weather-based contract (policy) provides covers for weather perils that affect the crop yield (e.g. deficit rainfall cover, excess rainfall cover, consecutive dry days cover). This cover is also segmented across the different crop development phases (e.g. sowing and germination, vegetative growth and flowering to harvesting, each phase being defined with a start and end date). Policy payouts are typically structured with specified triggers, above or below which payouts occur. Rates of payouts are defined at one, or several, strikes (values of the indices where payout function changes), with specific payouts amounts per strike. These policies are usually priced and verified using time series of historical weather and yield data, after de-trending, if needed.

Area-yield policies are generally priced based on a four-module building-block process (hazard, exposure, vulnerability, and loss modules). Typical steps involve the development of historical and simulated time series of weather data, the development of crop specific weather index (or indices) based on historical and simulated time series, the development of (vulnerability) models that correlate the weather index (indices) to crop yield and, finally, estimation of the risk metrics necessary for pricing and risk transfer.

Both types of insurance policies critically depend on the data available and require additional data cleansing and enhancement using additional data sources.

2.3. Data challenges

Weather-based indices ideally require ground-based weather stations spaced at less than 20–25 km [(1)]. A recent capacity-building project in Mozambique funded by the International Finance Corporation of the World Bank Group (IFC) [(2)] and jointly executed by Asia Risk Centre, Risk Management Solutions, and Guy Carpenter, is used to illustrate some of the data

1 Earlier studies used 25 km radii from a weather station as the distance over which observed precipitations were valid to develop weather indices correlating to crop yield. More recent studies show that spatial correlations of precipitations decays at distance more or less than 25 km, depending on the local topography and other climate factors.

2 *Local Capacity Building for Index-Based Catastrophe Micro(re)insurance in Mozambique*, Guy Carpenter & Company, LLC, and Asia Risk Centre o/b/o Risk Management Solutions, Grant No 579027.

challenges and possible ways to resolve them. The country has only 113 stations in 69 districts, while 73 districts are without stations. The time series of weather data is 10–50 years in length with many incomplete data over long periods. Use of reanalysed gridded data becomes a necessity in such situations. This way, it is possible to cover the region uniformly and for a longer period of time (50 years or more). The limitation is that those data are not being updated on a regular basis (they cannot be used for claim assessment) and that they contain a fair amount of assumptions in their development, which increases the uncertainty.

Yield data are also a challenge (e.g. maize production and yield in Mozambique are available from season 2000–01 to season 2008–09 through a branch of the Ministry of Agriculture); however, several seasons (out of the nine for which crop data are available) have been affected by severe droughts and other perils. Based on discussions with local stakeholders, the reliability of the data is somewhat questionable — another source of uncertainty.

Remote sensing-based methodologies are often needed in enhancing the available historical data. These methodologies have been extensively calibrated with ground data from the World Meteorological Organisation stations. They are continuously updated either daily or every 10 days (dekadal) at a high level of resolution (25 km or less) and are easily accessible on the Internet. The limitation of their use is that they cover only a short period of time (15 years or less), and thus cannot be used for estimating the tail risk (at high return periods of occurrence). For example, the data from the Tropical Rainfall Measuring Mission (TRMM) provide three-hourly and monthly rainfalls at 25 km grid resolution; the Water Requirement Satisfaction Index (WRSI) Precipitation Estimates operated by FEWS NET at the USGS and the National Oceanic and Atmospheric Administration (NOAA) have provided dekadal rainfalls at 10 km grid resolution since 1995.

2.4. Uncertainty quantification and risk metrics

Major efforts typically go into the selection of the indices and their calibration so their correlation with the crop yields are maximised. Examples of very simple indices include deficit rainfall, temperature deviations, consecutive dry days, etc. A very popular and robust index based on meteorological data is the Standardised Precipitation Index (SPI) which measures temporal and spatial deviation from the average rainfall in the region and rainfall requirements for the crop being studied (crop growing seasons). More complex indices, such as the WRSI, determine the ratio of the actual evapotranspiration to the optimum evapotranspiration. Computations are quite complex and include water balance (rainfall and soil moisture) over a high resolution grid, as well as temperature, humidity, solar radiation and wind speed over lower resolution grid for every dekad.

Other indices, based on both meteorological and crop physical parameters derived from remote sensing analysis, can also be used, including open source ones — such as the Normalised Difference Vegetation Index (NDVI), and Net Primary productivity (NPP) or proprietary indices, such as those developed by EARS [3].

3 http://ears.nl/about_ears.php

Figure 1: WRSI index vs. observed yield for maize (raw data) (Mozambique)

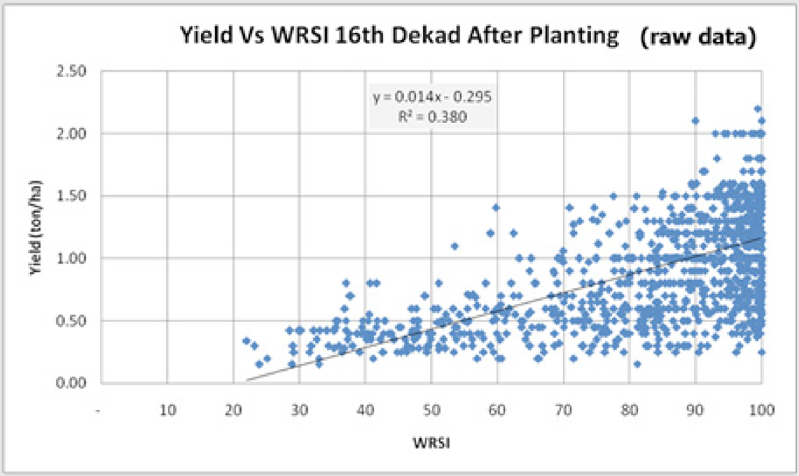


Figure 2: WRSI index vs. observed yield for maize (de-trended data) (Mozambique)

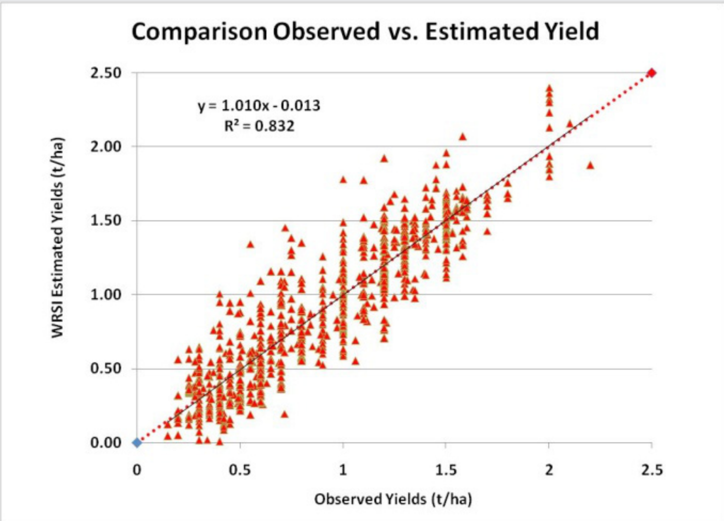


Figure 3: Quantification of uncertainty (Mozambique)

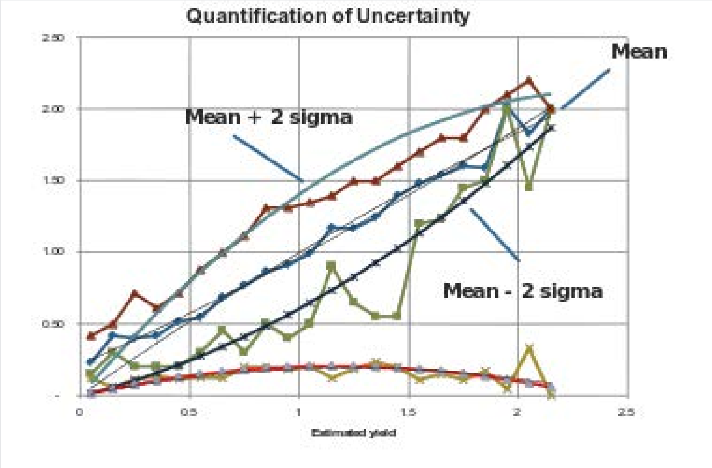
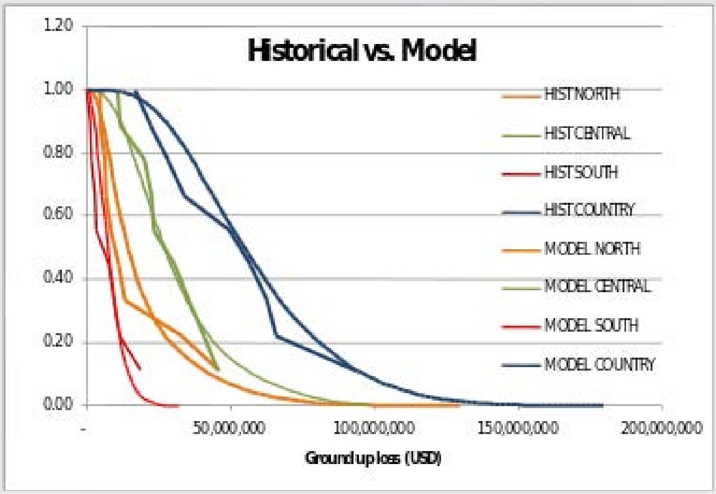


Figure 4: Ground up loss vs. Probability of exceedance (Mozambique)



It is clear that the development of weather-based indices and high-resolution insurance policies includes a significant amount of uncertainty, which needs to be dealt with and quantified. We illustrate this with correlation of the WRSI index and observed yields for maize in Mozambique, as shown in Figure 1. Each point in this figure corresponds to a given year and district. The raw data show a clear trend, but a very high amount of uncertainty. Instead of studying the yield itself, it is advisable to study the variations with respect to the reference yield. Also, analysing the country by regions separately could be useful in recognising regional yield variations and reducing the level of uncertainty. Figure 2 shows the relationship between the index and the yield after performing the above modifications. The trend is clean, yet the amount of uncertainty is still large enough to be explicitly taken into account for risk quantification.

Figure 3 summarises the quantification of the uncertainty. The mean estimate of the trend and the two sigma bounds are plotted along with the observed crop minima and maxima. The estimates of the standard deviations on yields (sigma) are shown as the bottom curve.

Figure 4 shows the modelled and historical ground up loss curves. Probabilities of exceedance at countrywide and regional level are estimated using historical and modelled data that take into account the uncertainty previously quantified.

Figure 4 shows a good match between the modelled and observed risk levels at countrywide and regional levels of aggregations. Basis risk at this level of aggregation is within the acceptable bounds and could be dealt with by primaries and reinsurers. However, due to the high uncertainty at higher levels of resolution (in this example, district level), basis risk from farmers perspective is still very high. This is a problem that does not have an immediate and easy solution and, in the next section, we provide our thoughts on the avenues along which more acceptable solutions could be found.

3. AVENUES FOR BASIS RISK REDUCTION AT FARMER LEVEL

We are exploring a couple of possible avenues to pursue in an attempt to better address the issue of basis risk from farmers' perspective, each with its advantages and disadvantages.

Hybrid solutions where the weather-based parametric index is defined at a lower level of resolution (e.g. regional or province level) and an indemnity-based solution is applied at higher levels of resolution (district or village levels). It should be noted that this aggregation does not need to follow political or administrative hierarchical boundaries. In fact, aggregation of districts or villages that are more homogeneous in terms of their agro-climatic, soil and other conditions would be more appropriate for reduction of basis risk at this level of resolution.

In this case, the weather-based index triggers aggregate payouts for the region it covers. These payments are then distributed at higher levels of resolution based on regional loss distribution estimated through actual on-the-ground sampling (e.g. crop cutting experiments, as is the case in India — NAIS and MNAIS schemes[4] or remote-sensing technologies that are currently being explored.

So, the hybrid solution has two components: (i) weather-based parametric trigger; and (ii) distribution of the aggregate payout to affected farmers in the region based on actual sampling or estimate of the loss (e.g. deviation from reference yields). While the transparency, low cost, and expediency of the parametric trigger solution at regional level remains, the costs of achieving fair payout distribution to affected farmers would go up, and the time to settle and execute the payments will become longer. The implication is that rural development policies will need to account for this and accordingly define the legislative and the regulating environment for agricultural insurance.

How to draw the balance between better handling of the basis risk from farmers' perspective and the simplicity, expediency, and transparency of pure parametric trigger solutions needs to be established on the basis of the specific conditions in the country and detailed parametric studies.

New technologies for the development of indemnity-based solutions that use high-resolution yield estimates from remote-sensing observations. Such a solution would be based on simulated and well-calibrated crop forecast high-resolution yield models that use remote-sensing parameters from satellite observations. Such a system will continuously monitor the status of the crops and will provide alarms of crop stress spots, yields forecasts, as well as yields assessment at the end of the season. The system requires a GIS (Geographic Information System) software platform to integrate all components, and has to be operated by an independent and reputable state or international agency. The system will have to have demonstrated crop yield assessment capability at sufficient level of resolution and sufficient level of accuracy, as well as being supported by standard and well-documented outputs so that yield trigger-based risk transfer programmes could be based on it. A recently launched initiative by the CGIAR (Consultative Group on International Agricultural research) for India, Pakistan, Nepal, Bhutan, Bangladesh and Sri Lanka may hold a promise for such a system to be developed for Asia.

4. CONCLUDING REMARKS

We note that resolving the issue of basis risk in a more satisfactory way from the farmers' perspective requires multidisciplinary and cross-functional collaboration between communities and governments, risk modelling and technology experts, as well as the engagement of catalysts (champions) to scale up the solutions and make them viable and sustainable for all stakeholders.

4 National Agricultural Insurance Scheme and Modified National Agricultural Insurance Scheme — see the FAQ in this document (http://www.agricoop.nic.in/MNAIS.pdf).

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21 Alternative methods to construct convenient indices with existing data

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KEYWORDS: agricultural insurance, risk exposure, index construction

SUMMARY

It is among the policymakers' primary objectives to develop an optimal, self-sustained, and market-based agricultural insurance system. However, similar to other insurance mechanisms, agricultural insurance also suffers from information asymmetry and moral hazard problems. One solution to overcome these issues is the index-based insurance schemes. This study investigates the potential index parameters that can be used to cover drought-related risks in Turkey. The data is based on a unique index which is conveniently accessible to interested parties. It consists of regional, weather-related, as well as farmer-specific characteristics. The model suggests a simple forecasting technique to determine the payment threshold. The index cannot be manipulated by the insured or the insurer. It also offers the additional benefits of reduced transaction costs during indemnity payments.

1. INTRODUCTION [1]

It is well known that agriculture is a risky business. Farmers face several types of risks, some of which can have catastrophic effects on their productivity. While most risk factors can be effectively eliminated through precautionary measurements, risk is an inevitable part of agriculture. Insurance can partially offset the damages by transferring the risk to third parties.

1 The Aginsurance Project is supported by European Commission under Marie Curie Grant No 247723. The opinions presented in this research are those of the researcher, and do not necessarily reflect the opinion of the Commission (http://www.aginsuranceproject.com).

Examples of agricultural insurance have existed for a long time. Discrete events, which can be easily identified (e.g. hail), have a long insurance history. For such events, the definition of the risk is clear, which makes it easier to offer insurance. However, in cases where the risk definition is less clear, the insuring agents are hesitant to enter the market. This has been more or less the case for the Turkish agricultural insurance market when it comes to covering drought-related losses.

Agricultural insurance in Turkey has a relatively short history. However, as a result of government subsidies and awareness programmes, the market is growing very fast. The current system offers only traditional insurance against non-systematic risks. The Ministry of Agricultural and Rural Affairs employs several hundred loss adjusters to estimate the losses after an insured event.

In its current form, offering coverage for systematic risks such as drought is not feasible. An event as such can have large-scale distortions to production, which are almost impossible to estimate on an individual basis. Loss adjusters will need to investigate and calculate farmers' losses on a case-by-case basis, which will create substantial overhead costs.

One solution we propose is enhancing the current scheme with index-based insurance against drought-related risks. The proposed model can also be applied to other systematic risks where a large number of farmers are affected over time.

2. CONTENTS

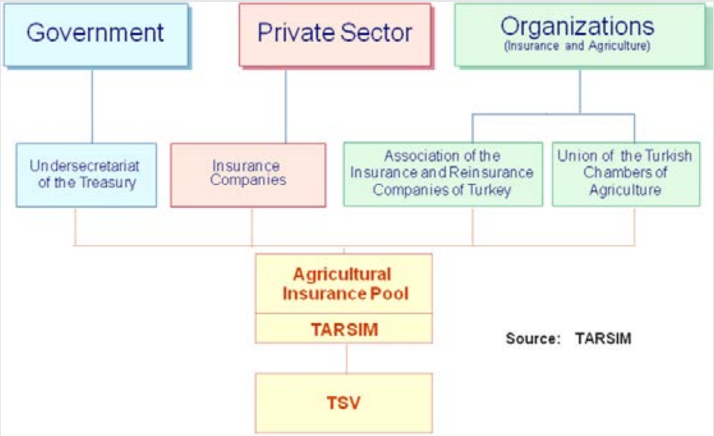
2.1. Current insurance system in Turkey

Turkey is an emerging economy, where 65 % of the GDP is derived from the service sector. Industrial activities constitute 26 % of the GDP. While only 9 % of the GDP is derived from agriculture, this sector employs about 30 % of the labour force. Processed food is one of the top agricultural exports.

Agricultural insurance is a relatively new concept in Turkey. However, since the introduction of government-subsidised insurance schemes, this field is experiencing rapid growth. Under the current system, 50 % of insurance premiums are supported by the state. The current system is based on collaboration between the government, the private sector, and non-profit organisations.

TARSIM is at the core of the insurance mechanism (Figure 1). Known as the agricultural insurance pool, the premiums are collected in this pool. This organisation engages in reinsurance agreements with global reinsurance companies. Local insurance agencies act as intermediaries between the farmers and TARSIM.

Figure 1: The main organisations active in the current insurance scheme include the state, private sector, and non-profit organisations



Under the current regime, crop insurance is the dominant sub-sector. The number of crop insurance policies is increasing at an annual rate of about 30 %. The total number of premiums in crop insurance recently passed TRY 100 million (about EUR 40 million) and the total insured value reached almost TRY 3 billion. The subsidised crop insurance is pretty popular among crop farmers, as the total number of policies had reached 400 000 by 2011.

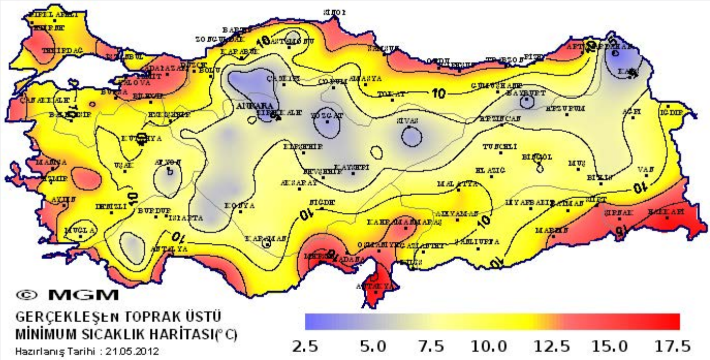
2.2. Index insurance possibilities

The current scheme offers protection against discrete events, which include frost, freeze, fire, flood, hurricane, ice storms, and hail. There is a demand from farmers to include coverage against drought but this request is deemed to be unsustainable by the state: besides the budget costs, there are several technical issues that need to be tackled before introducing drought coverage.

Recently, we organised a workshop on agricultural insurance, supported by the FAO-MDG Achievement Fund. Three main points were discussed in this workshop. Firstly, the idea of extending current coverage to include systematic risks such as drought or extended flood; secondly, a reduction in overhead costs; and, finally, the introduction of insurance to small-scale farmers. These ideas received attention from industry representatives, who wanted to offer insurance to small farmers.

However, under the current insurance mechanism, offering insurance to small-scale farmers is not feasible from actuarial perspectives. Each time there is a risk realisation, the

Figure 2: A visual sample of meteorological data (soil temperature)



Source: State Meteorological Institute.

total losses have to be checked, calculated, and adjusted on a case-by-case basis. Since systematic events such as drought can affect a large number of farmers at once, individual loss checks can be quite costly and time-consuming. Index insurance could fit well into this agenda. Using this innovative tool, we can introduce drought risk transfer mechanisms to several small farmers for lower overhead costs.

2.3. Data issues

Several issues need to be handled first, before we implement our action plan. One of the primary issues is the need for reliable data to model drought risk. As a result of long tradition in the State Meteorological Institute, there is reliable data which can be used to model meteorological events. The institute has been collecting rain/temperature data from hundreds of observatories spread across the nation for a long period of time (Figure 2).

The data tracks the normalized difference vegetation index, net water sufficiency index, as well as the soil temperature. The software called 'Drought Monitoring System' uses monthly data for the last 30 years to model both drought and precipitation indices. This data, if used efficiently, can provide a reliable source of information for actuarial risk modelling.

The other data we have to hand is the farmer registration data. This data has a relatively new history, but it includes extensive information on farmer attributes. Its basic variables can be categorised as socio-demographic observations, production data (trend and seasonality), income data, as well as insurance-related observations.

The plan is to merge these two data sets to create a reliable source of information, which can help us to model both the regional and farmer-specific risk factors.

2.4. Possible indices

The intention is to create two indices. The first would be a crop and farmer specific-risk index for drought and sustained flood possibilities (long-term risks) and the second, a pseudo-external index threshold that can be used as a trigger for indemnity payments.

Since we can model both the regional and farmer-specific risk factors, the premiums could be differentiated for each farmer.

For farmer *i*, located in region *j*, the premium would be:

Premium (F_{ij}) = {Risk of F_{ij} / Risk of Region_j} + Regional Risk

Thus, the total premium paid includes both a farmer-specific premium and regional premium, where the average risk index is a function of all farmers located in the same region.

For the external threshold index, we can define the yield in terms of farmer-specific (X1) and crop location-specific (X2) data, as well as an external threshold determinant (X3). Depending on the type of risk, the external threshold determinant can be defined as deviation from forecast rain or forecast temperature:

Yield = F (X1, X2, X3)

The differentiation of the yield with respect to X3, gives us the marginal effect of X3 on the yield.

2.5. How to define forecasts

The last challenge that remains is to define forecasts. The index insurance idea is fundamentally based on insuring the deviation from an index. There are several methods to forecast weather-related events from ultra-complex simulations to naive approaches. However, given the seasonality and (possible) trending nature of the weather data, Winter's method for adjusting for trend and seasonality could be applied. For a monthly data, the seasonality parameter will be equal to 12.

The threshold parameter will be decomposed into a level component (L_t), which is adjusted for trend (T_t) and seasonality (S_{t+a-p}).

According to this method, we first smooth the level forecast L_t:

$$L_t = \alpha \frac{Y_t}{S_{t-a}} + (1-\alpha)(L_{t-1} + T_{t-1})$$

Next, the trend forecast T_t is identified as:

$$T_t = \beta(L_t - L_{t-1}) + (1-\beta)T_{t-1}$$

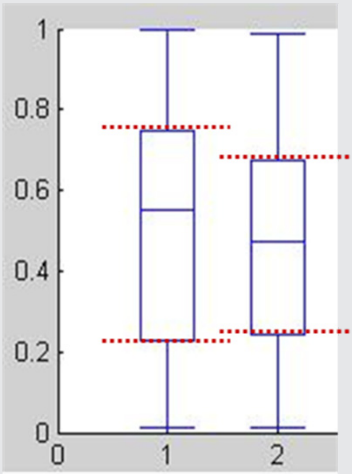
The third equation performs smoothing on the seasonal component:

$$S_t = \gamma \frac{Y_t}{L_t} + (1-\gamma)S_{t-a}$$

Using these three equations, we can finalise the forecast value for the period $t + p$ as:

$$Y_{t+p} = (L_t + pT_t)S_{t+a-p}$$

Figure 3: A visual simulation of the external threshold data for temperature and rain forecasts



In this model, the forecast errors form the basis for indemnity payments. External threshold forecast errors could be normalised to be between 0 and 1 without loss of any information (Figure 3). The triggers could be defined as extreme deviations from the mean/median observations. One proposition is to use the dotted lines for threshold payments. As such, forecast errors beyond the first and third quartiles could be considered as risk realisations, which require release of indemnity payments.

3. CONCLUSIONS

In this paper, we proposed an index-based insurance coverage against drought risks faced by the farmers in Turkey. The index threshold is determined externally. However, the effect of the index measure on farmers' productivity depends on the farmers' production function. The model is practically applicable as it uses already existing data for both premium and loss determination. It can also be extended to account for both regional and farm crop-specific yield deviations.

Even though the marginal effect of index measurements on productivity might be internally defined by the model, the individual farmers cannot manipulate their production function. Thus, the moral hazard would be kept at near zero. However, collectively, the farmers can change their production function in the long term. We believe this scenario is worth investigating further.

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22 Challenges to scaling up index-based insurance products and possible solutions

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KEYWORDS: **scaling up, cost effectiveness, simplicity of indices, climatic change**

SUMMARY

The main challenges in scaling up index-based insurance products include the availability of reliable, accurate and timely weather data, which starts with the establishment of a weather infrastructure that is adequate for monitoring weather over agricultural areas. Satellite estimates of weather (especially rainfall) have now been available for years. They need, however, to be validated for insurance purposes, among others, as regards spatial resolution, especially in hilly or mountainous terrain.

Some groundwork is required before index-based insurance products can actually take off, starting with the technical capacity of local institutions to develop, test and routinely provide operational indices. To be sustainable, the products must appeal to several categories of stakeholders, starting with reinsurers (who are the ultimate risk-takers), but also to farmers, their representatives, agricultural extension services and cooperatives. This implies that the products are sufficiently simple to be understood by all stakeholders. Simple insurance contracts also have the advantage that they can be operated and disseminated in a cost-effective manner. This should keep the price of premiums low for farmers and herders, making them affordable and increasing their willingness to pay.

Finally, attention must be paid to changing risk patterns, such as those that are brought about by the ongoing climatic changes.

Index science and technology

Climate science

23 Climate services in agriculture insurances

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KEYWORDS: **weather and climate hazard, climate services**

SUMMARY

Financial risk reduction products related to weather and climate hazards in agriculture need a baseline of a sound knowledge of extreme event occurrence, but also from their expected changes. The definition of what a weather or climate extreme event is has to be made in relation to its impact in the sector, so efforts in the development of observation networks, crop modelling and evaluation tools are needed to provide useful information to agriculture insurance providers. Those elements could provide consolidated and common evaluation tools on crop evolution in relation to weather and climate elements allowing the setting of thresholds for the design of insurance products and decisions about payments when an event has occurred. A list of hazards that impact on crops ranges from strong or hot winds, hail, frost or warm temperatures to floods or long-lasting dry conditions. This last event is one of the most powerful generators of losses or reduced benefits in agriculture. Drought monitoring and evaluation should be one of the most important aspects of climate services in agriculture insurances.

24 Index-based insurance challenges and issues for weather data providers

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KEYWORDS: national weather services, network of weather stations, automatic stations, time series, data quality

SUMMARY

Index-based crop insurance is a type of insurance that is linked to weather observations rather than a possible consequence of weather. Index-based weather insurance contracts are written based on historical weather observations collected from a neighbouring weather station operated by the National Meteorological Service (NMS). The underlying index has to be based on an objective measure that exhibits a strong correlation with the variable of interest. The weather variable that is used to develop the index must be observable and easily measured, objective, transparent, independently verifiable, reported in a timely manner, consistent over time and experienced over a wide area. The challenge for weather data providers is to ensure a sufficient density of near real-time weather observations, and the availability of consistent historical records. The data should be quality controlled and weather observations should be representative of all major agricultural production areas. The weather data provider should have a reliable data communication system. There is need to build institutional capacity for weather data providers to strengthen, operate and maintain a network of weather observations, data collection and management systems.

1. INTRODUCTION

Index-based crop insurance is a type of insurance that is linked to weather observations, such as rainfall, rather than a possible consequence of weather such as crop failure (Hess and Rosy, 2005). Nearly all existing index-based weather insurance contracts are written based on historical weather observations collected from stations that are operated by the weather data providers which are, in most cases, the National Meteorological Service (NMS).

In order for the crop indices to be a sound proxy for loss, they have to be based on an objective measure that exhibits a strong correlation with the variable of interest such as crop yield. Additionally, the weather variable that can form an index must be observable and easily measured, objective, transparent, independently verifiable, reported in a timely manner, consistent over time and experienced over a wide area.

2. CHALLENGES AND ISSUES

2.1. Data and weather infrastructure requirements

Sustainable index-based weather insurance programmes for food security require availability of historical weather observations. Daily weather observations are used for basis risk analysis and calculation of the index. Historical weather observations are needed to capture seasonal climate variability and longer-term climate cycles. Ideally, a long, clean, and internally consistent historical record of at least 25–30 years of daily data with less than 3–5 % missing data would be available for developing an index-based weather insurance programme.

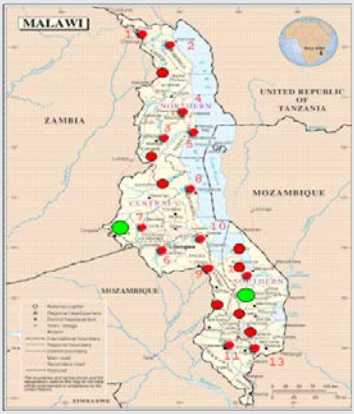
There could be no deal for index-based weather insurance if daily historical weather data are not available. During the pilot phase of the index-based weather insurance programme, the Department of Climate Change and Meteorological Services in Malawi, as a weather data provider, had 21 primary weather stations (red in the map, Figure 1) with excellent daily observation for over 30 years in addition to over 200 rain gauges around the country.

In many cases, the challenge for weather data providers is to make sure that the density of weather observations is sufficient and that consistent historical records are available, particularly in agricultural production areas. The frequency and spacing of weather observations needs to match the temporal and spatial changes of the weather phenomena. For example, precipitation can occur in solid, liquid and vapour form. Rainfall can result from very different weather processes resulting in very different spatial and temporal properties.

Rainfall and the monitoring of drought require a denser network of observations than temperature (Osgood, 2006.) Expanding and improving the network of weather stations and weather data available to users can expand the opportunity for index-based weather insurance programmes. This can be accomplished through both upgrading and improvements in existing infrastructure and data, and the installation of new equipment.

For example, in Malawi, in 2006, two rain gauges (green on the map in Figure 1) that had historical data, but were insufficiently reliable for the purposes of index-based weather insurance, were upgraded to real-time reporting, GSM-enabled, automated weather stations. As a result, 500 groundnut farmers benefited from the groundnut loan-weather insurance package that was available in Malawi at the time (World Bank, 2005).

Figure 1: Map of Malawi showing weather stations (2006)



The data should be quality controlled and the density of weather observations should be adequate and cover all agricultural production areas. Adequate means, among other things, that the stations must take into account the nature of the terrain and local climate gradients. The quality of the weather data is the most critical piece of information dictating the technical viability of index-based weather insurance. It is essential for constructing the index, censuring accurate rating and risk transfer markets, and minimising basis risk. The weather data used to construct the underlying weather indices should adhere to quality requirements including reliable and trustworthy ongoing daily collection and reporting procedures, daily quality control and cleaning.

Figure 2: A typical professional (synoptic) weather station in Malawi

The weather data provider should have a reliable ongoing daily data collection, daily data quality control and standard reporting procedures, appropriate maintenance of infrastructure, and good national and regional communication systems. Nearly all executed index-based weather insurance contracts are written on data collected from official National Meteorological Service (NMS) weather stations. National Meteorological Service weather stations produce weather observations that are made at internationally agreed times using standard regulations and practices set by the World Meteorological Organisation (WMO) and adhered to by all National Meteorological Services (NMSs) of the world. The National Meteorological Service communicates data to the Global Telecommunication System (GTS) for dissemination. The World Meteorological Organisation helps to standardise observing practices. The standardised nature of the global observing system means weather data becomes a common language that parties from different parts of the world can use to communicate and transfer weather risk.

2.2. Institutional capacity

For proper implementation of index-based weather insurance programmes, there is a great need to build institutional capacity in weather data providers, to enable them to operate and maintain weather observations, data collection and management systems; data rescue to translate massive amounts of paper-based records into digital records; data quality control to ensure consistency and completeness of records; and capacity to archive large databases. There is also a need to strengthen weather observation networks (Figure 2): all agriculture production areas should have a weather station at least every 20 km. Investment in observing networks is an investment towards improved risk management and development planning. Strengthening weather observation networks would allow more farmers to access index-based weather insurance and input financing and expand the risk retention capacity through risk transfer to the international markets.

3. CONCLUSIONS

The success of index-based crop insurance is dependent on the availability of weather stations and historical weather observations. The frequency and spacing of weather observations needs to match the temporal and spatial changes of the weather phenomena. Therefore, there is a need to improve meteorological networks and data management through the modernisation of weather stations, the installation of automatic stations, and institutional capacity-building. Many NMS recognise that, as a result of crop insurance, a new major customer could become available for near real-time weather data, next to the current main customer — civil aviation in most countries.

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25 Index weather insurance for smallholder farmers: who takes the risk?

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KEYWORDS: **index insurance, smallholders, agriculture, basis risk, weather generator, TRMM, crop simulation**

SUMMARY

Insurers will only provide index cover insurance where there is an official meteorological weather station with at least 30 years' data within 20 km of the insured crop. The insurer pays on the data recorded at the nominated station, so is covering a known risk. The insured has no guarantee that the insured crop will be exposed to the same weather as at the meteorological station, and therefore undertakes the basis risk in the event that it does not. Moreover, most of the rural populations in the tropics do not live within 20 km of an official weather station and so cannot be covered. We propose that the WorldClim database and crop simulation models can provide the data on which to base index crop insurance for the majority of the smallholders in the tropics.

1. WHAT IS THE PROBLEM?

Index insurance instruments for yield loss of agricultural crops due to unfavourable weather typically specify that the insured risk must be within 20 km of an official weather station with 30 years or more of records. The problem is that insurance instruments based on this specification can only offer coverage to the minority of smallholders in the tropics where official meteorological stations are typically few and far between. Moreover, rainfall in the tropics varies widely within short distances, especially in mountainous areas, so that 20 km is much too far.

Let us look at two examples of the dearth of historical meteorological data and what that means for smallholder farmers vulnerable to drought in southern and East Africa, Malawi and Ethiopia.

1.1. Malawi

Malawi (Figure 1) has an area of 118 000 km^2 and population of 13 million, according to the 2008 census, of which 85 % is rural. Malawi has 78 official meteorological stations (Figure 2 shows the data which are included in the WorldClim database) (Hijmans et al., 2005). Of these, 36 (46 %) have more than 30 years' data.

Where the population is at its most dense, there is a risk of drought 1 year in 12 (about 8 %). Using the 20 km criterion, 65 % of the rural population lives outside the 'insurable' area. Almost three quarters of these, 4 million people, confront moderate to high (1 year in 7) drought risk.

1.2. Ethiopia

Ethiopia has an area of 1 104 300 km^2 (Figure 3) and a population 74 million, according to the 2007 census, of which 84 % are rural. The country has 254 weather stations, only 34 (11 %) of which have data for 30 years or more.

Over 95 % (52.5 million) of the rural population lies outside the 'insurable' zone (i.e. further than 20 km from an official weather station with 30 years or more of historical data). Almost two thirds of these (36 million) confront medium to high (1 year in 7) risk of drought (Figure 4).

Figure 1: Malawi, south-east Africa

Malawi and Ethiopia are not exceptional cases; indeed, they are typical of the droughts and sparse weather stations to be found throughout the tropics. Clearly, most smallholders in the tropics will never be offered index insurance to cover them against drought while the requirement is that they are located within 20 km of an official weather station with more than 30 years' records.

1.3. Basis risk

The risk for index crop weather insurance is calculated actuarially on the data for a particular meteorological station, and the payout is determined by the events recorded at that same weather station. If the actuarial assessment is correct, the insurer assumes the known risks of index weather insurance. In contrast, however, it is the insured who assumes the basis risk of whether the meteorological station reflects what happens on their plot.

Figure 2: Data included in the WorldClim database (Malawi, 2006)

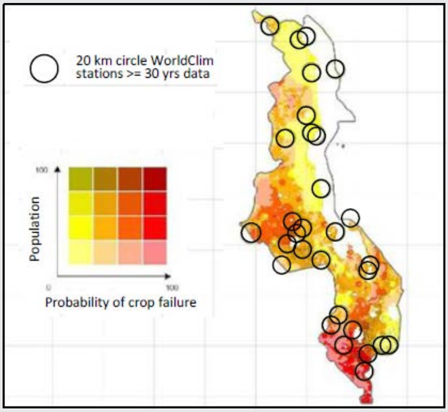
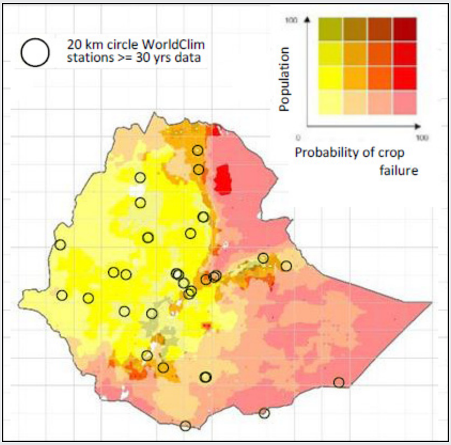


Figure 3: Ethiopia, East Africa

Clearly, the greater the distance the insured's plot is from the meteorological station, the greater the basis risk will be — to the insured, not the insurer. Smallholders whose plots are far from the meteorological stations will quickly recognise that they are the ones who are disadvantaged by the basis risk and will not buy the offered instruments.

There is obviously a need to be able to create weather data where none currently exists, and to provide greater spatial assessment of the risk so that the insured can buy cover without having to assume unreasonable amounts of basis risk.

Figure 4: The locations of WorldClim weather stations in Ethiopia with more than 30 years' records overlaid on a composite of an index of population density and the probability of crop failure



2. WHAT CAN WE DO?

In the short term, there is no way that we can create a network of weather stations with 30 years of historical data at a density needed to reduce basis risk for smallholders in the tropics to a level that they might find acceptable.

There are two possible technologies to overcome the problem: (i) the WorldClim data set; and (ii) the Tropical Rainfall Measuring Mission (TRMM).

2.1. WorldClim

The WorldClim database (Hijmans et al., 2005) uses data of 40 000+ weather stations worldwide to provide monthly climate data at a resolution of 30 arc-seconds, 1 km at the equator. The method interpolates using a thin-plate spline method with elevation from the shuttle radar terrain mission as co-variable data. The data are temporally satisfactory, but the data for more than 99 % of the 1 km pixels are interpolated.

2.2. TRMM

The TRMM data are spatially detailed, with a resolution of about 1.5 arc-minutes, about 3 km at the equator, but there are only data since 1997. The TRMM does not measure rainfall directly, but atmospheric humidity, from which it infers rainfall. The humidity proxy does not seem to be a serious problem, however. A more serious issue is that the satellite only passes over each pixel every 10 days or so. The daily estimates are estimated by interpolation, but, because of the temporal interpolation, the data show scant resemblance to actual recorded

Table 1: Actual measured rainfall and NASA data (http://power.larc.nasa.gov/cgi-in/cgiwrap/solar/agro.cgi?email=agroclim@larc.nasa.gov) for Eldoret, Kenya (0.5187° N, 35.2755° E) for the month of April 1997–99.

Date	1997		1998		1999	
	Actual	NASA	Actual	NASA	Actual	NASA
01-Apr	0.0	13.4	0.0	0.0	0.2	0.0
02-Apr	37.9	3.1	0.0	0.0	0.0	0.0
03-Apr	0.6	15.1	0.0	0.0	0.0	0.0
04-Apr	42.0	11.4	0.0	0.3	0.0	1.5
05-Apr	17.2	10.4	15.0	10.1	0.0	0.8
06-Apr	4.3	10.1	8.0	1.1	0.0	0.1
07-Apr	0.6	14.8	0.0	2.8	0.0	8.1
08-Apr	0.4	29.4	0.0	3.2	0.2	4.7
09-Apr	7.1	10.2	11.2	2.6	0.0	0.6
10-Apr	6.6	0.3	1.5	3.4	0.2	0.0
11-Apr	15.2	4.9	0.7	10.3	0.0	0.0
12-Apr	0.0	0.0	0.0	0.0	0.0	0.0
13-Apr	0.0	0.0	0.0	0.0	0.0	0.0
14-Apr	0.0	0.0	0.0	0.0	0.0	0.0
15-Apr	0.0	0.0	0.0	0.0	0.0	0.3
16-Apr	0.0	4.8	0.0	14.4	0.0	3.7
17-Apr	0.0	1.6	0.0	4.2	3.6	8.9
18-Apr	0.0	10.7	0.5	5.8	0.0	5.4
19-Apr	11.9	23.2	147.6	0.0	17.2	0.0
20-Apr	39.5	6.1	0.0	4.5	0.0	0.0
21-Apr	0.9	1.7	0.0	0.8	0.0	0.0
22-Apr	9.7	4.1	0.0	0.7	0.0	2.4
23-Apr	1.2	13.7	0.5	4.7	0.7	5.9
24-Apr	42.6	6.0	0.1	4.0	13.1	6.1
25-Apr	17.6	4.5	36.4	3.7	2.8	3.1
26-Apr	4.7	1.8	0.0	0.0	6.2	0.8
27-Apr	6.2	4.6	0.0	0.0	32.0	1.2
28-Apr	0.0	10.7	0.0	0.0	18.3	9.6
29-Apr	0.0	7.5	0.1	0.0	9.0	14.6
30-Apr	18.9	11.9	0.0	0.0	5.3	1.0

weather data (Table 1). Their utility to reflect crop performance is likely to be problematic on sandy soils, although they may be satisfactory on soils with higher water-holding capacity.

2.3. Comparison of WorldClim and TRMM

There is broad agreement between the two climatologies, but there are no data to support which is more accurate for actual, unmeasured precipitation for a given pixel.

Neither gives daily data, although NASA provides what purports to be daily data from the TRMM using an interpolation procedure. Casual comparison of the NASA daily data with actual data shows similar trends, but the actual data vary considerably (Table 1). We can generate daily weather data for any place in the tropics with MarkSim.

2.4. MarkSim

Weather in the tropics is controlled by the seasonal movement of the thermal equator and associated convectional cells, not by the more or less regular west to east progression of fronts as in temperate climates.

In the tropics, it is more likely to rain today if it rained yesterday. The weather generator MarkSim (Jones et al., 2002) uses a third-order Markov function to determine the probability that it will rain today (a second-order function is adequate for temperate climates). MarkSim generates daily data of maximum and minimum temperature, rainfall, and solar radiation for as many years as are needed. MarkSim's own data surface has a resolution of 10 arc-minutes (18 km at the equator), but we supply it with climate normals extracted from the WorldClim database to increase the resolution to 30 arc-seconds. At this resolution, basis risk is no longer a problem. Of course, assessment of payout requires a rain gauge close to the farmer's field. In western Kenya, rain gauges are typically mounted on the masts of mobile phone networks, where they collect data in real time.

2.5. Converting weather data into crop yields

There are two models that we use to simulate the growth, development and yield of many crops:

- the Decision Support System for Agrotechnology Transfer (DSSAT) suite of crop simulation models, which was developed by a US consortium (Jones et al., 2003); and

- Agricultural Production Systems Simulator (APSIM), which was developed by CSIRO and state departments of agriculture in Australia.

Both give comparable results and allow the simulation of crop yields given daily weather data, and both provide plausible data of crop yield as affected by weather, and 'cheap experience', that is numerical data that invariably reflect farmers' experience. We spell out the steps in this process more fully in Díaz Nieto et al. (2012).

3. FINAL COMMENTS

The CGIAR research programme on Water, Land and Ecosystems has a key initiative on rainfed systems. One major component of this will be to devise ways to assist smallholder producers to manage risk, which is a major constraint to increasing smallholder productivity and overcoming poverty. Index insurance is one of the obvious possibilities so the need to develop methodologies to overcome the current limitations is clear.

The question is: How can we help the insurance industry to provide cover where there are no historical data? We need to prove whether or not the WorldClim database, MarkSim, and simulation modelling can provide the reliable data insurers need to make actuarial assessments where there are no historical data. We believe that we have the tools to fill that gap. For more details, including an evaluation of the methodology as applied to dry bean in the north-central mountains of Nicaragua, see Díaz Nieto et al. (2012).

4. ACKNOWLEDGMENTS

We would like to thank the CGIAR research programme at CCAFS (1) for their support.

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26 Climate at different spatial and temporal scales

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KEYWORDS: **climate, gradients, definitions, decadal**

SUMMARY

Climate is typically defined in terms of the time-mean values of various meteorological variables such as precipitation, temperature, humidity, etc. The World Meteorological Organisation guidelines indicate such means be computed over the most recent three decades. However, the climate varies on a wide range of spatial and temporal scales and is known to be non-stationary. Given the existence of secular trends and other changes in behaviour, using the most recent three decades may not be optimal for assessing the likelihood of exposure to extreme conditions, for example. In this paper, some general concepts are provided when considering the spatial and temporal variability of climate with some illustrative cases relevant to index insurance metrics presented.

1. INTRODUCTION

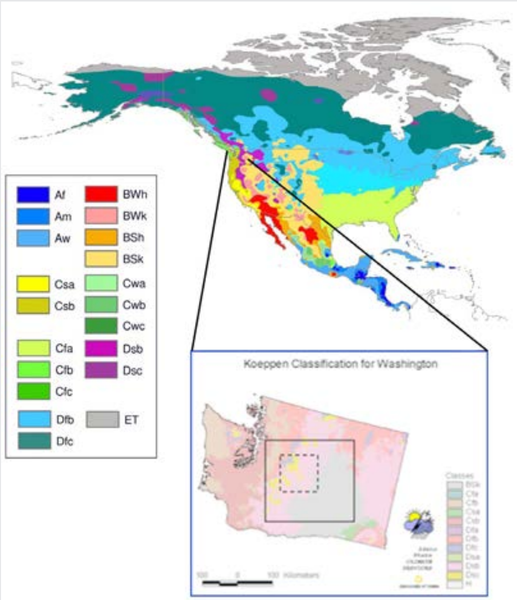
How long is the coast of Britain? This question was posed by Benoit Mandelbrot (1967) in a paper based on his early work that would later evolve into what is now known as *fractal analysis*. The answer is: It depends on the scale at which you perform the measurement. The coast becomes longer and longer as one measures it at finer and finer spatial resolution. Mandelbrot's fundamental insight was that, in addition, as one examines the coast (and many other natural objects) at finer and finer scales they tend to exhibit patterns that repeat those seen at coarser scales. This tendency is referred to as *self-similarity* and applies in the time domain as well (e.g. in signal processing). Generally, similar concepts hold when considering the spatial and temporal scales of variability of the earth's climate: it varies on a multitude of scales. Spatially, climate varies from the global scale (tens of thousands of kilometres) to the micro-scale (tens of metres) and in time over periods ranging from hundreds of millennia (ice ages) to just minutes (e.g. the formation of clouds).

It is sometimes stated that 'climate is what you expect' while 'weather is what you get'. But how do we know what conditions to expect from the climate? Statistically, the expected value of a random variable is expressed as the (weighted) mean of all values. Similarly, climate is typically described as the time-average value of a particular variable, such as temperature or precipitation. The World Meteorological Organisation specifies the most recent three decades should be used to determine climate means at a given location and a combination of such mean values of meteorological variables is often used to classify climate 'types' more broadly, an example shown in Figure 1. But, it is well known that the climate is not stationary, it may contain secular trends or exhibit other behaviour, which, from an insurance perspective, may make a 30-year average suboptimal in assessing exposure to climate extremes. An example of this for East African rainfall is shown later.

2. SPATIAL SCALES

Notice, in Figure 1, that, as in the case of Britain's coastline, more details of climate classification emerge as one moves to a finer spatial resolution. A fundamental concern, of course, is how representative point observations (made at *in situ* observing stations or in pixels of remote sensing data) of climate (and other) variables are in space. Nonetheless, factors such as spatial

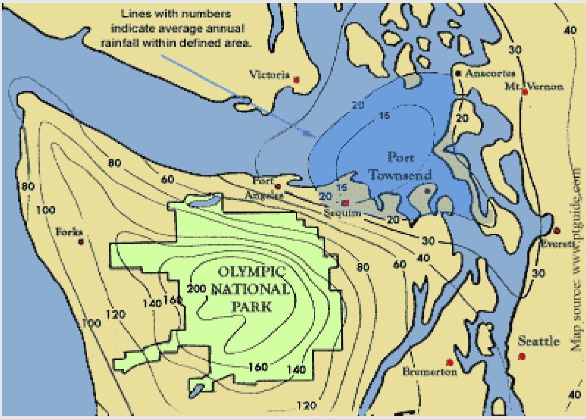
Figure 1: Top: Global climate types according to the Köppen classification scheme, which is based on average temperature and precipitation; bottom: climate classification for the state of Washington in the United States at greater spatial resolution (and a different colour scheme), finer and finer scale features of the climate would be resolved with more detailed temperature and precipitation data (suggested by the boxes in the bottom panel).



Sources: Top: Peel et al., 2007; bottom: http://oregonsbananabelt.blogspot.it/

gradients in elevation and the orientation of such topographic relief to prevailing wind conditions can have substantial impacts on spatial climate variations. A classic example is the so-called 'rain shadow' effect, where precipitation may vary by more than an order of magnitude over just a few kilometres in distance (Figure 2).

Figure 2: Variations in annual precipitation near Olympic National Park in Washington State in the north-western United States — contours indicate annual precipitation (inches). For reference, the width of the bay just north of the park is roughly 20 km.

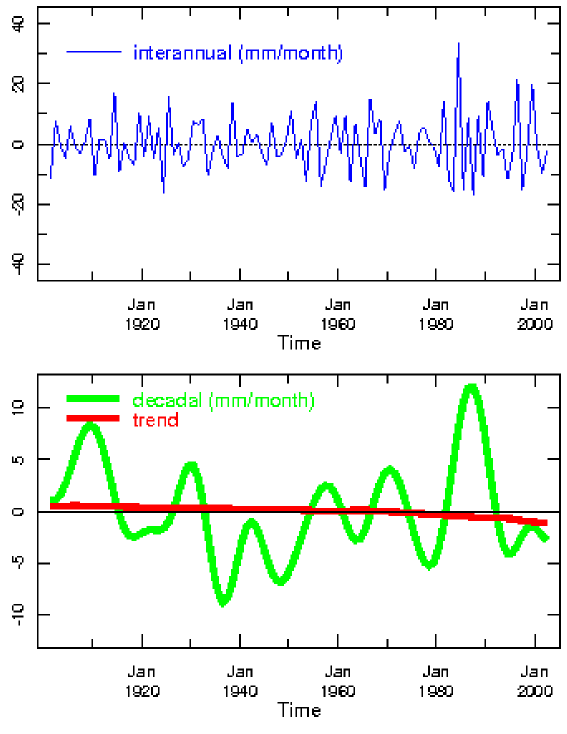


Spatial variability is also seen in patterns of climate change. For example, while global average temperatures have shown a fairly steady increase over the last 30 years, there are considerable spatial variations in the pattern of warming (not shown), indicating the importance of regional and local mechanisms in affecting local trends in temperature.

3. TEMPORAL SCALES

Using paleoclimate information obtained from ice cores, it is clear that the earth's climate has undergone significant changes over the past several hundred thousand years. Distinct glacial and interglacial periods are evident in such records, with the main driver being related to changes in the orbital parameters of the earth in its orbit about the sun with time. There are, however, very important changes in the climate system on much shorter timescales. For example, the decomposition of a time series of annual precipitation for an area in northern Mexico on different timescales is shown in Figure 3.

Figure 3: Top: inter-annual variations in the area-average rainfall across northern Mexico accounts for 80 % of its total temporal variance; bottom: decadal variability (green line) accounts for roughly 18 % of the variance, while the secular trend (red line) accounts for about 2 % of the overall variance.

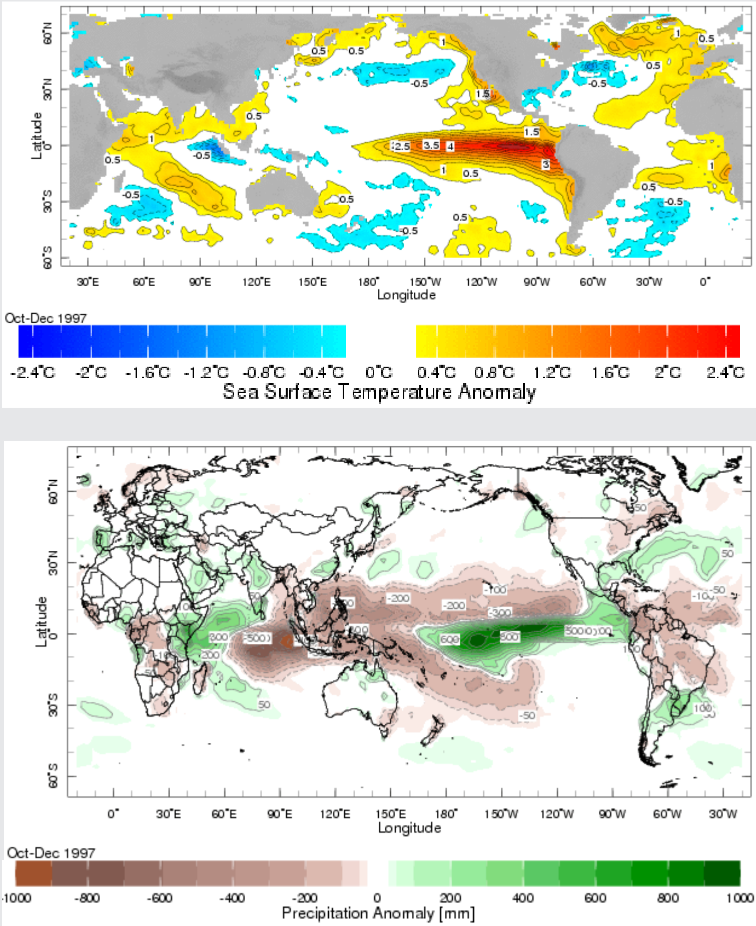


Source: IRI Timescales Map Room.

An important source of inter-annual (and on shorter, seasonal timescales) variations in climate is the El Niño-Southern Oscillation (ENSO) phenomenon. The extreme warm 'phase' of ENSO (El Niño events) is associated with warmer than average sea surface temperatures (SST) in the east-central tropical Pacific Ocean (Figure 4, top). These anomalous SSTs typically persist for several seasons and, crucially, are associated with changes in seasonal precipitation (and temperature) patterns around the globe, especially in the tropics (Figure 4, bottom).

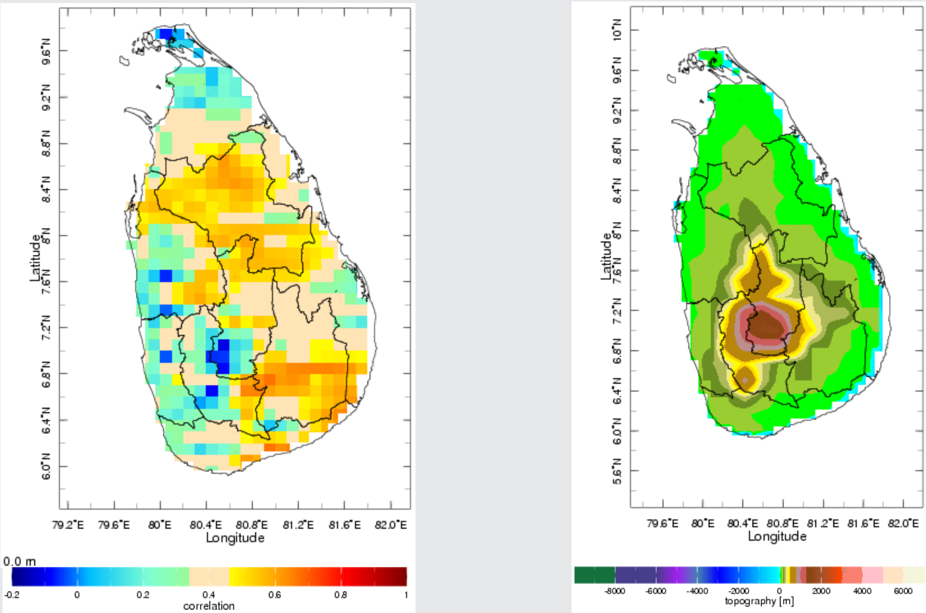
There is demonstrable skill in predicting ENSO events several months in advance, meaning there is predictability in seasonal precipitation in many places several months in advance as well. From an index insurance point of view, ENSO events can substantially shift the odds towards drier or wetter conditions relative to the long-term climate average in a given season or year.

Figure 4: Top: sea surface temperature departures from average (°C) during October–December 1997 when a major El Niño event was occurring; bottom: precipitation departure from average for the same season (mm) — brown shading indicates unusually dry, and green unusually wet, conditions. ENSO events offer some predictability to seasonal climate conditions in several parts of the world, in some cases even in areas outside the tropics.



As with the mean climate state, however, there are important spatial variations in rainfall associated with ENSO events at smaller spatial scales. An example is given in Figure 5 in the case of the October-December rainfall in Sri Lanka and its relationship to the ENSO phenomenon. Figure 5 shows the correlation between seasonal rainfall and a SST index

Figure 5: Left: the temporal correlation between October–December seasonal rainfall (analysis gridded to 10 km resolution based on data from over 200 rainfall stations) and a SST-based measure of ENSO — blue shading indicates no relationship; right: topography in the country. The interaction of the local topography with the wind flow patterns associated with ENSO is an important factor in determining the local response to the phenomenon.

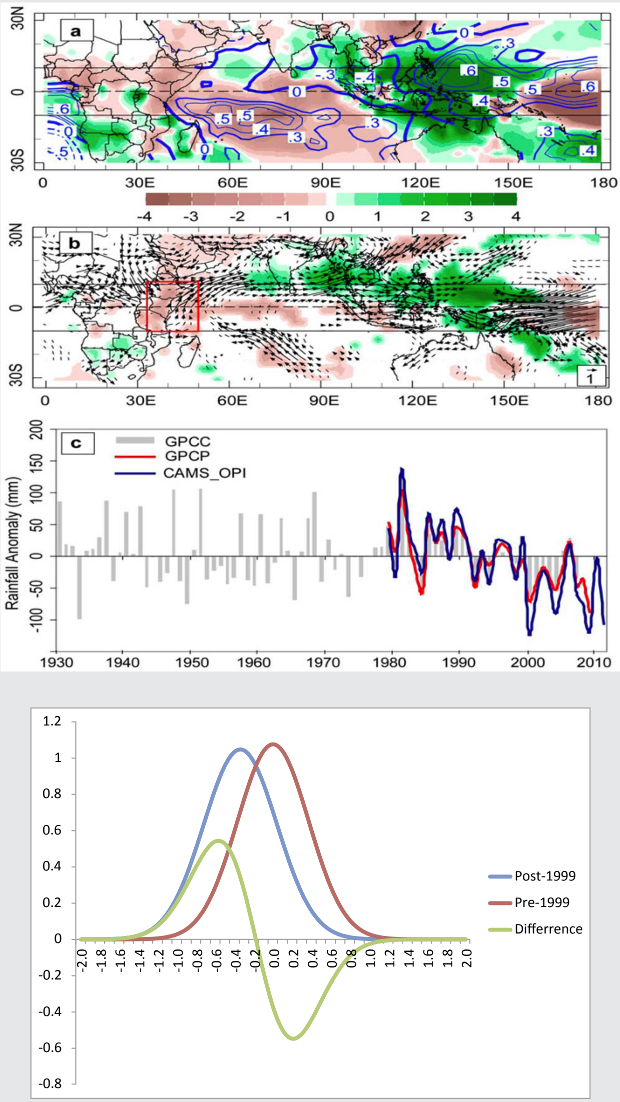


used for monitoring ENSO conditions (SST in the east-central tropical Pacific, from 5S-5N and 120W-170W). The spatial variations in the effect of ENSO on local precipitation in Sri Lanka are clearly indicated and result from the interaction of the low-level winds (which are affected by ENSO) and the local topography.

Local variations in the impacts of ENSO events are, of course, observed in other locations as well. Additional factors that affect this response include how ENSO events change regional storm tracks. The effect of ENSO also varies depending on the season considered, and unusually cool conditions in the Pacific (La Niña events) also impact seasonal climate (typically, opposite to El Niño).

Finally, changes in climate need not occur in a relatively smooth fashion (as in a gradual upward trend in global temperatures, for example). A recent example to highlight this is taken from East Africa. For the region as a whole, the so-called long rains (typically occurring between March

Figure 6: Top: the area-average (10S-12N, 30E-52E) rainfall departure from average for three data sets — notice the abrupt decline that occurred around 1999, effectively indicating a rapid transition to a new average climate state; bottom: there is still considerable year-to-year variability in rainfall after 1999, but the shift in the mean changes the probability distribution for rainfall across the region, as shown in the bottom plot.



and May) have undergone a rapid transition towards direr than average conditions, starting around 1999 (Figure 6, top). A recent study (Lyon and DeWitt, 2012) has linked this rapid decline to similarly abrupt changes in SSTs, primarily in the tropical Pacific Ocean.

The shift in East African long rains precipitation essentially represents a shift in the mean climate over a very short timescale. Again, from an index insurance standpoint this shift changes the probability distribution for rainfall amounts in the region.

The shift in the probability distribution in Figure 6 applies to the region as a whole; at a grid point scale, there will likely be more uncertainty in the distributions owing to fewer observations being used in the calculation. The availability of rainfall data across the region also varies spatially (and in time). Data availability and quality are, of course, also common issues when designing local index metrics for index insurance purposes.

4. CONCLUSIONS

Climate varies on multiple spatial and temporal scales and there are important interactions between different scales. Examples of the latter include local rain shadows set up by the interaction of the time-mean regional flow and local topography and regional variations in seasonal rainfall and temperature associated with the ENSO phenomenon. There are many others.

From an index insurance perspective, various climate variations and trends can substantially influence probability distributions of precipitation and temperature (and other variables) within a given growing season and year to year. On seasonal to inter-annual timescales, ENSO is an important factor, while longer term climate trends are also a consideration. The recent case of an abrupt decline in seasonal rainfall in East Africa also indicates that temporal trends need not be monotonic (or linear), which further suggests that the use of a ‘standard’ 30-year climate normal may not be optimal for assessing exposure to climate variations within a given year.

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27 Model or observation-based agricultural weather indices?

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KEYWORDS: drought, extreme forecast index, satellite verification, reanalysis, dynamical downscaling, probability forecasting

SUMMARY

Careful consideration should always be given to using tools which are most fit for purpose in any application. Regarding the construction of weather-related indices, we have three resources on which we could, today, base a quantified weather-index approach: (i) *in situ* weather measurements; (ii) remotely sensed estimates of vegetation or other weather-related parameters; and (iii) environmental models. In the most recent years, giant strides have been made with the resolution, precision and interpretation of remotely sensed and computer modelling approaches in ever more diverse applications in the environmental sciences. Meanwhile, we remain constrained, especially in the developing world, by the density, reliability and accessibility of suitable standards of *in situ* weather measurements. We should remember, too, that it is not entirely a question of a measurement or model approach since both *in situ* and remotely sensed measurements are fundamental to the creation of accurate starting conditions for models through the data assimilation process; the combination of measurements and models is a compelling and well-developed approach in, for example, weather forecasting and climate simulation. We should, therefore, in each case, look to harness the single or combined approach which is most suited to the geographic and index-specific challenge which faces us.

1. INTRODUCTION

Basic local measurements of key weather variables, if they are genuinely representative of the insured area, obviously have the advantage of not only being suited to the task of quantifying a reliable index value but also being simple and transparent for the insured to understand. Problems arise, however, when very localised weather occurs, which is poorly captured by the measurement network, in some cases, due to significant topographic effects. Any problems which lead to missing data can also require approaches which are not ideal, using neighbouring stations, for example, as the basis of a statistical fix. The quality and representativeness of the local station can drift due to changes in exposure of that station. In short, measurement networks demand significant ongoing care and investment.

The uneven provision of *in situ* weather measurements, especially in the marine environment and away from the ground surface was, of course, one of the spurs for remote sensing measurement approaches, especially using satellite-borne sensors (e.g. the soil moisture estimates shown in Figure 1). Satellite instruments have broadened observational coverage to remote environments while also, in some cases, providing regular updates.

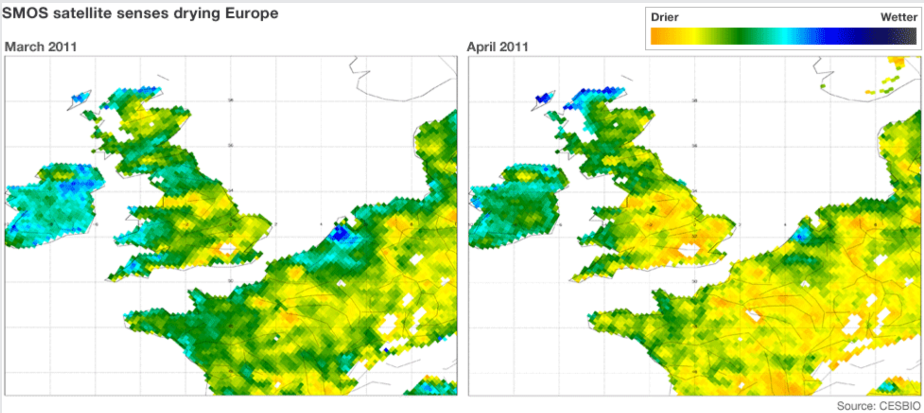
Even so, satellites cannot yet resolve some of the spatial and temporal weather detail which we need at sea level, especially over heterogeneous land surfaces. Meanwhile, over the last decades, weather models have been continuously refined so as to provide greater temporal and spatial detail and the capability to more realistically simulate a wide range of atmospheric processes and interactions with the biosphere, oceans and cryosphere, assisted by the global observing system and sophisticated data assimilation schemes. In other words, there is a strong dependency of real-time weather forecasting models on manual and automated measurements. Which begs the question of the extent to which today's weather forecast models, in the form of their starting conditions (analyses: T + 0) and very short-range forecasts (say, to T + 24), may be suited to underpinning a weather-index approach? Models operate over global grids and, due to the model-observation mix, seamlessly handle any missing data problems. On the other hand, short-range forecasts will, inevitably, have errors associated with them. Have we reached a point where the advantages of a model-dependent index approach outweigh the traditional measurement-dependency, at least for some applications and for some geographical areas?

2. DISCUSSION

Two of the most highly cited papers in atmospheric sciences are those which describe the model reanalysis data sets of ECMWF and NCEP (Dee et al., 2011; Kalnay et al., 1996). Although the spatial resolutions of these reanalysis data sets might not be suited to a weather-index approach, their popularity in the scientific community comes, at least partly, from the standard procedure by which these gridded climatologies have been constructed, their global nature, and the consistent and timely way in which they are updated. In short, the reanalysis approach has been adopted as a standard for monitoring observed climate change and for providing boundary conditions to test, for example, the performance of regional climate models. Can we, therefore, also envisage other model products, at higher resolution, as being fit for purpose for powering weather indices?

One way in which higher spatial resolution in the modelling world is achieved is by using a dynamical downscaling approach, whereby a coarse resolution model, often of global extent, is used to provide the initial and boundary conditions for a higher resolution model with a more limited domain. A nested approach may also be deployed whereby a further subdomain, at even higher spatial resolution, is included within the initial limited area, in order to simulate the desired level of detail. One-way nesting (coarse resolution domain to fine resolution domain) can be deployed to allow large-scale weather developments to trickle down to the more local scale while a two-way dynamic downscaling nesting method will enable feedback in both directions which may be important and more realistic.

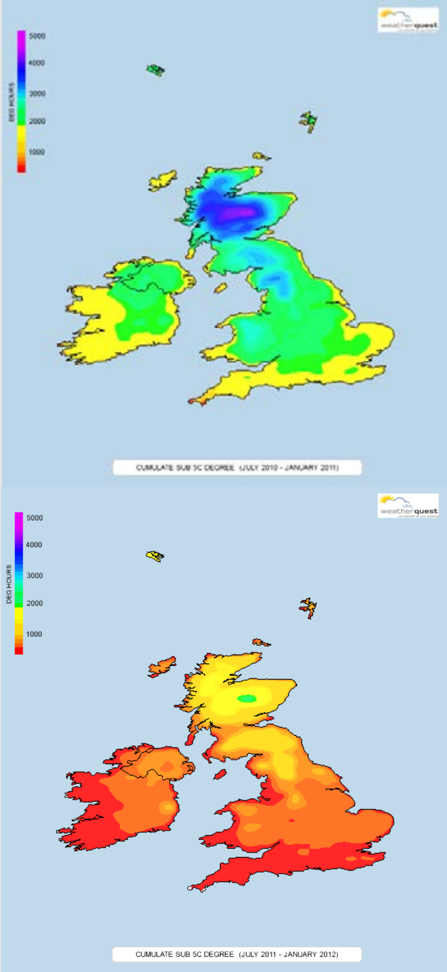
Figure 1: SMOS soil moisture estimates in north-west Europe



Arguably, operational weather forecasting has evolved to such a point now (largely as a result of advances in computing capacity) that the forecasting models used today are operating at resolutions which are sufficient, without further offline downscaling, to power weather index approaches. For example, world leading global weather prediction models, such as those operated by the European Centre for Medium-Range Weather Forecasts (ECMWF) and by leading national meteorological agencies, are typically run twice a day at global resolutions of < 20 km. Those same agencies, and private sector meteorological companies, are using these global models to provide the initial and boundary conditions for nested mesoscale models operating at spatial resolutions typically in the range 1–12 km. The accumulated chilling hours shown in Figure 2 are calculated from the analyses of such a mesoscale model. However, these latter are generally only deployed over the developed world or to support military activities. Is this current status sufficient to power present-day weather index requirements?

Of course, weather indices require knowledge of how extreme weather conditions have been, over a period, relative to some baseline period. Having a long record from which to construct a climatological baseline is a challenge faced by all methods which we might adopt. Measurement networks which regularly change are not helpful in this regard. Model climatology

Figure 2: Top: Mesoscale model analysis derived chilling hours (< 5 °C) for July–December 2010; and bottom: July–December 2011

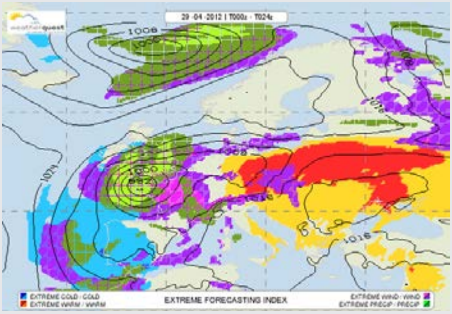


can also drift over time in the face of 'improvements' which are introduced to address other issues relating to model errors.

A very interesting, relatively recent product produced operationally by the ECMWF is the Extreme Forecasting Index (EFI) (Richardson, 2011). The EFI is a means by which the unusualness of weather conditions, compared to average, can be combined with the number of ensemble forecast members which predict the unusual conditions, to quantify an index value. Here, 'average' is the model climatology over the last 20 years. Although the model has errors/biases, which themselves are a function of forecast time horizon, the EFI is unaffected by this since the forecast also contains those same errors/biases. The EFI is currently calculated, globally, for time periods of 0–24 h, 24–48 h, 48–72 h, 72–96 h and 96–120 h. Let us restrict our consideration here to the shortest-range forecast, 0–24 h, since we are interested in focusing on the reality of what actually happened in a weather index application.

One might ask: Why use an ensemble probability-type forecast at all, why not just use the deterministic analysis or forecast relative to the long-term model average? The point is that by using a probability short-range forecast approach, we integrate a degree of uncertainty into our method which is arguably useful since, through judicious choice of index threshold, we can err on the side of the insured and allow for an error in the model simulation for a particular location or area, thereby minimising basis risk. Figure 3 shows an example 0–24 h EFI for a European domain, highlighting areas with unusual temperature, rain and wind characteristics. Note that the use of the word ‘extreme’ is avoided here since this is a relative term which may not necessarily lead to extreme impacts: a slight shower of rain might be unusual in a desert region but it is not in any sense extreme.

Figure 3: Extreme Forecasting Index (EFI) for the forecast period 0–24 h for a European domain



While weather conditions on an individual day might be most pertinent, for example, with respect to an insurance claim for damage to a property, weather indices are more commonly associated with cumulative conditions over a period, for example a monthly rainfall amount during a critical growing period. We can, therefore, imagine using the 0–24 h EFI product over successive model runs in order to accumulate the necessary conditions, rather than rely on a single long-range forecast from one model run.

It is useful, nevertheless, to finish by also considering the state of the art in model-based monthly forecasting as well. Figure 4 shows an example of a Day 5–11 and Day 12–18 weekly mean ensemble mean temperature anomaly forecast taken from the ECMWF Monthly Forecasting system (Bechtold et al., 2008; Vitart and Molteni, 2011; Richardson, 2011). The capability of both forecasts to successfully capture this European scale cold event highlights the ability of present day state-of-the-art forecast models to provide advanced warning of inclement weather, even in regions of the world, such as Europe, where predictability remains especially challenging. In some instances, such advanced forecasts may reduce insurance losses in those situations where sufficient trust is held in the forecast and mitigation measures are implemented.

3. CONCLUSIONS

Greater consideration should be given to the use and communication of state-of-the-art gridded model climatologies and forecasts to mitigate insurance losses and underpin weather index approaches, especially in those regions of the world where *in situ* weather measurements are less than ideal for such applications.

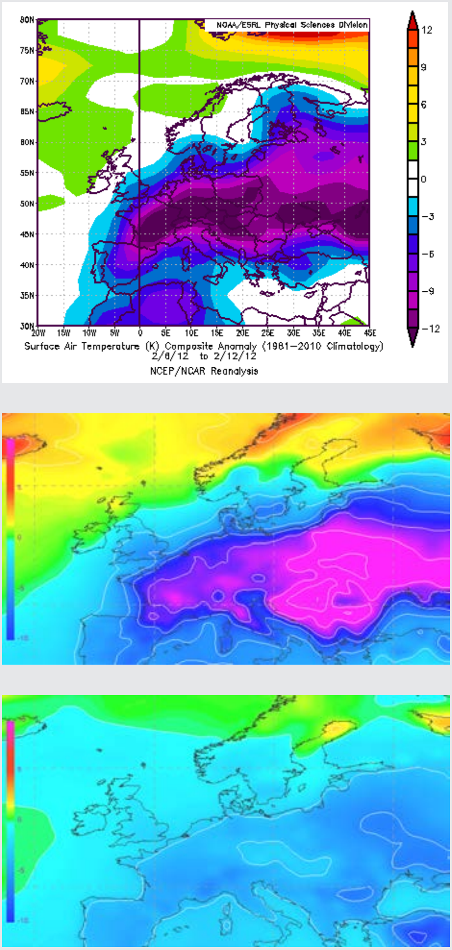


Figure 4: Top: surface air temperature anomaly (°C) for the period 6–12 February 2012 (based on 1981–2010 climatology); middle: temperature anomaly forecast for the same period 5–11 days ahead; and bottom: 12–18 days ahead

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28 Capturing the spatial variability of rainfall in weather-based index insurance

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KEYWORDS: **rainfall, satellite, gauge, variogram, spatial scale**

SUMMARY

Intrinsic to the design of many weather-based index insurance schemes is the concept that one can quantify the relationship between crop and climate. This relationship is highly dependent on the spatial and temporal scale that one studies it on, yet current index insurance schemes often use simple assumptions to decide the maximum distance between a gauge and an insured farm. This paper first discusses the spatial characteristics of rainfall before moving on to discuss how geostatistical techniques such as the variogram might be useful in designing index insurance contracts.

1. INTRODUCTION

One of the main objectives of index insurance is to be able to confidently capture the relationship between the chosen index and the underlying factor to be insured, thus reducing basis risk. In the design and implementation of weather-based index insurance, this commonly means that one wishes to capture the relationship between rainfall (or some other weather parameter) and crop yield. This is a non-trivial task, because, although there is often a strong link between crop and climate, it is frequently non-linear and highly dependent on the spatial and temporal scales that one studies it on.

This paper aims to introduce the reader to some of the features of the spatio-temporal variability of rainfall and to describe some geostatistical techniques which might be used to quantify it. The text first contains a brief introduction to the spatial characteristics of rainfall, concentrating in particular on those which might affect index design. Attention is then paid to geostatistical methodologies which might be used to model the spatial structure of rainfall. In particular, the text contains a description of the variogram, which might be useful for quantifying the spatial structure of rainfall.

Note that the examples of geostatistical analyses included in this paper relate to a case study in the Ethiopian highlands (Greatrex, 2012) and the paper also relies strongly on previous work by the authors (Greatrex, 2012; Grimes and Pardo-Iguzquiza, 2010) as referenced throughout the text, but attempts to place these in the context of weather-based index insurance.

2. REPRESENTING THE SPATIAL STRUCTURE OF RAINFALL

2.1. The spatial features of rainfall

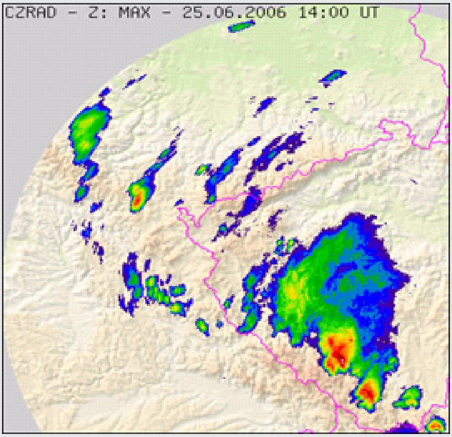
Rain gauge data sets are widely used in weather-based index insurance, both in index design and in determining payouts. However, many rain gauge networks are still relatively sparse and data is often difficult to access, especially when working in developing countries. In addition, most rain gauges must be managed by the relevant National Meteorological Agency rather than the insured farmers themselves, in order to ensure that the gauges are tamper-proof. The result of this is that the rain gauge used to create a contract is rarely sited on the farm to be insured, and is often located some distance away. If the gauge is too far from the insured location to correctly record its rainfall, then this will lead to increased basis risk.

It is, therefore, useful to know the maximum distance that a gauge can be sited from a farm before the gauge record is no longer considered representative of the farm's rainfall. This is easier to answer if one considers the underlying physical question: What is the spatial scale and structure of rainfall at the location of interest? Traditionally, many index insurance schemes have used an empirical distance of 20 km as a starting point, a distance derived from one of the original index insurance schemes based in Mali (Osgood, 2012). However, there are several features of rainfall (referred to as 'challenges' in this text) which might make such a simple assumption inappropriate.

- The spatial structure of rainfall is highly dependent on the geography and weather of the region of interest and is extremely variable in both time and space. For example, the spatial scale of an average rainstorm in Mali (approximately 20 km) might be very different to the spatial structure of frontal rain in South Africa, small-scale thunderstorms over the Ethiopian mountains, or rainfall from a squall line in the Sahel.

- The spatial structure of rainfall will also change during the course of the calendar year, depending on local weather conditions. Thus, rainfall from small-scale convection in the dry season will have a very different spatial structure to that of rainfall from large-scale organised convection at the height of the monsoon. This is important for index insurance as it means that one needs to know the time of year that rainfall is most likely to affect crop yield before one can answer questions about the scale an insurance contract can work over.
- The structure of rainfall is influenced by the temporal resolution of the rainfall measurement. For example, the spatial structure of daily rainfall amounts will tend to the spatial scale of local weather, whilst the structure of monthly or seasonal totals will instead reflect the large scale climatological situation (Grimes and Pardo-Iguzquiza, 2010). This means that index insurance contracts based on seasonal rainfall totals might be applicable further from a rain gauge than one based on daily rainfall amounts.
- The spatial scale of rainfall depends very much on the rainfall parameter being insured. In particular, rainfall occurrence (e.g. the number of rainy days/dry spell statistics) has a very different structure to rainfall intensity (e.g. rainfall totals/extreme rainfall). This is illustrated well in Figure 1, which shows a radar image of a convective cell. Here, there is a lot of fine detail in rainfall intensity: only a small region will experience very heavy rainfall, which could lead to adverse consequences such as flooding. In comparison, there is much more spatial coherence in rainfall occurrence. This matters because an index insurance contract designed to prevent flooding would need to consider the finer spatial scale of extreme rainfall, whilst one protecting against crop losses due to drought might be able to consider the larger spatial scales of whether it has rained or not. Therefore, this is, again, important for index insurance because a contract based on the number of rain days would apply to a very different spatial area to one concentrating on extreme rainfall amounts. Figure 1 also shows that there is no simple universal relationship between rainfall occurrence and intensity.
- The spatial structure of rainfall might not be isotropic around the rain gauge (e.g. it might not be the same in all directions). For example, in a region with frontal rainfall, the spatial structure might look very different when one looks north-south compared to when one looks east-west. This is particularly the case in regions such as the Sahel.

Figure 1: A radar image of a typical convective storm (Setvak, 2006): it is apparent that the spatial structure of rain/no rain is very different to the spatial structure of rainfall intensity.



- The structure of rainfall is highly influenced by the local microclimate. For example, the process of orographic enhancement normally means that rainfall intensity increases with altitude. However, Dinku et al. (2007) show that, in Ethiopia, the topography is so variable that a complicated rain-shadow effect occurs, meaning that rainfall amount decreases with height over many Ethiopian mountains. The issue of microclimate is important for index insurance because many gauges are traditionally situated along roads or in towns, rather than on tops of mountains or in agricultural areas. Therefore, care must be taken of the fact that the closest gauge to an insured farm might not be the most representative of its rainfall, and simple assumptions must not be made about the characteristics of rainfall without good local knowledge.
- Finally, the statistical characteristics of rainfall are difficult to model as it is highly skewed, has a joint distribution (rainfall occurrence and amount can be modelled as a Dirac and Gamma function respectively), and is heteroscedastic, where its variance depends on rainfall amount.

There are many techniques which can be used to model rainfall amounts. The next section concentrates in particular on geostatistical techniques as they are ideally designed to deal with the statistical characteristics of rainfall and address many of the challenges above. Note, however, that these techniques should still be used in conjunction with local knowledge rather than in isolation.

2.2. Rainfall and geostatistics

Geostatistics is the name for a family of techniques developed in order to study and interpolate auto-correlated or regionalised data (i.e. data that has a spatial correlation which varies with distance). The techniques are based on the concept that at a location, *x,* a set of observations, *Z*, can be modelled as a slowly varying mean background, *m*, plus a random fluctuation, *R*.

$$Z_x = m_x + R_x \qquad (1)$$

There are several studies discussed in Section 2.1 that suggest the field of geostatistics is well suited to addressing challenges, providing that basic assumptions of the method are correct (Grimes and Pardo-Iguzquiza, 2010; Lebel et al., 1987). In terms of index insurance, one technique in particular, the climatological variogram, is a useful tool for quantifying the spatial scale of rainfall at a given location. The full methodology behind this is explained in detail in Grimes and Pardo-Iguzquiza (2010) and in Greatrex (2012) but, in brief, imagine there is a set of observations *Z* of length *M* at locations $x_{(i.=1 \text{ to } M)}$, then make a list of all potential pairs of observations and sort by the physical distance *h* between them. These can then be split into bins of length 2δ. The mean variance at any given value of *h* is then given by:

$$\gamma(h) = \frac{1}{N(h)} \sum_{j=i=1}^{M} \sum_{i=1}^{M} (\beta(Z_{x_i} - Z_{x_j})^2)) \qquad (2)$$

where:

$$\beta = 1 \quad |(h-\delta) < |x_i - x_j| < (h+\delta)$$

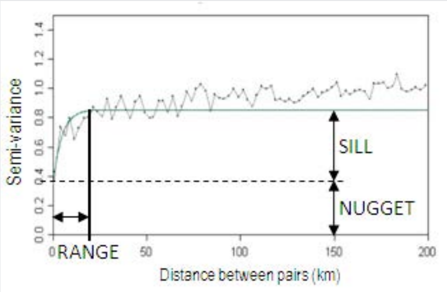
$$\beta = 0 \quad \text{otherwise}$$

(2) (3)

and *N(h)* is the number of pairs where *β* = 1.

To see the spatial distribution of a dataset, *γ* is calculated for varying levels of *h*. If *γ* is then plotted against *h* the resulting plot is called an experimental variogram. As rainfall data is often sparse, a climatological semi-variogram can be created by building up an 'average variogram' over several rainfall events, where each is scaled by the event's total variance (it is the inverse of the more common correlogram). This method assumes isotropy, second order stationarity, and that the spatial scale within all the events chosen is similar (e.g. that the spatial scale of a thunderstorm in western Ethiopian in June remains approximately constant). This means a variogram is sensitive to the events that the user chooses to include in the analysis. An example climatological variogram is shown in Figure 2 and its characteristics are described in Greatrex (2012).

Figure 2: Example of a climatological variogram (for June rainfall in the Oromiya Region of Ethiopia). The sill, nugget and range are marked for reference.



The **nugget** is the semi-variance as distance approaches zero. This might correspond to sampling error or the intrinsic uncertainty in a variable. In the case of rainfall, one might expect the nugget to equal zero because rainfall is highly spatially correlated at the scale of a few metres; however, measurement or location error means that this is rarely the case.

It is expected that as *h* increases, two samples of *Z* that are a distance *h* apart would become less spatially correlated. The distance at which the two samples become statistically independent of each other is defined as the **range** of the variogram.

The statement above means that at the range distance, the variogram will level off. The value of the semi-variance at this point is denoted as the **sill**. As a climatological variogram is normalised, the sill is conditioned to be at a semi variance of 1.

To make best use of the variogram, one can fit a model to estimate the underlying spatial structure in the data. Available models have to fit several stringent mathematical criteria (thus there is a limited choice), but all will output values of the nugget, mean and sill. The range in particular then provides a useful tool to check whether an insured farmer's field is near enough to a gauge for index insurance contract to be feasible. It is important to note, as discussed in Gommes (2012), the range of the variogram corresponds to statistical independence; for index design, a more stringent threshold and smaller range will probably be more appropriate.

The next section discusses how variograms can help address many of the challenges discussed in Section 2.1. However, this work is not suggesting that variograms should be used in isolation to define the spatial scale of rainfall. Instead, they should be considered as another tool, complementary to current methods and local knowledge, to ensure that index insurance contracts are suitable for a local environment. For example, the range from a variogram in a region such as East Africa or the Sahel might be a better starting point for creating an index insurance contract than assuming and empirical 'approximately 20 km'.

2.2. Variogram features

2.3.1. How much data is needed?

An experimental variogram depicts the **average** semi-variance at a given separation distance; thus, for a variogram analysis to be provide a good indication of the spatial structure of rainfall, one must also take care to abide by the assumptions discussed in the previous section and to use enough data to make a statistically robust plot. As shown in Figure 3, approximately 100–200 pairs of points in each distance bin is the lowest data limit possible before the variogram becomes unreliable. This means that it can be difficult to find enough gauges at close enough distances to make a variogram robust at the spatial scales of interest.

However, one is able to use a relatively short time series of data in this analysis. This makes the use of geostatistics interesting when one considers that there are several new dense gauge networks currently being designed for index insurance. The variograms in this paper were made using approximately 250 stations and 5 years of good quality daily data for the Oromiya Region of Ethiopia as shown in Figure 4.

2.3.2. Variograms of rainfall occurrence v rainfall amount

One of the main features discussed in Section 2.1 was that the spatial scale of rainfall occurrence can be very different to that of rainfall intensity. The variogram analysis allows one to look at these statistics independently and to correctly match the spatial scale study to the exact relationship used in the insurance contract between crop and climate. The difference between the spatial scale of rainfall amount and occurrence is illustrated in Figure 5. If one was designing an index insurance contract based on the number of rain days, then, in this case, the '20 km' maximum distance seems reasonable. However, if one was more interested in insuring against extreme rainfall intensity or floods, then most of the variability in the rainfall amount data is contained within less than 5 km.

Figure 3: Top: an experimental variogram for rainfall amount in May in the Oromiya Region of Ethiopia; bottom: this figure shows how many pairs went into each bin (when there are less than 200 pairs of gauges, the noise becomes too large to see the underlying spatial pattern).

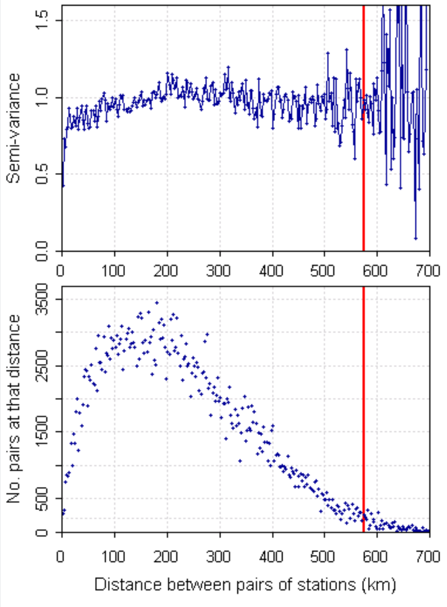
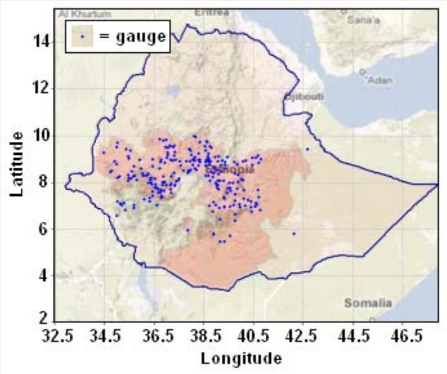


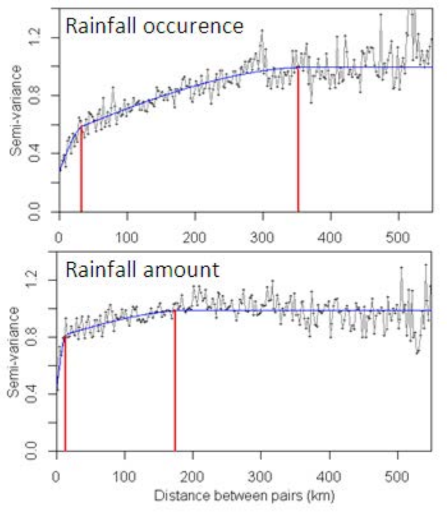
Figure 4: Rain gauges used to make the variograms shown in this paper (data is from 2002–06 and provided courtesy of the Ethiopian National Meteorological Agency)



2.3.3. Anisotropy

Using a variogram approach also allows a user to study whether the spatial structure of rainfall is isotropic and directional, or whether it appears the same in all directions. One can simply create a variogram where the distance used is the distance in some direction rather

Figure 5: Semi-variograms of rainfall occurrence and intensity (rainfall amount if raining) for May in Ethiopia. The thick red vertical lines correspond to the distances within which most, or all, rainfall at the pairs of gauges is related to each other (e.g. the variogram range).



than the shortest distance between the stations. This approach is well showcased in the work of Lebel to quantify the structure of rainfall over the Sahel (Lebel and Le Barbe, 1997; Lebel et al., 1987). In particular, Lebel showed that there was a much larger spatial correlation in rainfall when one looks in the north-south direction, compared to when one looks east-west, which might be expected in that region.

2.3.4. Including seasonality

As one can choose the events that comprise a climatological variogram, one can focus on purely the time of year and type of rainfall that affects crop yield. For example, if crop yield was more dependent on the small-scale convection at the start of the growing season (rather than the large-scale convection later in the season), then one could simply make a variogram using data from the starting month of the season. This, again, means that an index insurance contract can be tailored to exactly match the best relationship between climate and crop yield. Examples of variograms showing the structure of rainfall varying throughout the calendar year (in Ethiopia and in Uganda) can be found in Greatrex (2012) and in Maidment et al. (2012).

2.3.5. Software

Traditionally, creating a variogram might have been complex and time-consuming. However, there are now several specific software suites such as KrigeRain (Greatrex, 2011) and Info-Map (Pebesma et al., 2010) which allow the user to quickly and easily create climatological variograms, alongside many packages in programs such as Matlab and R.

3. DISCUSSION AND CONCLUSIONS

This paper aimed to show some features of the spatial structure of rainfall and how this can be quantified using geostatistical techniques. Using a variogram to measure the spatial structure of rainfall overcomes many of the complexities discussed in the paper and provides a relatively simple method of obtaining a baseline spatial scale in index insurance design.

The author is not, however, suggesting that a variogram analysis should supersede local knowledge or other techniques currently used for defining spatial scale index design (e.g. discussions with farmers), especially considering the importance of local microclimate and the sparsity of rain gauge observations. Data requirements, in particular, mean that it will not be feasible to create a variogram for every local climate around every gauge used in index insurance.

Instead, we suggest that the variogram might provide a useful baseline for quantifying the spatial scale of rainfall which can then be used as a starting point for discussion. Even if data requirements mean that a variogram can only be made for a region or a country of interest, it would still provide a more evidence-based starting point than simply assuming 'approximately 20 km', as is currently often the case. The existence of specific software packages also means that creating a variogram can be accomplished quickly and simply in weather-based index insurance design.

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29 Beyond simple, one-station rainfall indices

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KEYWORDS: spatial interpolation, geostatistics, crop insurance, basis risk, reference station, rainfall, crop modelling

SUMMARY

Most index-based insurance schemes adopt simple indices based on rainfall recorded at a reference weather station. The distance between station and the insured farmers' fields is usually considered 'acceptable' up to 20 km. The reason why simple rainfall triggers are preferred over more efficient model-based indices, and the reason why insurance schemes do not resort to spatial interpolation, is usually given as 'simplicity' and 'transparency', two desirable features for insurance contracts. This note argues that many of the standard assumptions on which current index-based insurance contracts are based are unsustainable in the long term. Although indices that are more complex (i.e. less elementary) entail a need for additional data, they more accurately estimate yields and behave better spatially. The main challenges are linked with the interactions between index developers, insurers and reinsurers, and farmers. The essence of the interaction is made of mutual technical understanding, commitment and trust.

1. INTRODUCTION

A number of general introductory documents to crop insurance in developing countries have been published recently by major development agencies and partners, including the FAO: Roberts, 2005; Iturrioz, 2009; Smith and Watts, 2009; Hellmuth et al., 2009; Hazell et al., 2010; IFAD, 2011; World Bank, 2011.

The World Bank (2011) lists the following desirable features of indices: (i) strong correlation with yield; (ii) observable and easily measured; (iii) objective; (iv) transparent; (v) independently verifiable; (vi) reported in a timely manner; (vii) consistent over time; and (viii) experienced over a wide area. There are many shades and interconnections between objectivity, verifiability, timeliness, etc. In the reality of index-based insurance practice, the above 'rules' are mostly transgressed in a number of ways, starting with the link between rainfall and yield, which cannot be captured by a simple index (de Bie and Morsink, in these proceedings).

The list above provides, nevertheless, a convenient checklist against which to judge the quality of indices. It would be useful to prioritise the items as some of them are mutually contradictory. For example, transparency and strong correlation with yield cannot be achieved except under very extreme conditions [(1)].

This note focuses on point (viii) by looking at the specific question of the distance which is acceptable between a farm and a reference station used to define when an index triggers. This question is also relevant for most other points, for example (iii) to (vi). The terms probably apply to a well-maintained automated rain gauge that is also properly sited and which automatically transmits data that are publicly available. If just one of the desirable features is missing, is the station no longer acceptable? Again, we run into the need of a hierarchical list of features that would not be evaluated on their own merit but in terms of the performance of indices.

Most index-based insurance schemes currently use a 'nearest neighbour' approach, i.e. they borrow data from the nearest weather station, provided the station is closer than an arbitrary distance, usually taken as 20 km (Osgood et al., 2007; Hazell et al., 2010). Other authors recognise that the nearest neighbour approach may be a problem but do not provide orders of magnitude and rules: 'in some places 20 km is far smaller than necessary, and in others the boundary is dangerously large' (Dinku et al., 2009.) Nevertheless, some papers (e.g. Rosema et al., 2010) have clearly questioned the 'standard': 'To adequately represent the spatial variation of convective rainfall systems, the distance between rainfall stations should not be more than a few kilometres. Current drought insurance practice requires the insured to live within a distance of 25 km from a suitable rainfall station. This, however, is very questionable and will already imply a high spatial basis risk, leading to cases of inappropriate payout'.

The present note attempts to systematically explore the distance up to which a station is representative, and concludes that real-world insurance cannot function without at least some form of spatial interpolation. It further makes the point that some non-elementary indices based on modelling have at least two advantages: (i) they simulate yields more accurately than the standard entry-exit rainfall model; and (ii) interpolate better as well.

1 Aldermann and Haque (2007) quote another 'checklist' provided by 'a private insurer' in an unspecified African country.

2. UP TO WHAT DISTANCE DOES A STATION REMAIN 'REPRESENTATIVE' FOR A NEARBY FARM? (2)

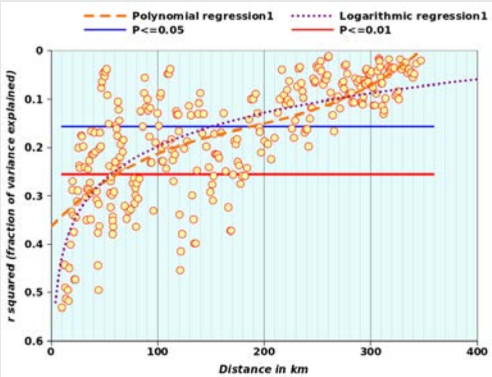
2.1. Why one-station indices are inefficient

This section focuses on rain gauges, although much of the discussion applies as well to other variables, such as wind speed, solar radiation, temperature and air moisture, which all play a significant part in the determination of plant production potential and crop water requirements.

It is assumed that the rain gauges being used in the illustration fulfil the following criteria.

- Their coordinates are known with sufficient accuracy (3) (i.e. within 1 arc-second, or about 30 m). Many weather services report coordinates to within 1 minute, which is not acceptable in hilly or mountainous terrain, as the corresponding horizontal uncertainty on station location may reach almost 3 km and include areas with large altitudinal differences.

Figure 1: Coefficient of determination r^2 (vertical axis) as a function of distance between 25 Ethiopian stations, under exclusion of the 25 couples where distance = 0 km, r^2 = 1. The polynomial and the logarithmic regressions (trend lines) show two possible ways to fit the variogramme data, and the considerable scatter about the idealised lines.



- They are properly sited (i.e. there are no obstacles in the immediate surrounding), as per WMO rules (WMO, 2008). Many stations are too close to obstacles (e.g. trees) that intercept rainfall, which may lead to very significant underestimation of actual rainfall.

2 All the examples are derived from the involvement of the author with the Ethiopian project described by Ahmed et al., 2010.

3 With current inexpensive GPS, it is very easy to accurately measure the coordinates and the elevation of weather stations. Among other things, this allows a rough check of some station characteristics using Google Earth (i.e. distance to buildings and other obstacles, such as trees.)

- The stations are properly maintained; in particular, debris, wasp nests and other obstacles are removed from the gauge at regular intervals.
- Readings are actually taken on the day for which they are reported, and 'no reading' is reported as such [4] rather than as 'zero' rain.

There are several reasons why indices based on one station only should be phased out in the actual practice of index-based insurance:

- Missing data do occur, for a number of good and not-so-good reasons. Most insurance schemes just gloss over the issue, while it is obvious that there must be an 'emergency' tool to fill the data gaps. Many technical options are possible, but beyond borrowing data from a nearby station, all of them implicitly or explicitly involve some spatial 'averaging'. It is also suggested that fairness requires that the approach used should be mentioned in the insurance contracts [5].
- The implementation of insurance requires both historical data used to evaluate risks and to 'calibrate' contracts and current season data. It may happen that otherwise perfect stations lack sufficient time series. In that case, there should be an accepted standard method to estimate historical data based on neighbouring stations. This can be done with several approaches, of which the extremes are: (i) estimating the data missing from the time series and then performing the usual statistical risk computations; and (ii) computing the statistical parameters that describe the rainfall distribution (e.g. gamma, beta and frequency of zeroes in the case of the gamma law) and then spatially interpolating the parameters, as was done, for example, by Husak et al. (2007). The second approach has a number of advantages over the first, starting with the much reduced number of interpolations and the greater stability over space of the more complex parameters compared with raw climate variables.
- 'Nearest neighbour' interpolation creates arbitrary spatial 'boundaries' in payouts to farmers. Two fields in the same condition and separated by a short distance may receive rather different payments from the insurance if they are assigned to different weather stations. This is unlikely to happen if each index is an interpolated 'average' of several stations.
- Tampering with individual stations or poor quality of readings is less likely to affect payouts if some spatial interpolation (multi-station index) is used.

2.2. Spatial dependence assessment

The standard tool to assess how the similarity between stations varies with distance is known as a variogram. For a precise definition and an overall introduction to geostatistics of rainfall, refer to Grimes and Pardo-Iguzquiza (2010) and Greatrex in these proceedings.

4 It is very common that 'no reading' eventually becomes 'zero rainfall' and gets absorbed into climatological records.

5 Some borrowing of data from neighbouring stations has to occur in the real -world if the reference station somehow fails. To that extent, one-station rainfall indices can exist only with perfect weather stations.

Here, we adopt a very simple approach which consists in computing the Pearson coefficient of correlation *r* between accumulated rainfall readings taken at 25 Ethiopian stations more or less continuously covering the zones of N. Shewa, N. and S. Wollo and W. Gojjam (Figure 1). The locations of the stations and their coordinates are given in the annex to this text. The available data cover the 29 years from 1981 to 2009. For any period over the year (end of May to early September), dekads [(6)], 15 to 25 in the present case, it is thus possible to compute the coefficient of correlation between any two stations. Since *r* is symmetric (the correlation of between station S1 and S2 is the same as the correlation between S2 and S1), the number of distances (couples of points) available with 25 stations is 300, or 325 if we include the correlation of each point with itself [(7)] ($r = 1$, distance = 0 km).

Figure 1 shows a lot of data scattering. Much smoother variograms are obtained by grouping points according into distance classes. Here, we prefer to show the 'real picture' to stress the fact that there is significant variability between spatial correlations. It is also in order to specify that the original data suffer from a large fraction of missing data (38 % on average) and that the missing data were estimated using one of the simplest interpolation techniques after 'nearest neighbour', i.e. inverse distance weighting (IDW) [(8)] using 62 stations (Annex, Figure A1). As a result of the application of IDW, the 1981–2009 time series includes no missing data. In addition, the procedure of missing data estimation results in the stations with estimated data being more similar to each other than they are in reality. There is a slight overestimation in rainfall [(9)], and not only for rainfall amounts close to 0 mm. All these factors concur to produce a variogram that is slightly more optimistic than reality (i.e. where the strength or correlations is artificially increased).

2.3. How to interpret a r^2 variogram

Figure 1 shows the lines that correspond to statistical significance of the correlations at the 0.01 and 0.05 threshold levels. They correspond approximately to $r^2 = 0.16$ for $p <= 0.05$ and $r^2 = 0.26$ for $p <= 0.01$. We might decide that the corresponding distances are 150 km at $p <= 0.05$ and 50 km at $p <= 0.01$ (for the logarithmic fit of the variogram). A different interpretation is proposed: if we remember that the coefficient of determination r^2 indicates which percentage of the regression is accounted for, we find that we account only for 16 % and 26 % of the variability of rainfall in S2 if we use S1 instead. This is, clearly, very low. In reality, we would like to account for at least 70 %, 80 % or 90 % of the variability, which corresponds to values of r^2 of 0.7, 0.8 and 0.9. Table 1 shows the corresponding distances.

6 To avoid the confusion between 10-year periods (decades) and 10-day periods, the WMO Commission for Agricultural Meteorology (CAgM) has recommended the use of the word 'dekad'. There are three dekads in each month, the last with 8 (February), 9 (February in leap years), 10 or 11 days.

7 With N points, we have N(N − 1)/2 couples.

8 IDW is a spatial average where the weighting factor is based on the distance between stations: the closer the station, the greater the weight. See Chen and Liu (2012) for a recent example.

9 There are several reasons for this overestimation: (i) when an altitude correction is applied, some interpolated values are slightly below 0 — they are reset to 0 as a matter of routine, thereby artificially increasing the average; (ii) if a spatial average is based on at least one non-zero value, the result is a non-zero average.

Note that contrary to Figure 1, Table 1 is based on 325 points (i.e. it includes the 25 points for which distance = 0 km and *r* = 1).

Table 1: Rainfall accumulated over four groups of dekads corresponding to typical phenological phases (Annex): d(r = 0.471) and d(r = 0.367), distance up to which correlation between stations remains significant at the 0.05 and 0.01 thresholds; d(r = 0.83), d(r = 0.89) and d(r = 0.94), distance at which a station accounts for 70 %, 80 % and 90% of the variance of a neighbouring station). The table includes the 25 couples where distance = 0 km, r^2= 1.

		Dekads			
		15-25	20-25	26-28	29-32
n=325	Model r	0.69	0.68	0.72	0.74
	d(r=0.471)	44 km	42 km	76 km	320 km
	d(r=0.367)	94 km	88 km	168 km	365 km
	d(r=0.83)	2.83 km	0.42 km	0.52 km	53.78 km
	d(r=0.89)	1.57 km	0.07 km	0.26 km	3.89 km
	d(r=0.94)	0.77 km	0.01 km	0.12 km	0 km

If we wish to account for 90 % of the variability of rainfall in one station based on another station, then distance between stations should not be larger than 770 m (rainfall accumulated over dekads 15 to 25) or 120 m (rainfall accumulated over dekads 26 to 28). If we accept to account only for 70 % of the variability, then the nearest station should be at a distance between 420 m and 53.78 km.

2.4. Relative error variograms

Instead of using the coefficient of determination as a measure of similarity between stations, it is also possible to use the more intuitive relative errors, i.e. to determine the average relative error that affects an estimate of rainfall at S1 if S2 is used instead. Since relative errors can be positive or negative, Table 2 shows the average of the absolute values of the relative error [(10)].

The results confirm those in Table 1: at 20 km, the absolute value of the relative error varies from 29 % to 126 % (+ 100 % is exactly double the actual amount); if we insist that the error should not exceed 10 %, then the farm to be insured should be at a distance between 1.4 km and 3.9 km from the reference station, depending on the dekads over which rainfall is accumulated.

10 Contrary to r^2, the relative error is not symmetric (i.e. the error that affects the rainfall in S2 when estimated with data from S1 is different from the error affecting S1 when estimated using data from S2).

Table 2: Some characteristics derived from variograms based on the absolute values of relative error (%): E%(d = 5) — short for E%(d = 5 km) — is the average error (%) at a distance of 5 km. In the same way, d(E% = 10) is the distance (km), at which the average absolute error is 10 %. The table is based on the 1981–2009 time series.

		Dekads			
		15-25	20-25	26-28	29-32
n=625	Model	*Rational*	*Rational*	*Exponential*	*Exponential*
	Model r	0.43	0.39	0.26	0.16
	E% (d=5)	20	27	24	34
	E% (d=10)	25	27	24	67
	E% (d=20)	29	31	45	126
	E% (d=30)	31	33	64	179
	d(E%=10)	1.5	1.4	3.9	1.4
	d(E%=20)	5.2	4.4	8.1	2.9

Needless to say, the present analysis is very crude; it is valid only for a very specific set of stations in central Ethiopia. It, nevertheless, shows that a farm should normally not be at a distance larger than just a couple of kilometres from the reference station.

2.5. Rainfall gradients

Another approach to estimating horizontal variations of rainfall is the computation of spatial gradients (i.e. to map out the way in which the rainfall increases in a given direction). The gradients are expressed in millimetres of rainfall per kilometre (intensity), with an associated direction. The discussion following focuses on intensity only — an example is given in Figure 2. Gradients can be assessed using various methods, including variograms. In this discussion, we have used a simpler approach implemented in the FAO software New_LocClim, which is based on the regression of rainfall data against geographic coordinates (Gommes et al., 2004; Grieser, 2006.)

Of course, gradients (mm/km) tend to be stronger when total rainfall amounts (mm) are larger, so that they can be inter-compared only if they are standardised with reference to rainfall amounts. In practice, this is achieved by dividing the gradient by the amount of rainfall, resulting in a dimension of km^{-1}. Since the numbers tend to be small, they were multiplied by 1 000 in Table 3, which illustrates some features of horizontal gradients in three areas in Ethiopia.

In this specific example, gradients are remarkably stable at 4 to 5 1000/km, with some exceptions: late season gradients tend to be much larger than early or whole season ones. The immediate consequence is that the extent to which a station is representative over a given distance undergoes seasonal changes. The area over which a station is representative (regardless of the criteria adopted to decide representativeness) is not a circle, but some kind of 'irregular ellipsoid' more and more affected by elevation as distance from the station increases. In addition, the orientation of the ellipsoid changes with season, so that a station that may have provided an adequate proxy for a given field at the time of planting no longer 'works' at flowering. Incidentally, the above observations are an additional argument in favour of some form of spatialisation.

Table 3: Comparison between horizontal gradient magnitudes in three zones in Ethiopia under the same conditions as in Figure 2: the zones are S, north Shewa (SE group of districts in Figure 2); W (N and S Wollo, NE districts); and G, west Gojjam, NW district. The groups of dekads correspond to phenophases of major crops cultivated in the area.

		Dekads				
		15 to 25	20 to 25	26 to 28	29 to 32	15 to 32
S	mm	730	587	86	49	846
	mm/km	3.1	2.4	0.7	0.6	4.3
	1000/km	4.2	4.1	8.1	12.2	5.1
W	mm	561	470	51	24	640
	mm/km	2.5	2.3	0.8	0.2	3.7
	1000/km	4.5	4.9	15.7	8.3	5.8
G	mm	1146	751	174	55	1383
	mm/km	5.5	3.1	0.1	0.3	5.5
	1000/km	4.8	4.1	0.6	5.5	4

Table 4: Same variables as in Figure 3 for teff 1981–2009 — the two reference periods are the flowering phase and the complete cycle.
NB For ETA over the crop cycle, the error never exceeds 17 % (Figure 3).

		Rainfall		Actual evapotranspiration	
		Crop cycle	Flowering	Crop cycle	Flowering
n=625	Model r	0.38	0.15	0.34	0.24
	E%(d=5)	12	54	6	15
	E%(d=10)	21	100	9	21
	E%(d=20)	32	173	13	24
	E%(d=30)	38	228	15	25
	d(E%=10)	4.1	0.9	11.0	2.9
	d(E%=20)	9.6	1.8	Note	8.9

2.6. Some additional considerations: beyond rainfall-sum indices

The period over which rainfall is accumulated plays a part when deciding up to what distance a station can be taken as a reference for a given field. Without entering into a detailed discussion, it can be shown that the output from somewhat more sophisticated indices which involve a soil water balance usually behave better spatially than simple rainfall [11].

Table 4 and Figure 3 compare raw rainfall data with a more sophisticated indicator (actual evapotranspiration, ETA, mm) over the growing cycle and the flowering phase for teff.

The ETA is computed as in the standard FAO Water satisfaction Index (WSI) [12] (i.e. water balance calculations start 5 dekads before planting, assuming a pre-season crop coefficient of 0.5). Soil water-holding capacity was arbitrarily set to 100 mm (Araya et al., 2010, use 96 mm). The ETA obviously buffers rainfall variability and the water stored in the soil introduces a memory effect that hides short-term local variations, resulting in significantly lower errors and better representativeness over larger areas.

2.7. Is there an ideal station density?

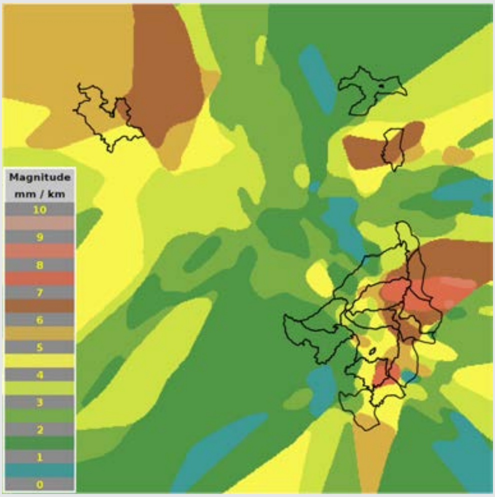
Eventually, the density of stations must be decided based on the capacity of the network to predict crop loss. Collier et al. (2010) have a rather interesting section on 'real-world data constraints', where they, rightly, note that 'the availability of weather index insurance will be severely limited if each index must be based on actual data from a single weather station and that data constraints are less binding for risk aggregator products than for household products' [13]. Aggregator products correspond, as well, to the practice of regional crop modelling and forecasting, an area where there is considerable operational experience available at a scale that corresponds to area-yield indices (Gommes et al., 2010).

11 The smoother spatial behaviour may also be due, to some extent, to being defined more precisely, to the fact that spatial variability of soil features is imperfectly taken into account.

12 The FAO WSI has become a standard semi-quantitative crop monitoring tool. Many descriptions (and variants too) are available in the literature in addition to the original publication by Frère and Popov (1979, 1986); see, for example, World Bank, 2006.

13 By 'aggregator products', Collier et al. indicate products directly derived from spatial averages, such as agricultural statistics.

Figure 2: Magnitude of the rainfall gradient for the dekads 15 to 32 (1981–2009 average). The map is based on 62 stations; it was smoothed using the median of 9 pixel boxes centred around each 1 km pixel. The map covers the area from 8.5 N to 12.5 N latitude and 36.5 E to 40.5 E longitude.



If single-station indices, nevertheless, continue to be implemented in the future because of the transparency and communication constraints associated with the farmer-rainfall-insurer-reinsurer continuum, then very large numbers of stations will need to be deployed. The resulting costs will, logically, have to be passed to the insured (Collier et al. 2010). Whether this can be sustained economically is open to debate. New rain gauges have no historical data attached and, thereby, require an act of faith by farmer, insurer, and reinsurer in whatever model is used to decide on payouts (or not) based on data from these gauges, in combination with risk data from other sources (i.e. stations). If single-station indices must be used because of fear of black boxes, then setting up new stations is not really the solution.

Figure 3: Variation of average absolute error as a function of distance for rainfall and ETA (teff, 1981–2009) over the whole cropping cycle (season) and the flowering stage

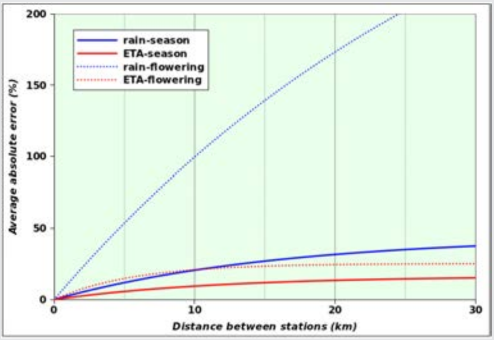


Figure 4 is based on an equation derived by Ali et al. (2005) for Sahelian conditions (i.e. conditions that are much more favourable to insurance index development than those in Ethiopia or Malawi if we consider spatial variability of rainfall). Figure 4 shows the number of rain gauges required to achieve a given relative error affecting spatial average rainfall.

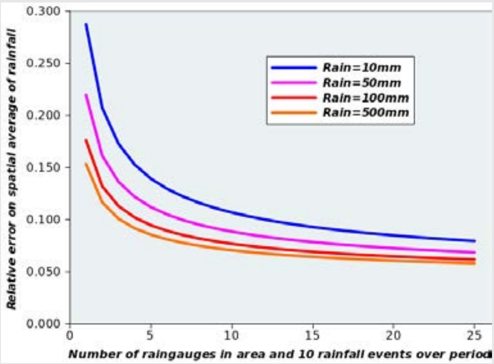
It appears that (i) the error is larger for small rainfall amounts, and (ii) the 'efficiency' of additional rain gauges decreases after 5–10 rain gauges. If we consider that 10 % relative error on rainfall is acceptable, the area described in Figure 2 or Figure A1 would require at least 150 rain gauges to correctly estimate the spatial average rainfall.

2.8. Satellite-based estimates of rainfall

A final comment on satellite-based estimates of rainfall: the whole area is subject to the problem of statistical significance v agronomic significance we have mentioned above. For example, Beyene and Meissner (2010) conclude that RFE [14] 'images can be used reliably for early warning systems and that they can be used to base decisions on magnitude, timing, duration and frequency of rainfall deficits on different spatial and temporal scales'. They show examples where correlation values between gauge data and satellite estimates reach 0.5 or even 0.75 for an overall level of significance is 0.01. The corresponding values of r^2 indicate that only 50 % of the gauge rainfall variance is accounted for. This is not sufficient for single-station indices, but may be adequate for some 'aggregator products' still to be defined [15].

Altogether, the current situation is such that 'there is almost surely an overall negative correlation between the amount (and quality) of [available] data in different countries and the risk of life or livelihood-threatening drought in those countries' (Aldermann and Haque, 2007).

Figure 4: Relative error affecting spatial average rainfall over an area with a radius of 100 km (about 31 329 km²), which corresponds roughly to a 'pixel' of 177 km x 177 km



14 Rainfall Estimate — there are many sources of freely available rainfall estimates: http://earlywarning.usgs.gov/fews/africa/web/readme.php?symbol=rf; http://www.met.reading.ac.uk/tamsat/about/; http://geonetwork3.fao.org/climpag/FAO-RFE.php

15 They may be useful for aggregator products to insure zonal or regional governments against the cost of relief operations.

3. CONCLUSIONS

This paper shows that indices based on simple rainfall sums by phenological phases have a very limited spatial range of validity, usually not exceeding a couple of kilometres. In addition, their performance as proxies for yield is mostly undocumented and valid only for extreme water shortages.

In the words of Baethgen at al. (2008), 'restricting an index to time-averaged meteorological variables shifts the responsibility for relating them to production-related losses on to the intuition of the various stakeholders. Quite complicated contracts can result if local experts impose ad hoc adjustments, such as upper limits to dekadal rainfall to account for run-off'.

Because all crop models incorporate a soil-water balance component, their spatial interpolation is much more meaningful than that of the simple indices.

Still, according to Baethgen et al. (2008), 'the decision about choice of an index for agricultural or food security applications should recognise and seek to balance the trade-offs between basis risk and the communication challenges associated with a given model, and not assume either that communication challenges are insurmountable or that basis risk is trivial'.

Very little actual experience exists regarding complex indices based on modern tools, including geostatistics, crop simulation, stochastic weather generators, etc. It is likely, however, that the more comprehensive the scope of the indices (e.g. farm income indices, beyond yield indices), and the larger the spatial scale, the more efficient the insurance will be in terms of basis risk reduction (Binswanger-Mkhize, 2012).

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ANNEX: THE STATIONS USED IN THE ILLUSTRATIONS AND TABLES

All figures and tables are by-products of the project *Interlinking insurance with credit to enhance smallholder agricultural productivity: a pilot application to Ethiopia* (Ahmed et al., 2010). They correspond to the area illustrated in Figure A1, bounded by the northern latitudes 8.5 and 12.5 and the eastern longitudes 36.5 to 40.5. This is a high potential area where drought is less of a problem than excess rainfall and late season frost, although severe droughts do occur (e.g. in 1984).

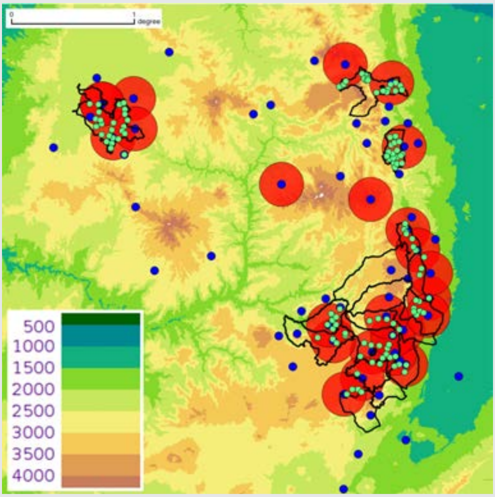

Figure A1: Red dots: 25 reference stations for the preparation of the variograms (marked with '*' in following list), their radius covers approximately 20 km (i.e. 40 km across); blue dots: 62 stations (all those in the list) used to estimate missing data in the time series of the 25 reference stations; green dots: 120 villages where crops are to be insured, in principle, based on the time series and actual rainfall in the 25 stations. The background colour indicates elevation in metres.

The dekads used in the tables correspond to typical generalised phenological phases for teff and early sorghum:

- 15 to 25: vegetative phase for sorghum;
- 20 to 25: vegetative phase for teff;
- 26 to 28: flowering for both crops;
- 29 to 32: maturation and grain filling (actually one dekad shorter for teff and one dekad longer for sorghum);
- 15 to 32: whole sorghum cycle.

The following list identifies the 25 stations used in some of the graphs, as well as the 62 stations mentioned in the text. The coordinates of the stations are a home-made mix of values from the National Meteorological Agency (NMA [16], essentially cooordinates given to two decimals, GPS readings by project staff, and Google Earth 'adjustments' (e.g. when the NMA coordinates correspond with locations outside villages).

Name	Longitude	Latitude	Altitude (m)
* adet	37.49314	11.27461	2 198
* aliyu-amba	39.78606	9.56535	1 812
* chercher	39.8	10.6667	1 472
* debele	39.69638	9.65657	3 195
* debre-berhan	39.51087	9.66868	2 760
* debre-sina	39.7608	9.84701	2 698
* deneba	39.19332	9.75923	2 694
* enewari	39.15728	9.8855	2 659
* gudoberet	39.68049	9.80146	3 082
* jeweha	39.97307	10.10611	1 154
* kembaba	37.40067	11.41194	2 114
* korata	37.5667	11.7333	1 887
* kotu	39.4333	9.44999	2 787
* majete	39.88033	10.49681	1 558
* mezezo	39.9667	9.96669	1 332
* muja	39.28991	12.0085	2 792
* robit	39.66997	11.85937	1 551
* sayent-ajbar	38.77084	11.03289	2 840
* seladingai	39.62797	9.95645	2 852
* sheno	39.28494	9.32453	2 882
* tebasit	39.49808	10.91087	3 427
* tis-abay	37.57908	11.48753	1 650
* werebabo	39.77	11.34	2 337
* zege	37.31242	11.68872	1 800
addis-abeba	37.86	12.11	2 020
ankober	39.73481	9.59445	2 978
arb-gebeya	38.543	11.604	1 900
arerti	39.3987	8.83334	1 933
artuma	40.0254	10.58663	1 771
bichena	38.2	10.45	2 452

16 http://www.ethiomet.gov.et/stations/information

Name	Longitude	Latitude	Altitude (m)
bokeksa	39.8833	11.3667	1 946
combolcha	39.7333	11.1167	1 898
debre-markos	37.74	10.33	2 458
deke-istifanos	37.2667	11.9	1 803
durbete	36.9167	11.3333	2 019
feres-bet	37.5833	10.85	2 991
fetra	38.9333	10	1 807
fitche	38.75	9.8	2 800
gerba	39.25	11.1	2 831
geregera	38.6842	11.6823	2 816
ginager	39.5667	9.3167	3 126
gondar	37.4715	12.6111	2 209
gosh-meda	39.3833	11.5333	2 218
guder	39.7833	8.94999	1 041
jihur	39.25	10.0333	2 530
koremash	39.5	9.15	1 821
kundi	39.4667	11.3667	2 540
lalibela	39.04	12.04	2 497
lemi	38.9	9.8167	2 553
melka-sedi	40.2167	9.46669	731
meragna	39.1333	10.1	2 030
merawi	37.2167	11.5833	1 863
merssa	39.65	11.6667	1 681
molale	39.65	10.1167	2 967
muke-turi	38.8667	9.55	2 639
nazreth	39.28	8.55	1 622
rike	39.8336	10.7678	1 445
ruga	39.8	11.5333	1 726
sarmider	39.6667	10.3333	3 106
senbete	39.98725	10.30925	1 424
sirinka	39.6167	11.55	2 127
yegem	39.8	10.2667	3 174

Alternatives to simple rainfall-based indices

30 Temperature, sowing dates and variety as crop insurance index for irrigated wheat in northern and Central Sudan

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KEYWORDS: wheat, irrigated, Gezira Scheme, crop, insurance, variety, temperature.

SUMMARY

Weather has always been a source of risk for many economic activities. The main winter crop in Sudan is wheat. Temperature is the main limiting factor. For a given temperature, field sowing date and variety play a crucial role in the yield of the wheat. Forecasting of temperature has been attempted by the Sudan Meteorological Authority during the past few years in order to assist the planning and management of the winter crops (mainly wheat). To reduce the risk, the sowing date is staggered over a period of 30 days around the recommended sowing date. Furthermore, a number of varieties are used. Some are short season, 90–100 days, while others are long season, 120–130 days. The risk in Central Sudan is higher as the winter season is shorter than that in northern Sudan.

Water shortage is generally expected during sowing, especially in the Gezira Scheme. This water shortage generally leads to a delay in sowing, which leads to a drop in yield. Insurance companies can monitor the water shortage problem very well in the Gezira Scheme. However, it is very difficult to deal with temperature in the absence of a seasonal forecast of temperature. This paper explains the importance of sowing at the recommended dates and choosing appropriate varieties of wheat. This may help insurance companies to design their policies for the insurance of irrigated wheat in northern and Central Sudan.

Day length and temperature requirements are key factors in variety selection. Varieties can be grouped as winter or spring types according to chilling requirements, winter hardiness and day length sensitivity. Winter wheat requires a cold period or chilling (vernalisation) during early

growth for normal heading under long days. Winter wheat, in its early stages of development, exhibits a strong resistance to frost, down to – 20 °C. This resistance is lost in the active growth period in spring and during head development and frosts in the flowering period may lead to head sterility; because of this, sometimes more damage is done to the winter crop by spring frosts than by winter frosts.

1. INTRODUCTION

The main winter crop in northern and Central Sudan is wheat. It is grown by farmers in small areas on the banks of the River Nile in northern Sudan. It is irrigated by lift irrigation. Previously, locally made wooden machines called *Sagia*, driven by bulls and donkeys, were used but, since the 1950s, areas have increased and diesel pumps have replaced the *Sagias*.

In Central Sudan, wheat was introduced in the Gezira Scheme in the late 1960s. Since the 1970s, it has become a major winter crop with areas reaching 200 000 ha. In the 1980s, additional areas were planted with wheat in three other irrigated schemes namely New Halfa, Rahad and Suki, covering areas of about 50 000 ha.

The main limiting factor for wheat growth is temperature. Northern Sudan has lower temperatures and longer seasons than Central Sudan. The irrigated schemes in Central Sudan are rather marginal areas for wheat. The normal maximum and minimum temperatures (1981–2010) for Dongla (northern) and Wad Medani (Central) are shown in Table 1 for the winter season November–March.

2. CROP INSURANCE INDEX

2.1. Crop insurance index

The concept of crop insurance was introduced very recently — the last 5 years or so. It started in the Gezira Scheme covering only one crop — cotton. The insurance mainly covered pest damage and water shortage.

In northern Sudan, water shortage is generally not a problem. Areas are small and irrigated using pumps which are under the control of the farmers. Recently, most diesel pumps were replaced by electrical pumps. The electrical supply from the Marawi Dam is now reliable. In this paper, the main case considered will be the Gezira Scheme (Figure 2).

Figure 1: Daily maximum and minimum temperatures and diurnal variation from 1 January to 20 February 2011

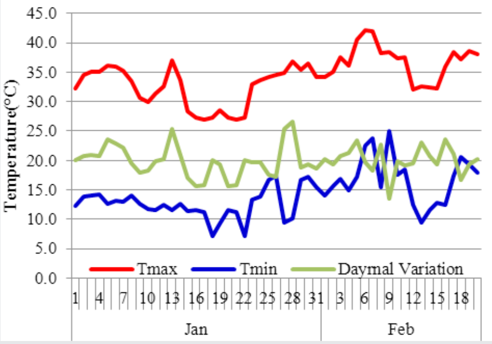
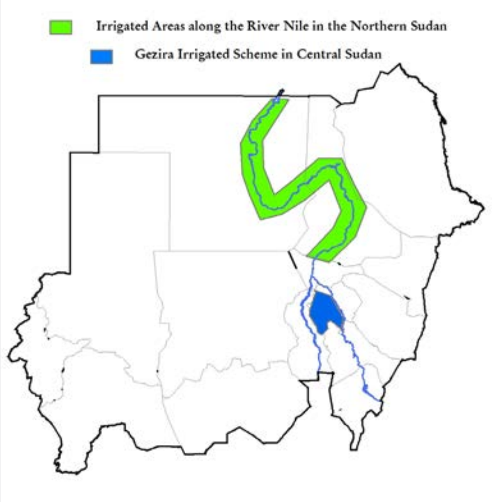


Figure 2: Irrigated areas in northern and central Sudan



2.2. Water shortage in the Gezira Scheme

The main constraint of water is during the sowing time in November. The availability of water for wheat sowing during November is linked to water used for cotton and the delayed groundnuts. The areas allotted for wheat are based on available water and the capacity of the main canal. The plan is to sow by 31 October. However, this has never been achieved since 1970. This is due to delay in sowing dates of groundnuts caused by intentional delays to get higher prices and by share-croppers to get more nuts underground.

This delay affects the availability of water for the first irrigation of wheat which is about 50 % higher than the normal irrigation. This unavailability of water causes a delay in the sowing date of wheat as the winter season in Central Sudan is very short.

2.3. The sensitive phase of wheat

The sensitive phases of wheat for temperature are flowering, seed setting and seed filling. These phases for wheat sown in November are from mid-December to mid-February. So, for Central Sudan, the field temperature during the period of mid-December to mid-February is crucial.

Therefore, detailed analysis of the field temperature is needed. Ten-day mean maximum and minimum temperatures from 1 November to 31 March year by year for 30 years from 1981 to 2010 for both Dongola and Wad Medani for comparison are available (Table 1 and Figure 3). Years with abnormally high temperatures, especially during the period 10 January to 20 February as in Figure 1, should be highlighted. The frequency with which this occurred needs to be defined (i.e. the number of years with this phenomena: if there is a pattern, one year in two, three, four or five years).

Furthermore, the high temperature in November is negative. Delayed sowing shifts the critical period from January/February to February/March. For much longer delays in sowing, March temperatures assume importance.

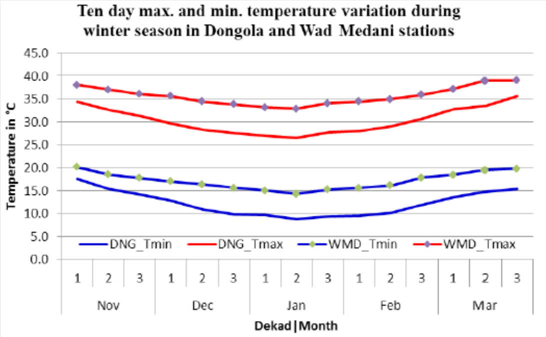
Table 1: Ten-day mean maximum and minimum temperatures from November to March for Dongola and Wad Medani stations

Station		Dongola		Wad Medani	
Month	Dekad	Tmin	Tmax	Tmin	Tmax
Nov	1	17.5	34.3	20.1	38.0
	2	15.2	32.5	18.5	37.0
	3	14.2	31.3	17.7	36.0
Dec	1	12.8	29.5	17.0	35.6
	2	10.8	28.2	16.3	34.4
	3	9.8	27.5	15.6	33.8
Jan	1	9.7	26.9	15.0	33.1
	2	8.7	26.5	14.2	32.8
	3	9.3	27.6	15.2	34.0
Feb	1	9.5	28.0	15.6	34.4
	2	10.1	29.0	16.1	34.9
	3	11.9	30.6	17.8	35.9
Mar	1	13.5	32.7	18.4	37.1
	2	14.7	33.4	19.4	38.9
	3	15.2	35.5	19.7	39.0

2.4. Varieties

Long season varieties, such as *Elaine*, are assigned for northern Sudan, while short season varieties, such as *Condor*, are grown in Central Sudan. Cultivating long season varieties in Central Sudan is risky. Insurance policies depend on information on the varieties grown and the sowing dates. Delayed sowing with short season varieties is not as serious as delayed sowing with long season varieties.

Figure 3: Ten-day normal (1981–2010) maximum and minimum temperature variation during the winter season in Dongola and Wad Medani stations in Sudan



2.4. Monitoring sowing dates and varieties

For insurance purposes, the monitoring of sowing dates and varieties is important, and this needs a large labour force. The labour force must be qualified to identify and confirm, or otherwise, the various varieties. Meteorological data is crucial for abnormally high temperatures. Fortunately, specific variation in temperatures is not great. So, only a small number of meteorological stations are needed to cover a large area: thermometers are reliable and have a long life span.

3. CONCLUSIONS

The most important issues in the Gezira Scheme are the planning of areas, sticking to the agreed sowing dates and making sure water is stopped to groundnuts by 31 October.

Choosing the appropriate varieties according to the field temperature is fundamental.

The availability of meteorological data especially maximum and minimum temperatures, and wind speed, during February and March is very important.

An ‘insurance policy’ for the farmers is a condition set by the Agricultural Bank in order to receive credit for inputs (e.g. seeds, fertilisers, weedicides and pesticides).

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31 The potential of ‘Weather health’ (WH) and ‘Daily weather and agriculture’ (DWA) concepts as insurance indices

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KEYWORDS: **roving seminars, weather health, WH, daily weather and agriculture, DWA, insurance**

SUMMARY

An evaluation study was conducted from January to December 2008 and January to March 2011 in India (Andhra Pradesh), Sri Lanka and Bangladesh to understand the outcomes of the roving seminars on adoption of weather and climate information. Around 72 % of the 2 200 farmers and students in 28 randomly selected villages and polytechnics who attended said that the knowledge they gained from ‘Weather Health’ (WH) observed through ‘Daily Weather and Agriculture’ (DWA) had been useful and that they had been able to reduce the cost of cultivation of their crops by 11 %. The remaining 28 % of farmers and students strongly believed that they had become self-reliant in dealing with weather and climate issues on their farms, but were unable to directly quantify the benefit to them. It was concluded that the WH and DWA concepts have enough potential for use as ‘weather indices’.

1. INTRODUCTION

According to Singh and Aruna (2005) the association between ‘soil’, ‘plant’ and ‘weather (atmosphere)’ by virtue of a common process or component in agricultural crop production is known as the ‘Soil-Plant-Weather continuum’. For agricultural purposes, ‘soil’ is defined as ‘A dynamic natural body or the solid portion of the surface of the earth on which plants grow’. Agricultural crops are defined as 'Plants carefully selected and developed over many years and sown on suitable land to produce food for humans and animals, wood, fibres and other materials'. 'Weather' is defined as a state or condition of the atmosphere at a particular place and given instant in time (Murthy, 1996, 2002). Crop production strategies involve all these three components.

2. THE CONCEPTS

The following concepts (Murthy, 2007a, 2007b, 2010, 2012a, 2012b) were developed to use weather as non-monetary input in agriculture.

2.1. The 'Weather Health' (WH) concept

In the 'Soil-Plant-Weather continuum', both soil and plant contain 'water' and 'air'. Therefore, they have 'life' and justify the use of the scientific terms 'soil health' and 'plant health'. However, both 'water' and 'air' are 'weather elements'. Therefore, weather has 'life' and WH for crop production is defined as 'The potential force through which weather elements perform their several and co-operative functions optimally for better crop health to produce potential yields'. In order to further determine that weather has 'health', Murthy (2012a) observed that all the weather elements:

- have a characteristic state or condition;
- constitute existence;
- participate and facilitate metabolism, growth, reproduction, etc.;
- are responsive to stimuli.

The hypothesis: Weather has 'health'. If the WH is good and optimum, then optimum agricultural crop yields are possible and vice versa.

2.2. The 'Daily Weather and Agriculture' (DWA) concept

To observe the WH, the DWA concept was used (Murthy, 2002, 2007a, 2010, 2012a) which is both an agricultural meteorological 'tool' and 'service'. In this concept, the farmers observe WH as follows.

- they collect daily weather data available in the newspapers along with pictorial diagrams and paste it on white sheets chronologically;
- wherever available, they obtain information on weather from radio, television, the Internet, mobile telephones, etc., and record the same at appropriate points on the white sheets and observe its influence on crops;
- after observing the trends of weather and its influence on crops, the WH is determined. Based on WH, the management options for all agricultural operations, namely ploughing, fertiliser application, sowing, inter-cultivation, spraying of chemicals, top dressing of fertilisers, etc., will be adopted by the farmers;

- they make use of the recommendations made available in technical handouts in the local language and in the book 'Weather Agriculture' (Murthy and Reddy, 2009).

This operational agricultural meteorological tool and service involves 'no money' because the newspapers are bought by the farmers and villagers to learn and enrich themselves on several issues (political, entertainment, medical, etc.) In Asia, daily newspapers are very inexpensive.

In an evaluation study conducted in India, Sri Lanka and Bangladesh, after organising roving seminars sponsored by WMO, it was concluded that around 72 % of the 2 200 farmers and students in 28 randomly selected villages and polytechnics who attended said that the knowledge they gained from WH observed through DWA had been useful and that they had been able to reduce the cost of cultivation of their crops by 11 %. The remaining 28 % of farmers and students strongly believed that they had become self-reliant in dealing with weather and climate issues on their farms, but were unable to directly quantify the benefit to them (Murthy, 2012b).

2.3. Growing Degree Days

Next to WH, DWA and rainfall probabilities, the concept of Growing Degree Days (GDD) was also used in the 'Weather-Agriculture' book (Murthy and Reddy, 2009) and in technical handouts in the local Telugu language.

By definition 'Degree days' are summations of mean temperatures over a base temperature (Nuttonson, 1955). The GDD is also known as 'Heat units', 'Thermal units', 'Effective heat units', 'Growth units', etc. The accumulations are made on a daily basis and cover phenological events of crop plants or intervals between dates (McMaster, 1997; Chakravarty and Gautam, 2002).

The concept assumes that:

- there is a direct and linear relationship between the growth of a crop plant and air temperature (Nuttonson, 1955);

- a crop requires a definite amount of accumulated heat energy for optimum crop yields (Chakravarty and Gautam, 2002);

- the biotic potential of an agricultural crop plant is dependent on the heat requirement for its growth, development, reproduction, grain yield, etc. (Pruess, 1983).

2.4. The canonical form for calculating GDD

The canonical form, prescribed by McMaster (1997), for calculating GDD is:

Degree days (^{0}D) = $\Sigma\{ (T\,max + T\,min)/2 - T\,base\}$

where:

T max and T min represent the daily maximum and minimum temperatures, respectively; and T base is the base temperature.

Usually, degree days are expressed as ‘^{0}D’ to distinguish them from temperature units.

2.5. The base temperature

The base temperature is below that at which the internal metabolism activities of crop plant cease to function. Though the base temperature varies from crop to crop, it is constant for a specific crop. In India, during *Kharif* season (south-west monsoon crop season), the base temperature is taken as 10 °C and for *Rabi* (north-east monsoon season crop), the base temperature is taken as 5 °C (Murthy, 2002).

2.6. Advantages and importance of GDD

The GDD is a small and simple concept relating plant growth, development and maturity to the air temperature. The growth of plant is dependent on the total amount of heat to which it is subjected during its lifetime. The GDD is useful in many ways:

- guiding all the agricultural operations, land-use planning, etc.;
- forecasting crop harvest dates, yield and quality;
- forecasting labour required for agricultural operations;
- introducing of new genotypes in new areas;
- predicting the likelihood of successful growth of a crop in new areas;

2.7. The most successful example of GDD concept

Chakravarty and Gautam (2002) were highly successful in developing weather-based fore-warning models and rules in northern India for indicating the qualitative level of infestation of mustard aphid well before any damage appeared. They concluded that, in any year, if the accumulated degree-days from 1 January to 15 January is around 90 (^{0}D), then, it is possible that the year could be a high infestation year. On the other hand, if the degree-days are around 140, there could be a low infestation year.

2.8. The Comparison Concept

The Comparison Concept (Murthy, 2007a) takes into account the past 7–10 days of weather and climate as well as the forecast for 7–10 days, and derived parameters (GDD, PTU and

HTU [1]) as the basis for forewarning. These derived parameters are compared with the scenarios of past seasons or years and a suitable set of common similarities on crop yield, incidence and vigour of pests and diseases and their influence on crop performance are derived. This scientific information helps to determine both ongoing and future scenarios of occurrence and incidence and vigour of pests and diseases, crop yields, etc. This concept is also useful to develop rules of thumb. Farmers adopt appropriate management options based on technical handouts.

3. CROP INSURANCE

Insurance is a ‘tool’ to protect ‘subjects’ against a small probability of a large unexpected loss. It is also a ‘technique’ to provide ‘subjects’ with a means to transfer and share risk where losses suffered by a few are met from the funds accumulated through small contributions made by many who are exposed to similar risks. There are two insurance schemes followed across the world.

3.1. Traditional and general crop insurance

This is a means of protecting farmers against financial losses arising from named or all unforeseen perils beyond their control. The payout structures are developed specifically to indemnify the farmers against shortfall in crop yield.

3.2. Weather-based crop insurance

This is another means that uses the influence and effect of weather elements as ‘proxy’ for crop yields in compensating the deemed crop losses by farmers. The payout structures are developed to compensate farmers to the extent of the losses deemed to have been suffered by them using weather triggers.

4. UTILITY OF WH AND DWA IN CROP INSURANCE

Reddy (2002) and Hess (2007) emphasised that to estimate a ‘weather index’ that relates to crop yields, it is essential to have a suitable model that integrates ‘Soil-Plant-Weather’. The WH and DWA concepts fulfil these conditions and can, therefore successfully be used in both traditional crop insurance and weather-based crop insurance schemes.

1 Heliothermal Unit (HTU) and Photothermal Unit (PTU).

4.1. Additional advantages to farmers

The farmers who insured their crops are advised to observe their ‘crop health’ based on WH through DWA. The additional advantages to the farmers are:

- ‘weather-wise” cultivation of their crops;
- use of weather as a ‘non-monetary’ input to all their agricultural operations;
- the understanding of which weather elements exert influence (positively and negatively) at which phenological stages of their crops;
- they become agricultural scientists in their own right, through field experience if limited formal training is given;
- above all, they understand clearly what the ‘influence and effect’ of weather can be and what the ‘impact’ is, and whether the monetary benefit they receive is ‘correct or otherwise’.

4.2. Modifications to GDD

To further enhance the biological meaning and wider area coverage of GDD applications in WH and DWA concepts, the following modifications are suggested:

- converting GDD into HTU and PTU;
- use of heliothermal units: GDD x number of actual sunshine hours;
- use of photothermal units: GDD x day length (hours, the product of degree day and day length or any day);
- incorporation of an upper temperature threshold (Gilmore and Rogers, 1958; McMaster and Smikar, 1988);
- using only the maximum or minimum temperature or position of the day (Cross and Zuber, 1972);
- incorporating functions for other environmental factors that affect phenology or the process being considered (McMaster, 1995; McMaster and Wilhelm, 1995).

5. CONCLUSIONS

The WH and DWA concepts have enough potential to be used as ‘weather indices’ (Murthy, 2010, 2012a, 2012b).

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32 Remote sensing of vegetation: potential applications for index insurance

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KEYWORDS: **optical remote sensing, agriculture, index insurance, anomaly indicators, high temporal resolution**

SUMMARY

In food insecure regions of the world, index insurance can represent an effective instrument to improve farmers' access to credit and foster investments aimed at increasing crop productivity (e.g. fertilisers, high-yielding seeds and other technologies). Insurance indexes are usually based on rainfall measurements from weather stations. However, there is often a shortage of rainfall data because of the sparse network of meteorological stations in developing countries. Earth Observing (EO) systems providing optical imagery with high temporal resolution can be used to fill this gap and deliver timely information on actual crop and pasture development for the design of index insurance indicators. Opportunities and challenges of remote sensing indicators are discussed in this contribution.

1. INTRODUCTION

Crop index insurance is a financial product in which the indemnity payout depends on an index related to potential yield performance rather than directly on the actual yield loss. The index is usually based on rainfall data (with payout triggered below and above defined thresholds) or on other types of crop yield proxies (i.e. evapotranspiration). Such insurance products can have a positive effect in food insecure regions with high climatic variability because it can reduce the risk associated with crop failure and facilitate access to credit, thus allowing farmers to improve cropping techniques (Brown et al., 2011).

In developing countries, methods based on meteorological data are limited by the scarcity of networks of weather stations, discontinuity of measurements and reduced availability of long-term time series. In this context, satellite remote sensing (RS) can provide an easily accessible and independent source of information about crop development across large regions (see Ceccato et al., 2008, for a discussion focused on the index insurance topic).

Different techniques and Earth Observation (EO) instruments are currently used to derive vegetation biophysical parameters and rainfall estimates, both products being of potential interest to index insurance. This contribution focuses on optical satellite RS for monitoring vegetation status.

2. RS OF VEGETATION

Vegetation development can be remotely monitored making use of Vegetation Indexes (VIs) that are a mathematical combination of the signal collected in the visible and near infrared regions by space-based instrument. Among other VIs, the Normalised Difference Vegetation Index (NDVI, Rouse et al., 1974) is commonly employed for this purpose. VIs are well suited to be indicators for crop and pasture index insurance because they estimate the actual vegetation standing biomass and growth, are measured daily by many different sensors, and time-series of up to 30 years of observations are available today. Drawbacks include the difficulty of coping with changes in technology and design of the sensors from the 1980s to the present, with enormous advancements in resolution and accuracy through time.

Although VIs provide a robust proxy of biophysical activity of plants at a wide variety of scales, there are optical properties that can be affected by several confounding factors such as the background reflectance (e.g. soil humidity), the three-dimensional structure of the canopy and the view and illumination geometry. For these reasons, many users prefer to use modern RS products derived from radiative transfer techniques able to give access to key vegetation properties that are largely free from external factors (Pinty et al., 2009). Among these, the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR, the capacity to absorb radiation driving the photosynthetic process) is a key variable that acts as an integrated indicator of the status and health of vegetation and plays a major role in modelling the gross primary productivity of vegetation.

Rainfall information (from weather stations or satellite estimates) represents, instead, one of the drivers of vegetation growth, and, despite a clear agreement with RS biophysical products in dry ecosystems, the relationship between the two variables is not linear. In fact, several factors may mediate the relation between precipitation and actual growth, among others: intensity and temporal distribution of rainfalls, soil water recharge, and other meteorological drivers such temperature or incident radiation, nutrient availability, and disturbances. Thus, although the two measurements can both be used for index insurance, they should be viewed as complementary.

Finally, it's worth noting that RS indicators can be effectively used to monitor biomass production — essential for characterising pasture production — but they can only be used as proxy of crop yield. In fact, final crop yield in terms of seed production depends upon a range of factors (e.g. nutrients, water stress during critical phenological stages, pests and diseases occurring after crop maturity) that are not captured by RS and have to be modelled with empirical relationships with ground observations. Since index insurance products insure growing conditions and not the actual yield obtained by a farmer, this is acceptable.

3. TEMPORAL V SPATIAL RESOLUTION

EO systems generally show a trade-off between the spatial and temporal resolutions: a high spatial resolution is associated with a low temporal resolution (frequency of revisiting time) and vice versa. High spatial resolution EO systems can offer pixel sizes of less than 1 m at the expense of a revisiting time of several weeks. This type of imagery is better suited for crop identification and mapping of major disturbances (e.g. floods, fires) than for continuous monitoring of vegetation development. At the other extreme of this resolution trade-off, geostationary meteorological satellites provide nearly continuous observations of the same area at the cost of a low spatial resolution (a few kilometres). Between these systems, low to moderate resolution sensors (e.g. MODIS, SPOT-VGT) provide daily revisiting frequency and a spatial resolution ranging from 250 m to 1 000 m. Although these spatial resolutions are not optimal for small agricultural systems, they observe the landscape daily, which is suitable for monitoring the development of vegetation. In addition, long-term time series of observations usually needed to develop index insurance indicators are available (11 years, 13 years and more than 30 years for MODIS, SPOT-VGT, and NOAA-AVHRR, respectively). Finally, they are promptly available and usually free.

4. ANOMALY INDICATORS FOR INDEX INSURANCE

Low spatial resolution satellite imagery has been extensively used for crop and pasture monitoring for over 20 years (see Rembold et al., 2010, for a review). A commonly used approach relies on the comparison of the actual crop status, as indicated by a selected RS indicator, to what can be assumed to be the normal condition (the 'long-term' average computed on the available RS time series). In order to ensure data continuity and exploit longer time series, the inter-calibration of RS indicators from multiple EO instruments with similar design to build consistent time series has been proven feasible (e.g. Brown et al., 2006).

Under the assumption that, at a given location, production tends to follow an average pattern, it is possible to design a RS-based insurance scheme that protects against a decline in the RS biophysical indicator. Thus, reimbursement could be triggered if the indicator for the insured season negatively deviates from the average. A number of research issues have to be defined in order to adopt this simple scheme. Firstly, besides choosing the RS indicator, the timing of the analysis plays a crucial role in the final results. In fact, several solutions are possible for the

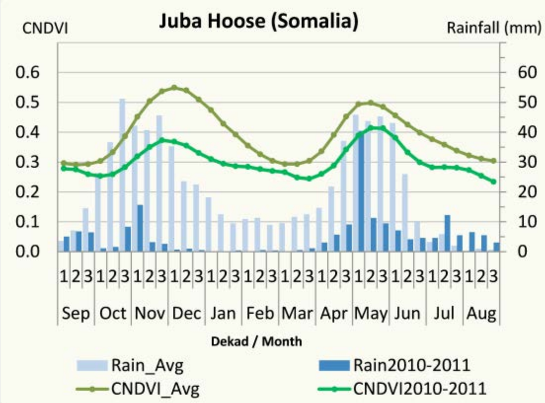


Figure 1: SPOT-VGT NDVI and TAMSAT rainfall estimates temporal profiles of the seasons 2010–11 compared with the 'long-term' average (1998–today)

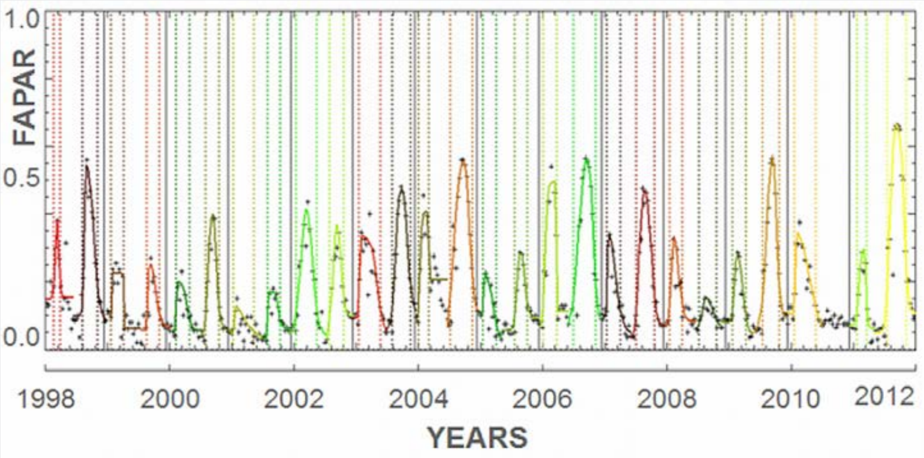
comparison of the current season with long-term average, for example: fixed timing or period; timing of the maximum value of the RS indicator attained during an expected growing period; overall evolution during the actual growing period. In particular, the latter indicator requires the retrieval of actual vegetation phenology (start and end of growing season) from the RS data and it is thus expected to be robust to possible anticipation or delays of the growing period. Secondly, the definition of the threshold used to trigger reimbursement has to be defined carefully, and tuned to bear in mind the local inter-annual variability. Finally, once the index is defined, its reliability has to be assessed through validation against ground observations of actual yield.

5. CURRENT USE OF ANOMALY INDICATORS

Anomaly indicators are routinely used by various organisations (e.g. FEWSNET, Famine Early Warning System of USAID; FAO, Food and Agriculture Organisation of the UN; JRC-MARS, Monitoring Agricultural Resources Unit, Joint Research Centre of the EC) to generate frequent crop status reports used for food security assessment. As an example, Figure 1 shows that the 2010–11 seasons for a given location in Somalia experienced poor growing conditions with respect to average.

Anomaly computation methods based on the automatic recognition of vegetation phenology (Meroni et al., 2012) may also be applicable to index insurance purposes. Such methods use the RS observations time series to document the timing of the start and end of the season. Such phenological events are afterwards exploited to compute the cumulative RS indicator during the season, a proxy of total gross primary productivity, for every season in the time series (Figure 2).

Figure 2: Retrieval of phenology from Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) time series using a model-fit approach. The time series refers to a location in Somalia characterised by two growing seasons per year (SPOT-VGT data, 1 km spatial resolution).



The anomaly for the season of interest *i* can be expressed as standard score (Z-scores):

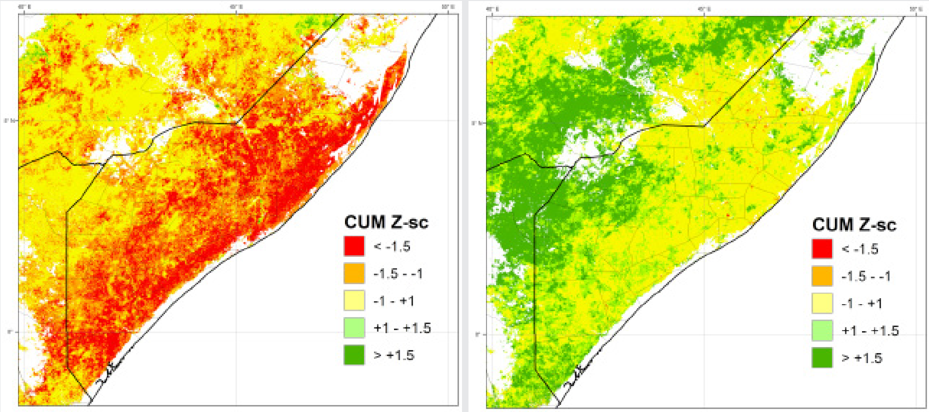
$$Z_i = \frac{x_i - \mu}{\sigma}$$

where μ and σ denote the mean and standard deviation of the time series of the variable *x* (i.e. cumulative RS-indicator over the seasons).

Under the assumption of normal distribution, Z-scores are a convenient way to measure anomalies since deviations from the mean are weighted by their inherent variability. Anomalies at different locations and at different times can then be then compared in terms of how extreme they are. With direct application to index insurance, the Z-score of a given season estimates the probability of occurrence of the observed condition at the same location with respect to its distribution, as observed for the previous years in the time series. For example, a Z-score of − 1.5 for the last season indicates that, according to the long-term time series distribution, the probability of observing a smaller value is 6.7 %.

By repeating such analyses for each pixel belonging to the region of interest, it is possible to map the indicator anomalies in terms of Z-scores, as in the example in Figure 3 showing very poor and average to above average vegetation conditions in Somalia for the *Deyr* season 2010 and 2011, respectively.

Figure 3: South Somalia, cumulative Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) anomalies for the *Deyr* season in 2010 (left) and 2011 (right) (SPOT-VGT, 1 km spatial resolution)



Deriving anomalies can help analysts to determine the locally-relevant threshold that may be applied to a particular location, even if payout is based on high resolution imagery such as Landsat (30 m) or SPOT (10 m). Anomalies let communities know what the growing conditions were during a similar year or during the worst year in the past decade, and relate them to the upcoming year, enabling the derivation of a threshold for payout that is acceptable to all.

6. CONCLUSIONS

The use of RS for index insurance presents both opportunities and challenges. Unlike meteorological indicators such as rainfall that estimate the potential vegetation growth, RS-based biophysical indicators track the actual biomass development. An approach based on RS anomaly indicators, exploiting long-term time series of low spatial resolution EO data, may be suited to the development of cost-effective index insurance indicators. Based on this approach, the design of various anomaly indicators is possible so that a correct and scientifically sound selection of the index is of utmost importance. Since index insurance requires a post-season assessment, methods exploiting the RS observations of the whole growing period are likely to be more useful. For this purpose, vegetation phenology cannot be considered a priori known and constant. A more realistic approach based on the retrieval of variable phenological events from the RS observations can be implemented.

With index insurance, farmers would not be reimbursed if harvests actually fail but only if the biophysical index exceeds the predefined thresholds. Therefore, besides the index design, the definition of reference values and thresholds used to trigger the insurance payout is a critical step. Finally, the validity of the RS-based scheme for the insured crop must be rigorously assessed and validated.

RS products can also be used to assist and complement the analysis based on meteorological indexes, for example by using spatially distributed phenological data to tune the period for cumulative rainfall computation. Additionally, RS-based anomaly maps can be employed to cross-check the usability of a selected weather station for the computation of the insurance meteorological index at a particular farmer's location. Significant anomaly differences between the farmer's location and the station would indicate that the station is not representative of the climatic conditions experienced by the insured crop.

The use of RS in index insurance schemes also has known limitations. VIs and RS biophysical products estimate the green biomass of vegetation, not the seed productivity. Possible yield reductions unrelated to biomass underdevelopment must be modelled or taken into account in the insurance scheme. Additionally, the low to moderate spatial resolution (250–1 000 m) of current high temporal resolution EO systems enables the monitoring of the landscape rather than single fields. However, this may not be a critical issue for index insurance that is focused on average crop performances attained in a given area.

RS of vegetation represents a promising tool for index insurance. A comparison of rainfall-based indices and ground validation of RS-based indices is needed to evaluate the reliability of the method.

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33 Feasibility of using the FAO Agricultural stress index system (ASIS) as a remote sensing-based index for crop insurance

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SUMMARY

Drought is one of the most frequent climate-related disasters occurring across large portions of the world, often with devastating consequences for the food security of agricultural households. This study proposes a novel method for calculating the empirical probability of there being a significant proportion of the total agricultural area affected by drought at sub-national level. Firstly, we used the per-pixel Vegetation Health Index (VHI) from the Advanced Very High Resolution Radiometer (AVHRR) averaged over the crop season as the main drought indicator. A phenological model based on the Normalised Difference Vegetation Index (NDVI) was employed for defining the start of season (SOS) and end of season (EOS) dates. Secondly, the per-pixel average VHI was aggregated for agricultural areas at sub-national level in order to obtain a drought intensity indicator. Seasonal VHI averaging according to the phenological model proved to be highly correlated with the drought events recorded during the period (1981–2009) and is, therefore, a valid drought indicator for the African continent. The final results express the empirical probability of drought occurrence over both the temporal and the spatial domain, representing a promising tool for future drought monitoring and for developing a remote sensing based index for crop insurance.

1. INTRODUCTION

Droughts can have devastating effects on water supply, crop production and rearing of livestock. They may lead to famine, malnutrition, epidemics and the displacement of large populations from one area to another. The Global Information and Early Warning System on Food and

Agriculture (GIEWS) of the Food and Agricultural Organisation (FAO) of the United Nations is the leading source of information on food production and food security for every country in the world. The GIEWS, located in the Trade and Markets Division (EST), and the Climate, Energy and Tenure Division (NRC) aim at developing an Agricultural Stress Index System (ASIS) for assessing agricultural areas with a high likelihood of water stress (drought) on a global scale. This system is being established in collaboration with the Flemish Institute for Technological Research (VITO-TAP) and the Monitoring Agricultural Resources (MARS) unit of the Joint Research Centre of the European Commission (JRC).

The core of the ASIS has been developed and described by Rojas et al. (2011). This study, which was limited to the African continent, was a 'single shot' exercise mainly based on the 16 km resolution weekly composite images derived from NOAA-AVHRR, provided freely by the NOAA Center for Satellite Applications and Research (STAR). The main challenges now consist in the extrapolation of the system to the global scale and in the use of near-real time dekadal 1 km resolution data of METOP-AVHRR, as provided by VITO.

To develop a remote sensing-based index appropriate for crop insurance, some minor adaptations to the ASIS are needed. It is proposed using the percentage of agricultural land affected by drought at administrative level as an index for paying off the indemnity.

2. MATERIALS AND METHODS

2.1. Data

The main data proposed for developing the index-based insurance is the Vegetation Health Index (VHI) derived from the existing long-term time series of NOAA-AVHRR data. This data set produced by the Center for Satellite Applications and Research (STAR) of the National Environmental Satellite, Data and Information Service (NESDIS), consists of weekly VHI images at 16 km resolution for the period 1981 (week 35)–2010 (week 11) [(1)].

It could be possible to use the METOP-AVHRR at 1 km resolution but since the historical archive of METOP starts only in 2007, an inter-calibration with NOAA-AVHRR sensor data would be necessary.

Two additional spatial data sources are needed for aggregating the VHI over space: a global agricultural crop mask and administrative regions boundaries. In the case of crop insurance, a more detailed crop mask for the area of interest should be used.

1 http://www.star.nesdis.noaa.gov/smcd/emb/vci/VH/vh_ftp.php

2.2. Methodology

2.2.1. Vegetation Health Index (VHI)

For drought assessment, we selected the Vegetation Health Index (VHI) developed by Kogan (1995, 1997). This index has been successfully applied in many different environmental conditions around the globe, including Asia (Kogan et al., 2005; Ramesh et al., 2003), Africa (Unganai and Kogan, 1998), Europe (Kogan, 1986), North America (Kogan, 1995; Salazar et al., 2007), and South America (Seiler et al., 2007). VHI is a composite index combining the Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI). The VCI (Kogan, 1994) is a scaling of the Normalised Difference Vegetation Index (NDVI) between its maximum and minimum value according to the following formula:

$$VCI_i = 100^* (NDVI_i - NDVI_{min}) /(NDVI_{max} - NDVI_{min})$$

where:

$NDVI_i$ is the smoothed weekly NDVI; and
$NDVI_{max}$ and $NDVI_{min}$ are the absolute maximum and minimum NDVI, respectively, calculated for each pixel and week during the period 1981–2010 from the smoothed NDVI.

The VCI was designed to separate the weather-related component of the NDVI from ecological factors (Kogan, 1994). It not only reflects the spatial and temporal vegetation variability of vegetation but also allows the impact of weather on vegetation (Kogan, 1994; Unganai and Kogan, 1998) to be quantified. In general, the VCI captures rainfall dynamics better than the NDVI, particularly in geographically heterogeneous areas.

The TCI is similar to the VCI, but uses the brightness temperature *T* estimated from the thermal infrared band 4 of AVHRR instead of the NDVI. Kogan (1995) proposed this index to remove the effects of cloud contamination in the satellite assessment of vegetation condition due to the fact that AVHRR channel 4 is less sensitive to water vapour in the atmosphere compared to the visible light channels. High temperatures in the middle of the season indicate unfavourable or drought conditions, while low temperatures indicate mostly favourable conditions (Kogan, 1995). The expression, consequently, is:

$$TCIi = 100^*(T_{max} - T_i)/(T_{max} - T_{min})$$

VHI combines VCI and TCI for week i according to:

$$VHI_i = w1^*VCI_i + w2^*TCI_i$$

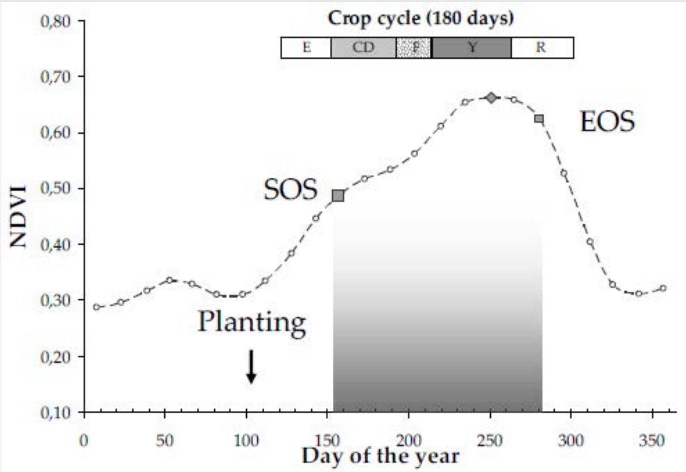
where w1 and w2 are weights summing to 1 so as to bound VHI between 0 and 1.

These weights may be adjusted according to the phenological stage to place more significance on vegetation biomass or temperature. For example, Unganai and Kogan (1998) determined the weights based on the correlation between the VCI and the TCI with corn yield anomalies. In near normal conditions, vegetation is more sensitive to moisture during canopy formation (leaf appearance) and to temperature during flowering. Since moisture and temperature contribution during the crop cycle is currently not known, we assume that the share of weekly VCI and TCI is equal (w1 = w2 = 0.5). However, for the stand-alone version of ASIS for crop insurance applications, these coefficients should be adjusted using national agricultural statistics.

2.2.2. Determination of the optimal VHI integration period for agricultural areas (temporal aggregation)

The VHI can detect drought conditions at any time of the year. For agriculture, however, we are only interested in the period most sensitive for crop growth (i.e. the vegetative stage after the crop establishment, till flowering and grain filling) (Doorenbos and Kassam, 1979). To determine the most sensitive period, we first derived the start of season (SOS) and end of season (EOS) from the NDVI time series. For this, we used the 50 % and 75 % thresholds respectively. In short, for each pixel, we first determine per year the maximum NDVI value and the preceding minimum NDVI value. The SOS is defined as the moment when NDVI reaches 50 % of the NDVI amplitude (i.e. maximum – minimum) while the EOS is the moment after maximum when the NDVI curve reaches 75 % of the amplitude (Figure 1). A double season was only retained for those administrative units where at least 50 % of the pixels allow for a good separation between two seasons (i.e. the presence of two clear minima and maxima).

Figure 1: NDVI profile showing the period of analysis defined by the start of the season (SOS) and the end of season (EOS). The crop cycle is divided into five development stages: E: establishment; CD: crop development; F: flowering; Y: yield formation or grain filling; and R: ripening stage. Stages CD, F and Y are the most sensitive to water deficit.



2.2.3. Geographic VHI aggregation

In a second stage, in order to directly identify the administrative units affected by agricultural drought, we determined what percentage of the unit's agricultural area experienced VHI values below 35 during the crop season. This threshold, introduced by Kogan (1995) to identify drought conditions, was obtained by correlating the VCI with different crop yields under diverse ecological conditions. However, it is highly recommended that a specific calibration of this threshold be carried out in the region or country where the index-based insurance will be applied. Within each administrative unit, the analysis was limited to agricultural areas based on the crop mask mentioned in Section 2.1. Only pixels having at least 25 % of crop land were considered. A weighted average (with weights equal to the percentage of crop land) was calculated for each administrative region. Regions were excluded in case less than 10 valid pixels (i.e. with at least 25 % of crop land and with a valid VHI) were present (Genovese et al., 2001).

The final results were aggregated at sub-national administrative level in order to allow easy comparison with existing agricultural production statistics.

2.2.4. Probability mapping

In order to compute the probability of drought affecting significant portions of the agricultural area of each administrative unit, we introduced two minimum arbitrary thresholds, one of 30 % and another of 50 %. In practice, when over 30 % of the total agricultural area of an administrative unit is affected by drought, we assume that a large number of agriculture households are impacted by drought. When more than 50 % of an agricultural area is affected by drought, we assume an extreme drought event with serious impact on regional food security. These thresholds could be adjusted depending of the crop insurance to be implemented. We assume that the occurrence of a certain percentage of area affected by drought in year *t* is independent on climate in other years. If *P* is the probability of a drought event, the number *n* of years that the event happens in a period of *N* years follows a binomial distribution (Evans et al., 2000).

3. RESULTS

Figure 2 shows an example of the transformation of the VHI averaged during the crop season 1983/84 at pixel level into the percentage of agricultural areas affected by drought (VHI below 35) at sub-national level.

Averaging the VHI over time shows the drought persistence during the cropping season. In addition, by calculating the percentage of agricultural area affected by drought, we analysed the spatial impact of the drought at sub-national level for each crop season during the study period. The temporal and spatial aggregations give a good estimate of the drought intensity during the most water stress sensitive stages of crops.

Figure 2: (A) Average VHI image for the crop season 1983/84; (B) percentage of agricultural area affected by drought (VHIb35) based on (A). The average crop season VHI shows the temporal impact of drought while the percentage of affected agricultural area explains the spatial dimension of the drought.

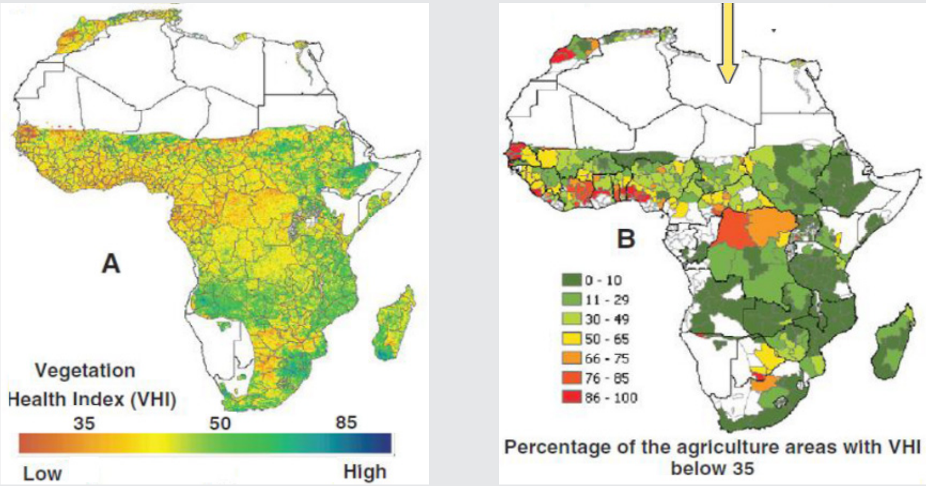
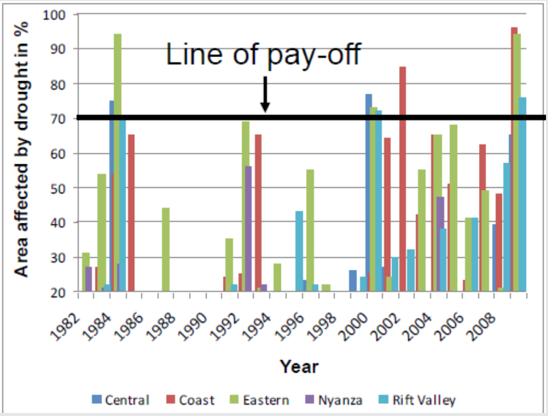


Figure 3 shows a hypothetical case of pay-off at sub-national level for Kenya based on the spatial and temporal integrated remote sensing index defined as an 'agricultural area affected by drought in percentage'. In this case, the line of pay-off was arbitrary defined as when 70 % of the agricultural area in a province is affected by water stress. Thus, the insurance will pay out in 1984 and 2000 to the farmers in the Central, Eastern and Rift Valley provinces; in 2002, it would pay out only in the Coast province; and, in 2009, it would pay out in the Coast, Eastern and Rift Valley provinces. In the time series analysed, the Eastern and Rift Valley provinces have a higher probability of being affected by drought than the Central and Coast provinces. Therefore, farmers in the Nyanza province will not be interested in signing a contract at a 70 % line of pay-off. The insurance contract for Nyanza province could use the 40 % line of agricultural area affected by drought as a trigger; in this case, the farmer would be paid in 1992 and 2004. The crop insurance could be adjusted with the percentage of area affected by drought and the premium of the insurance to reach an agreement with the farmers of each province.

Figure 3: Hypothetical case of pay-off at province level, using the line of 70 % of agricultural area affected by drought in Kenya (1982–2010)



4. CONCLUSIONS

The proposed methodology could prove helpful in developing remote sensing index-based insurance for food security in developing countries. It is based on per pixel analysis of drought indicators that takes into account both the temporal and spatial integration of drought. The proposed remote sensing index will work better in countries with semi-arid conditions where water stress is the main limiting factor of agriculture production

With respect to weather station-based indices, a remote sensing-based index presents the advantage of exhaustive ground coverage. On the other hand, rainfall estimates derived from remote sensing or general climate circulation models present the disadvantage of over/underestimating rainfall; in this case, we prefer to consider the NDVI as a proxy for assessing the crop condition (which itself depends on the water available to the crop). However, there are some well-known limitations to remote sensing as the NDVI is affected by soil humidity and surface anisotropy. Composite products used in most applications tend to limit these effects that cannot be ignored completely.

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34 Integrating drought and satellite-based indices in support of risk management and insurance in East Africa

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SUMMARY

Drought occurs in every part of the world and adversely affects the lives of millions of people each year, causing significant damage to economies, the environment, and property. Remote sensing observations are now being used to monitor various aspects of the terrestrial environment that are influenced by drought including vegetation health, evapotranspiration (ET), soil moisture, and groundwater. Over the past decade, the launch of many new satellite-based remote sensing instruments coupled with advances in computing and analysis techniques has led to the rapid development of many new tools that hold considerable promise for drought monitoring in addition to the traditional climate-based drought indices. This paper highlights two of these emerging integrated tools that may help in risk management and insurance: (i) the Vegetation Drought Response Index (VegDRI); and (ii) a predictive vegetation condition tool called the Vegetation Outlook (VegOut). These tools were developed for the continental United States. The specific methodologies and products are also briefly discussed. Future opportunities and considerations for integrating remote sensing information into operational drought monitoring and risk management in East Africa are highlighted.

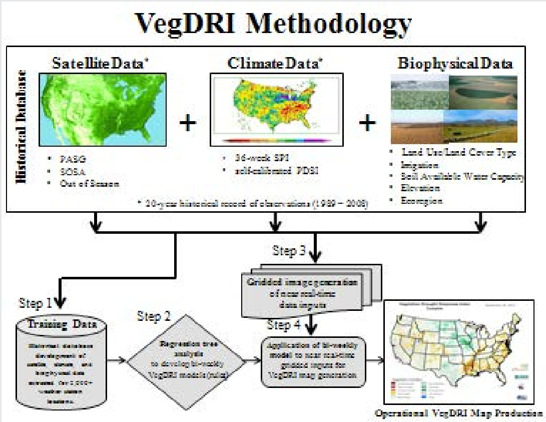
1. INTRODUCTION

Traditionally, climate-based drought indicators such as the Palmer Drought Severity Index (PDSI) and Standardised Precipitation Index (SPI) have been used for drought monitoring. However, climate-based drought monitoring approaches have a limited spatial precision at which drought patterns can be mapped because the indices are calculated from point-based meteorological measurements collected at weather station locations. In addition, weather stations are scarce in remote areas and not uniformly distributed. As a result, climate-based drought index maps depict broad-scale drought patterns that are produced from point-based data using statistic-based spatial interpolation techniques, and the level of spatial detail in those patterns is highly dependent on the density and distribution of weather stations. Therefore, the spatial detail in climate-based drought index maps is limited because of the dependence on uneven and sparse weather station distributions, which limits drought planning and monitoring activities in areas not well covered by weather stations.

On the other hand, in the past three decades, remote sensing has proven useful for large-area vegetation monitoring given the synoptic coverage, high temporal repeat cycle, and continuous, moderate resolution observations of satellite-based sensors. In particular, time-series Normalised Difference Vegetation Index (NDVI) data from the global imager, the Advanced Very High Resolution Radiometer (AVHRR), has been widely used for vegetation and ecosystem monitoring (Tucker et al., 1985; Jakubauskas et al., 2002). Analysis of time-series NDVI data and NDVI-derived metrics have been an effective means for identifying vegetation condition anomalies (e.g. apparent declines in vegetation health). As a result, time-series AVHRR NDVI data have proven to be a useful indicator of general vegetation stress and have been routinely integrated into drought monitoring activities throughout the world. Tucker et al. (1985) were one of the first to demonstrate the utility of AVHRR NDVI data for this application over Africa's Sahel Region and, since that work, this index has become a staple of operational monitoring programmes such as the Famine and Early Warning System (FEWS). Although these numerous operational products have been useful for vegetation monitoring, they are limited for effectively characterising the impact of drought on vegetation because the anomalies caused by drought stress cannot be discriminated from anomalies produced by other environmental causes of vegetation stress (e.g. flooding, fire, pest infestation, and hail damage) and anthropogenic drivers (e.g. land cover/land-use conversion). Additional information is required to discriminate the drought-impacted areas from locations where the vegetation is being influenced by these other environmental and anthropogenic factors.

The Vegetation Drought Response Index (VegDRI) and the Vegetation Outlook (VegOut) are new drought monitoring and prediction tools that integrate satellite-based NDVI observations, climate-based drought index data, and several biophysical characteristics of the environment to produce an indicator that expresses the level of drought stress on vegetation. VegDRI integrates concepts from both the remote sensing-based NDVI and the climate-based drought index approaches to produce 1 km resolution maps that characterise the intensity and spatial pattern of drought-induced vegetation stress over large areas. In the VegDRI approach, the 1 km NDVI images provide detailed spatial patterns of vegetation conditions, which are analysed in combination with dryness information represented in the climate-based drought index data to identify and characterise the intensity and spatial extent of drought conditions. Biophysical parameters such as the land cover type, soil available water-holding capacity, irrigation status, and ecological setting of an area are also analysed because these environmental characteristics can influence specific climate-vegetation interactions. VegDRI was developed in a collaborative research effort between the National Drought

Figure 1: The Vegetation Drought Response Index (VegDRI) Methodology



Mitigation Center (NDMC) and the US Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center and is designed to be a near-real time, national drought monitoring tool for the conterminous United States. The 1 km VegDRI maps depict more spatially detailed, drought-specific information related to vegetation than traditional drought monitoring tools. In addition, this information is provided, at relevant spatial and temporal scales, to decision-makers working at the local to national level. The VegOut is an experimental product that provides the outlook for up to 6 weeks. These two monitoring and predictive tools and their potential application to risk management and insurance are briefly discussed below.

2. VEGETATION STRESS MONITORING AND PREDICTION INDICES

2.1. VegDRI

VegDRI is a new hybrid vegetation index (VI) for drought monitoring, developed by the NDMC and the USGS for the United States (Brown et al., 2008). VegDRI integrates traditional satellite-based NDVI observations and climate-based drought index data along with general biophysical information about the environment to detect 'drought-related' vegetation stress.

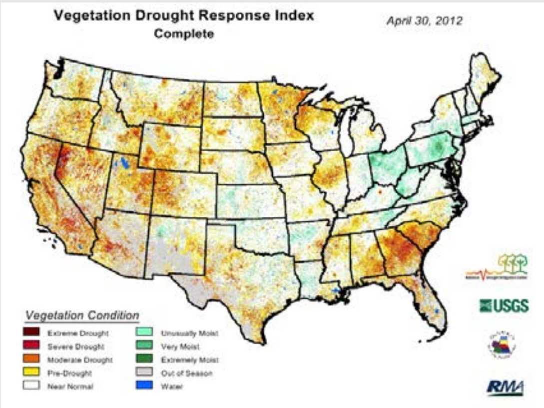
VegDRI is designed to discriminate drought-related vegetation stress from stress resulting from other types of environmental factors such as fire, flooding, pest infestation, plant disease, and land cover change that mimic a drought signal.

Figure 1 shows the methodology that VegDRI uses — including the high resolution 1 km AVHHR NDVI-derived variables (e.g. percentage of annual seasonal greenness and start of season anomaly) — to acquire information about the spatial distribution and general condition of vegetation. Two climate-based drought indices, the modified Palmer Drought Severity Index (PSDI) (Palmer, 1965; Wells et al., 2004) and the Standardised Precipitation Index (SPI) (McKee et al., 1995), are also included in VegDRI as measures of broad-scale dryness across the landscape to complement the higher resolution, 1 km NDVI-related vegetation information. VegDRI also incorporates several general biophysical variables that include ecoregion, elevation, irrigation status, land use/land cover type, and soil availability water capacity. Each of these biophysical characteristics was integrated into VegDRI because they can influence the sensitivity of vegetation in a given location to drought stress.

The four-step process in Figure 1 shows that biweekly, empirical-based VegDRI models were developed across the calendar year (26 total periods) by applying a regression tree analysis technique to a 20-year historical record (1989 to 2008) of AVHRR NDVI, PDSI, and SPI data and the biophysical variables (which remained static over the time period) for 2 400 weather station locations distributed across the CONUS [1].

The period-specific models are then applied to current NDVI observations and climate-based drought index data for the corresponding biweekly period while holding the biophysical variables constant to operationally produce 1 km VegDRI maps in near real-time for the CONUS (Figure 2).

Figure 2: A 1 km resolution VegDRI map over the contiguous United States for 30 April 2012



1 Contiguous United States.

Figure 2 presents an example of a VegDRI map over the CONUS for 30 April 2012. VegDRI detected major areas of severe to extreme drought conditions in the western United States (i.e. California, Nevada, Oregon, Utah, Wyoming, and western Colorado) and south-eastern United States (i.e. Alabama, Georgia, South Carolina, and northern Florida). Additional VegDRI maps for other dates can be found on the Internet [2]. As seen in Figure 2, VegDRI classifies several levels of vegetation drought severity based on a modified version of the PDSI classification scheme. The classification system used in VegDRI contains four classes of drought severity in addition to a pre-drought category (i.e. dry end of the near-normal range), as well as four non-drought classes representing near-normal to above-normal vegetation conditions. The 'out of season' class, which is defined based on the analysis of time-series AVHRR NDVI data, represents locations where VegDRI values were not calculated because a green vegetation signal has not been historically detected at that time in the satellite observations. Omitting VegDRI calculations over these 'out of season' areas is very important during the dormant non-growing season months and for locations with extremely sparse vegetative cover (e.g. south-western United States in Figure 2) in order to avoid a 'false positive' drought signal from being detected. The modified set of PDSI classes in VegDRI represents an objective classification scheme to characterise drought severity that is familiar to the drought community. It overcomes the challenge of selecting thresholds for discriminating drought and non-drought conditions, as well as distinguishing between different levels of drought stress when traditional VIs such as the NDVI are used. These threshold values are typically arbitrarily selected through subjective analysis of the VI information, which is problematic because the thresholds can vary by land cover type, geographic location, and season.

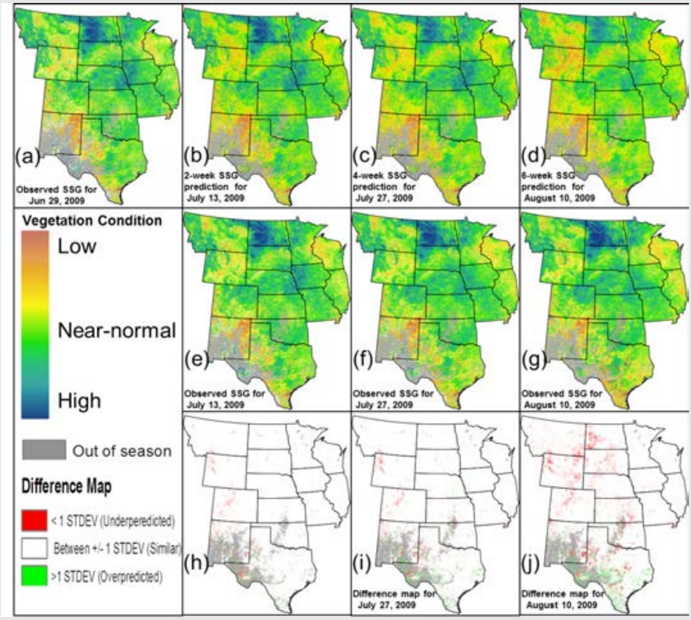
Currently, the operational production of biweekly VegDRI maps is restricted to the CONUS, but the potential exists to transfer this hybrid index concept to other parts of the world by modifying the specific climate, satellite, and biophysical variable inputs to the data sets that are available for a specific area. Multi-year time-series NDVI data sets are globally available from both AVHRR and MODIS to generate comparable satellite inputs, but the specific climate-based drought indices and other biophysical variables would be tailored to a specific country or region. In addition, the transition from AVHRR to MODIS-based NDVI inputs into VegDRI that is currently underway will enable more frequent weekly map updates and also allow a higher spatial resolution 250 m VegDRI product to be tested. This hybrid index has tremendous potential for environmental application including risk management and insurance.

2.2. VegOut

VegOut is a new predictive tool developed by the NDMC that provides future outlooks of general vegetation conditions in a series of 1 km resolution standardised seasonal greenness (SSG) maps at multiple time steps (Tadesse et al., 2010). The SSG is a geographically and temporally standardised metric derived from time-series AVHRR NDVI that provides a general measure of general vegetation conditions. VegOut builds on the VegDRI concept by utilising the same set of satellite, climate, and biophysical input variables and empirical regression tree modelling approach. However, VegOut incorporates a fourth teleconnection component

2 http://vegdri.unl.edu

Figure 3: (a) Observed seasonal greenness (SSG) for 29 June 2009; (b), (c) and (d) are 2, 4, and 6 week outlooks; (e), (f) and (g) are observed SSG for 13 July, 27 July and 10 August corresponding to the 2, 4, and 6 week outlooks, respectively; and (h), (i) and (j) show the difference between the predicted and observed greenness for the corresponding 2, 4 and 6 week outlooks, respectively.



in its models by integrating seven oceanic indices from the Atlantic and Pacific oceans. The VegOut SSG predictions are based on time-lag relationships between satellite-observed vegetation conditions and the preceding climatic, oceanic, and satellite observations.

A set of biweekly VegOut models were developed from a historical 20-year record of climatic, oceanic, and satellite observations for each 14-day period across the year to calculate 2, 4 and 6-week SSG outlooks. Longer outlooks over periods up to a maximum of 52 weeks (i.e. 1 year) are possible, but most of the VegOut work to date has focused on these shorter outlooks because consistently higher predictive accuracies have been attained for 2–6 week time intervals across the growing season (Tadesse et al., 2010). For a given biweekly period, each outlook model is applied to the current observations to predict future SSG values at the 2, 4 and 6-week time steps based on events in the historical record that had a similar pattern among the climate, oceanic, and satellite variables. For a more detailed description of the specific data inputs and methodology used in VegOUT, see Tadesse et al. (2010).

Experimental VegOut maps are currently being produced for a 15-state region of the central United States. Figure 3 shows a series of VegOut maps produced in mid July 2009 over this area. The predicted SSG patterns of the 2, 4 and 6-week VegOut maps calculated on 28 July had strong spatial agreement with the observed SSG patterns on the corresponding August and September dates of the three outlooks. This example illustrates that VegDRI performed well over the region's diverse climatic conditions (ranging from arid to humid) and land cover types (crops, forest, grassland, and shrub land).

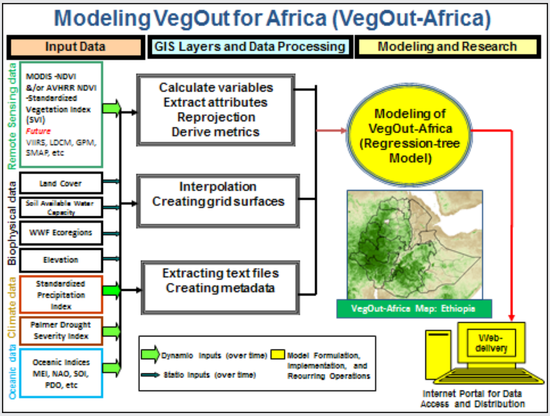
The only notable discrepancy between the predicted and observed SSG was the slight under-prediction of SSG values at the lower end of the SSG value range over the far northern part of this area in the 6-week VegOut map (Figures 3d and 3g). In statistical testing of the VegOut models, Tadesse et al. (2010) found relatively high predictive accuracy ($r^2 > 0.8$) for the three outlook intervals across the growing season. Although the predicted SSG changes depicted in the VegOut maps represent a composite of both normal seasonal vegetation changes (e.g. green up or senescence) and weather-related conditions (e.g. surplus or deficit of soil moisture for plants), this outlook informational could be used as an early indicator of future drought stress for drought monitoring and highlight geographic areas of interest where drought conditions might be expected to emerge or intensify. Work is planned to expand the coverage of VegOut across the CONUS, and the potential exists to extend this concept internationally by modifying the VegOut inputs to the specific data sets that are available for a given country or region.

2.3. Integrated drought monitoring approach to help in decision making in risk management, insurance, and food security in East Africa

Reducing the impact of drought and famine remains a challenge in East Africa despite drought relief assistance in recent decades. This is because drought and famine are primarily addressed through a crisis management approach when a disaster occurs, rather than through preparedness and proactive risk management. Moreover, drought planning and food security efforts have been hampered by a lack of integrated drought monitoring tools, inadequate early warning systems, and insufficient information flow within and between levels of government in many East African countries. In addition to new and improved monitoring tools, it is essential to customise and integrate existing drought monitoring tools for East Africa to improve food security systems and reduce the impacts of drought and famine. A proactive approach to risk management and insurance requires the collective use of multiple monitoring tools, which can be used to detect trends in food availability and provide early indicators at local, national, and regional scales of the likely occurrence of food crises. In addition, improving the ability to monitor and disseminate critical drought-related information using available modern technologies (e.g. satellites, computers, and modern communication techniques) may help trigger timely and appropriate preventive responses and, ultimately, contribute to food security and sustainable development in East Africa (Tadesse et al., 2008).

Efforts are under way to build an early warning system in East Africa using improved monitoring tools that integrate satellite, climate, oceanic, and biophysical data. Figure 4 shows the proposed inputs and products of the experimental tool called VegOut for Africa (VegOut-Africa). This product is expected to have contributions for risk management, insurance, and food security decision making. A pilot study is under way in Ethiopia to build a conceptual framework for the country and extend it to the East African region.

Figure 4: Proposed inputs, process, development, and dissemination of the VegOut-Africa maps and products



3. CONCLUSIONS

The field of remote sensing offers many new opportunities to support insurance and risk management in the developing world. However, a holistic approach among scientists, insurers, and the general public is very important. Given the complexity of drought and the fact that its impacts can accumulate gradually over time and vary widely across many locations and sectors, an integrated drought monitoring tool is essential for risk management and insurance decision making as well as developing and implementing effective food security planning strategies (Tadesse et al., 2008; Goddard et al., 2003).

Modelling approaches such as VegDRI and VegOut that integrate remotely-sensed information with other types of data offer significant potential to advance drought monitoring capabilities beyond the use of traditional satellite vegetation indices such as NDVI. In addition, a satellite-based remote sensing 'toolkit' is rapidly emerging to characterise key components of the hydrologic cycle related to drought that will improve these integrated monitoring tools. These tools are expected to have strong potential in risk management and insurance applications in East Africa.

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35 Earth Observation-derived yield assessments for index insurance in agriculture: logic of variability sources and reality

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KEYWORDS: index insurance, agriculture, food security, earth observation, rainfall, NDVI

SUMMARY

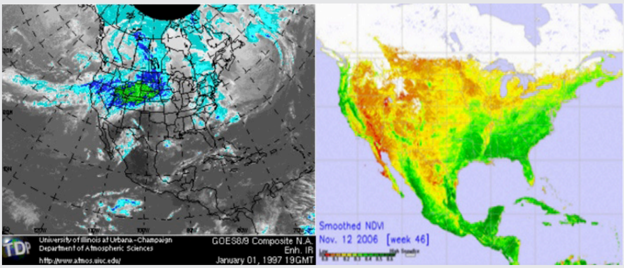
Agroecosystems differ spatially in their performance depending on the characteristics of the soil, terrain, hydrology and climate, but also of culture, societies, markets, processing capacities, proximities, etc. Fields of a homogeneous region, further tend to vary in performance due to varying farmer, household and decision-making characteristics. Index insurance efforts covering 'droughts' or additional 'weather risks' to support agricultural development policies such as food security must be aware of all these variables when defining the thresholds at which a policy must provide payouts and the methods to disburse such payouts. It is argued that when yields are to be insured, crop production 'indices' must be as closely related as possible to data that capture crop performance if one wants to provide value to farmers and create a sustainable insurance market in the long term. In that case, use of rainfall (P) is the most distant link to yields and, when used, unwarranted error propagation is a given (high basis risk) possibly causing non-payout in areas where drought was a serious occurrence and vice versa. Also argued is that the notion of so-called basis risk when yields of neighbouring fields vary, is a non-issue or at least overemphasised, because it implies that better on-farm risk management receives an award when drought occurs and poor management leading to substandard yields to a non-payout situation since weather and crop production in the area proved acceptable.

1. INTRODUCTION

Index insurance efforts deal with covering the production risk by farmers as caused by drought and other perils. Many support agricultural development policies to gain food security; they compensate, for example, input losses (seeds) or output losses (yields) afflicted by adverse weather (mainly drought) and other yield-limiting and yield-reducing factors such as hail, storm, frost, pests, etc. Payouts are determined based on thresholds for indices that correlate with outputs. The indices focus on farmers' risks that occur at regional level, and to which the whole population is exposed. They exclude yield losses caused by substandard site-specific management or field-specific perils that underpin negative outliers for the targeted farmer population.

Many micro-insurance companies aim to capture the spatial-temporal dynamics of weather, mainly through use of rainfall records. They require details of extreme weather events that impact on yield. Due to the overwhelming evidence that the major cause behind yield failures is water availability (linked to rainfall), past studies have tended to focus on capturing rainfall variability (Figure 1), and less on how variability in rainfall impacts on production. Since 'variability' forms the key to risk-studies, a few real-life aspects of spatial and temporal variability of agroecosystems are first discussed.

Figure 1: Rainfall (left) is more 'dynamic' than land cover greenness (NDVI) (right), leading to issues to spatially capture P over time accurately. NDVI basically reflects the result of 'productive' rainfall over time. NDVI is accordingly the main indicator used by all major 'early warning' institutions.



Spatial variability occurs at any scale: that can be seen through the difference between neighbouring fields as well as by patterns within a single field (Figure 2). Causes are past land modification through land use (leading to differences in, for example, organic matter content or drainage), present growth limiting conditions such as nutrient deficiencies, low pH, high bulk density, etc., and yield-reducing factors such as pests, insects, diseases, hail, strong winds, etc. Differences in land management by field, but also historic differences in land use are sources of long-lasting effects on area and local soil conditions.

Temporal variability results from differences in weather conditions (rainfall, snow, frost, wind, hail, etc.) plus seasonal effects on pest and disease incidences. Figure 3 shows the variability in yields (2001–05) for about 1 000 individual fields by year (wheat, Andalucía). It is clear that 'always' some farmers face yields below 1 000 kg/ha, but that in 2005, their frequency was abundant.

Figure 2: Spatial variability of crop condition at different scales, ©TerraSphere

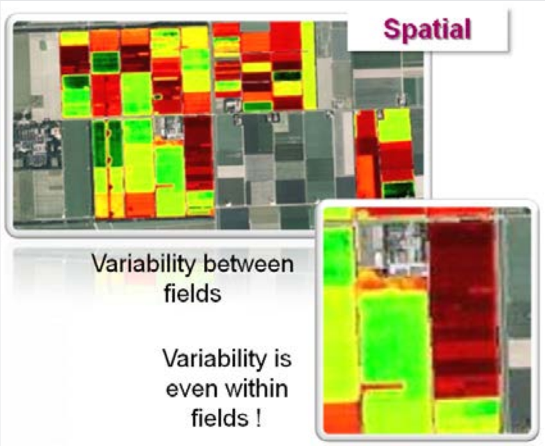
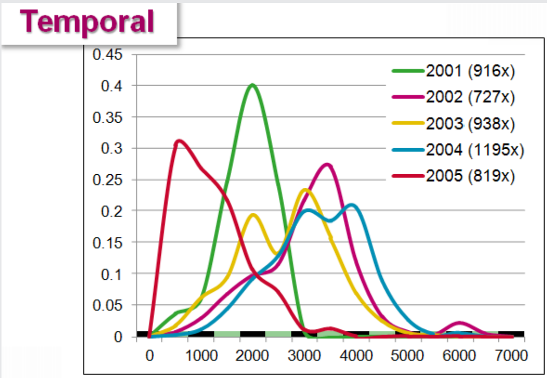


Figure 3: Frequency distribution of rain-fed durum wheat yield variability (kg/ha), Andalucía, Spain



Source: Juncta de Andalucía.

Ideally, for insurers, the locations of fields with poor yields are close (not scattered in between fields with acceptable yields) and yields correlate well with the weather index in use. Providing such correlations at aggregated levels (district to province), masks a large portion of the variability studied: correlations must be prepared based on sufficient repeats at field level. A first comparison for rain-fed wheat yields in Andalucía (Figure 4) shows that clusters do occur, that at local level yield variability remains high, and that generalisation by administrative areas makes poor sense. Operating insurance schemes and validation exercises at administrative levels often ignore the mentioned sources of variability (soil, terrain, hydrology, climate, culture, societies, markets, processing capacities, proximities, etc.) and that rainfall patterns, at best, correlate with terrain and vary from year to year. Flores et al., (2006) describe the ground survey method used to collect the annual Andalucía data.

Farm variability resulting in management differences at field level is another source with impact. When, at field level, a certain yield is feasible, growth-limiting and yield-reducing factors cause a potential yield gap that a farmer tries to counter through management according to his capabilities. Success to do so can differ considerably between fields and farmers, resulting, for homogeneous areas, in normal or skewed yield distributions, under the assumption that individuals of the population studied all operate under likewise conditions. Such a population can be specified as low-income farmers who are not able to adequately invest in on-farm risk management due to high levels of risk aversion or credit constraints. What matters is that communities in different areas or different stakeholders in one specific area may operate at different 'development' levels (Figure 5). By population, from subsistence to commercial levels, adoption rates of available technologies can vary, socio-economic realities and behaviour characteristics can differ, and shocks to the systems will differ concerning impact. Insurers must thus treat areas/populations for which the development levels differ, differently.

Figure 4: Andalucía, Spain: rain from January to June 2005 as grid (*Source:* IRI); durum wheat areas (hatched areas); 2005 field counts for 700 m x 700 m segments with low to high yields as pies; administrative boundaries (black; *Source:* Junta de Andalucía).

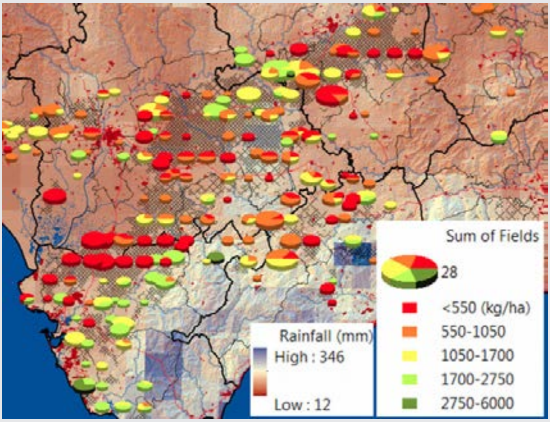
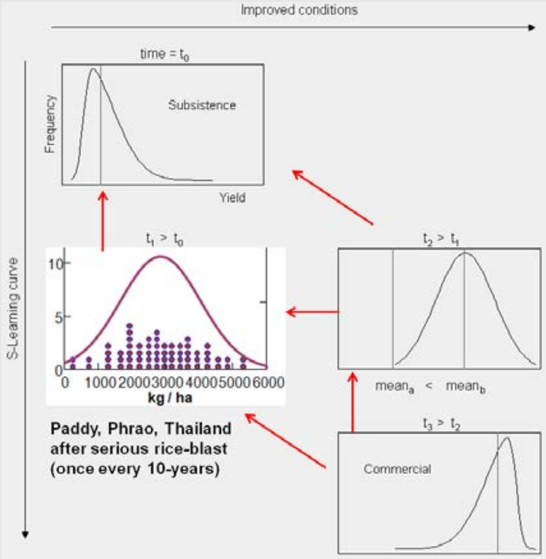


Figure 5: X-axis: trend over time (improved conditions and technology availability); Y-axis: adoption rate of available technologies following the S-learning curve define the path from subsistence to commercial farming. The remaining variability between yields obtained in an area (normal or skewed) relates to differences in farmer abilities. Farmers experience a setback in their achieved progress when a shock (drought) hits the area (red arrows; Laborte et al., 2012; de Bie, 2000).



2. ASSESSING CROP YIELDS

Figure 6 shows the basic logic to assess crop growth and crop yield. Achieved yields relate more to accumulated biomass, less to growth, and even less to weather (P). Traditionally, crop growth models simulate crop growth starting with weather and soil data that are seldom available, leading to results to estimate actual yields. Results remained unsatisfactory. Interaction between yield-reducing and yield-limiting factors versus remedial management carried out by farmers is not part of present simulation algorithms, leading to substantial error propagation when actual yield estimations are the aim. Accordingly, in practice, only potential and water-limited yield estimates are prepared with a subsequent correction using past differences between simulated and actual production statistics. This method harbours considerable assumptions.

Crop growth models that simulate crop growth perform best when remote sensing information on growth or biomass is used to force (adjust) modelled values. That method is, at present, still studied at academic levels, but is expected to become operational in due course. Figures 8 and 9 show some preliminary results.

Figure 6: Crop production logic, from inputs (rainfall) to soil (moisture buffer) to growth (including result of interactions between yield limiting/reducing factors and management), to biomass and finally yield. RS symbols indicate where remote sensing provides 'readings'. Crop growth models mimic the growth process. When RS growth or RS biomass data are used to force the growth models, accuracy improves while error propagation and basis risk reduces.

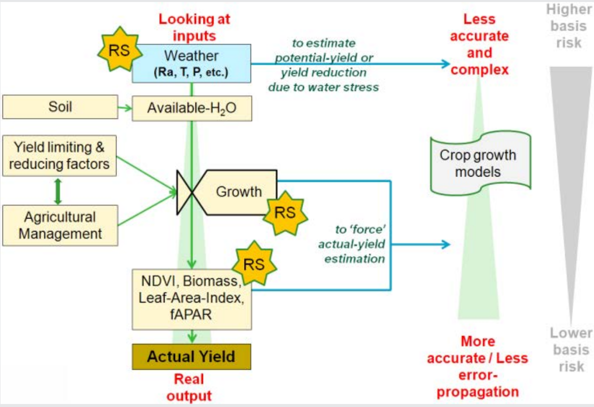


Figure 7: Evolution in crop yield assessment methods

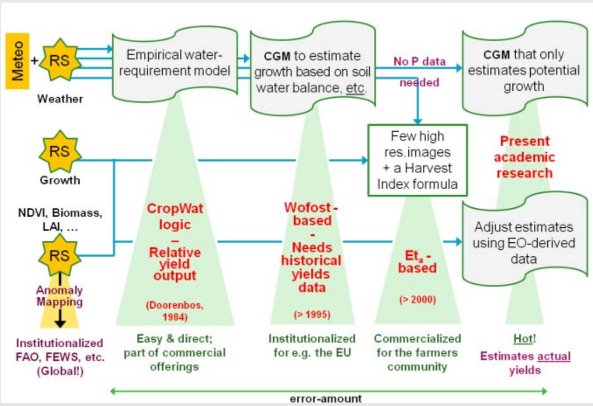
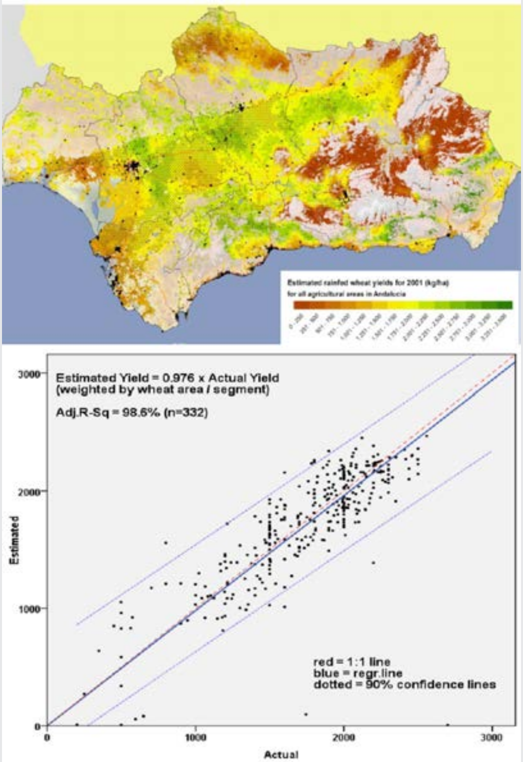


Figure 8: Top: actual durum wheat yield estimates for Andalucía (2001, 1 km resolution), using a RS-based forcing technique (heat flux) with crop growth models; bottom: validation graph (R2 = 98 %, 332 700 m x 700 m areas) indicating that, at local level, variability remains (farm variability; Khan, 2011).



From the 1970s onwards (Figure 7), different phases took place in estimating the impact of water deficit on crop growth. Simulation techniques developed by the famous 'School of de Wit' and the FAO, and the works by Doorenbos and Kassam proved of high value. The former resulted in WOFOST (WOrld FOod STudies), a detailed crop simulation package with high data requirements, essentially intended for the study of plant physiological processes, and the latter resulted in CropWat (AquaCrop), a simple but practical tool for water management support. Both had no RS-based data assimilation capabilities.

Later, RS-data led to methods to estimate biomass, greenness, and Leaf Area Index (LAI) that all have 'accumulation' properties, and methods to measure instantaneous crop growth using the heat balance method (water transpiration (= growth) cools down the leaf surface) that has time-independent characteristics. By the late 1990s, efforts started to explore the assimilation of RS-data into crop growth models. The long delay between the availability of imagery caused delays in the issuance of detailed and operational analyses. That problem is, at present, remedied though at the cost of spatial resolution. Given shortcuts leading to huge new assumptions (e.g. use of harvest indices), field-specific yield assessments cannot yet be prepared through the available RS-data.

3. WEATHER-BASED INDEX INSURANCE

To price insurance products and to formulate thresholds that farmers comprehend (used to define when payments are due), insurance companies require data to model the probability of shocks and their impact. Certain levels of basis risk can be acceptable from the perspective of insurers and reinsurers, even if more indicative indices (RS-based) are available. However, as Clarke (2011) demonstrates, basis risk often leads to products with low value for farmers, especially in cases of downside risk where farmers pay a premium, experience a loss and still do not receive a claim payout. From a development policy perspective, this is not desirable. Furthermore, this downside risk may lead to low levels of trust in index insurance and its providers, potentially disrupting the index insurance market in the long term (Morsink, 2012).

Regrettably, the community of both insurers and farmers are mostly unfamiliar with the use of satellite imagery leaving the use of rainfall measurements as the preferred option. This logic also holds for crop growth models that estimate yields based on, for example, imagery. A farmer must understand the basic data used and be able to reproduce the threshold analysis made through them.

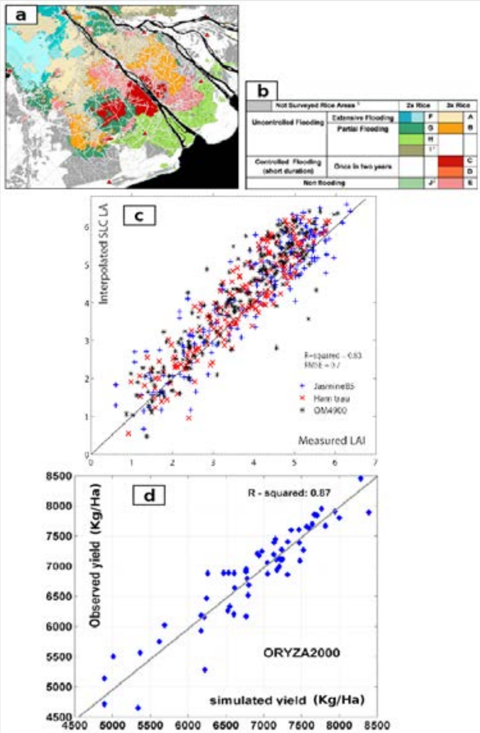


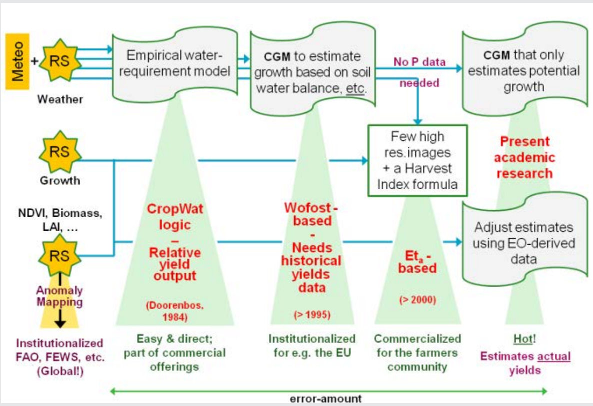
Figure 9: Actual irrigated rice yield estimates for 58 sites: (a): in the Mekong delta in Vietnam, the sites are characterised by different cultivation typologies; (b): Leaf Area Index (LAI) was estimated based on the SLC (Soil-Leaf-Canopy) canopy reflectance model and used as input for crop growth models: (c): validation graph for LAI; and (d) validation graph for yields. Nguyen Thi Thu Ha, in preparation.

This led to the assumption by insurance companies that a direct relationship between point-based rainfall records (at weather stations) and yields achieved in the area exists. The companies insufficiently considered the lessons learned and progress made during the past 40 years in the fields of agronomy and remote sensing (RS) (Figure 10). This generated insurance products characterised by high levels of basis risk, which is undesirable from the perspective of value and economic farm development. Besides rain amount, fields in an area are exposed to many other perils. Figure 11 shows the variety of sources of risk leading to claims to a multi-peril insurance product in Spain where the dominant risk (hail) represents 41 % of all claims.

It is unnecessary to state that point-based rainfall measurements poorly relate to rainfall received at certain distances to those points, and that combined use with RS-based techniques (as at IRI) already led to excellent well-calibrated spatial rainfall products (Figure 4). Promoting the use of crop growth models functions well for government institutions dealing with early warning and sustainability issues, but will not fulfil the requirement that farmers must be able to reproduce the analysis made as stipulated in their insurance policy.

At best, they provide the means to validate accuracies of designed threshold methods. Thus, the requirement to assess RS-based data that relate to growth and biomass (Figure 6) is identified. Most represent 'hard-data' that can stand exposure in court (personal communication, VITO). Their use creates the trade-off situation between a product that is easily understandable versus a product with reduced basis risk and potential longer-term sustainability.

Figure 10: The weather-based index insurance approach ignores years of efforts by agronomists on operational early warning methods based on remote sensing.



4. USE OF AN NDVI THRESHOLD AS TRIGGER

Given that most leading national and global institutions base early warning procedures on the use of NDVI data, further scrutiny of NDVI data is needed. Their value stands proven. Figure 12 provides a typical output of an early warning monitoring centre. Present versus long duration means define performance at pixel level.

Figure 11: Causes of multi-peril insurance claims by agricultural enterprises in Spain for 2011 [1]

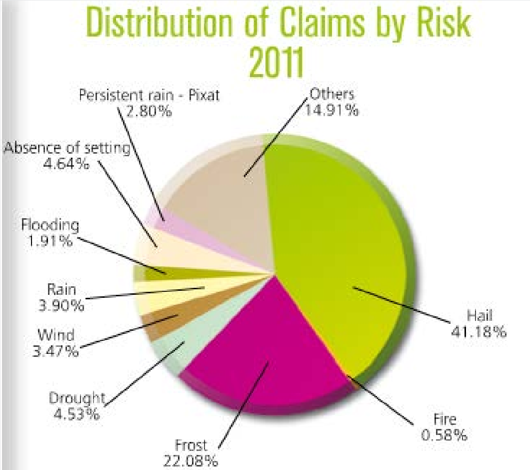
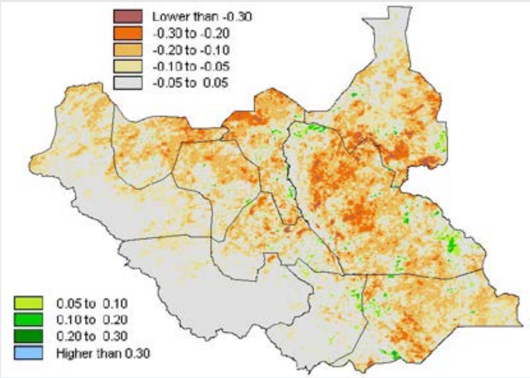


Figure 12: Anomaly NDVI map for Southern Sudan. The product is pixel-based and indicates where land cover greenness is above and below average. It needs to be combined with additional information on cropping systems, farming systems, crop calendars, population coping capacity, vulnerability, etc.



Source: WFP, 2010.

1 http://www.agroseguro.es/memoria2011/PROGRAMA/MINIMEMORIA_Inglesa_2011/mini_ingles_2011.html

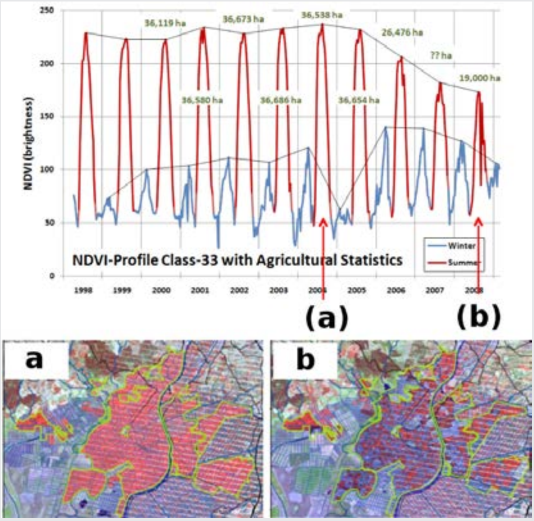


Figure 13: NDVI-derived map unit representing irrigated rice (green line; Sevilla, Spain). The historic NDVI behaviour (1998–2008) with official data on rice area planted. High-resolution imagery (ETM) taken at the peak of the rice crop growing period (a: 2004 and b: 2008).

From an agricultural policy perspective, knowing what is where, in which development stage farmers in an area are (Figure 5), if all have similar population/behaviour characteristics, how they performed in the past (frequencies of extremes), what are prevailing risk-management activities, and which technology is poorly adopted creating yield gaps, are all frequently discussed in connection with index insurance schemes. Special interest focuses on options to close prevailing yield gaps by relating adoption of needed technologies (Figure 5) to insurance schemes through e.g. credit mechanisms.

To link required biophysical, socio-economic and historic events data to NDVI-anomaly products requires stratification (mapping of classes) using long-duration NDVI imagery. Such an effort provides historic variability by strata (meso units) and possibly indicates when, for example, a drought hit, when cropping system practices changed or when farmers reduced cropping intensities (Figure 13).

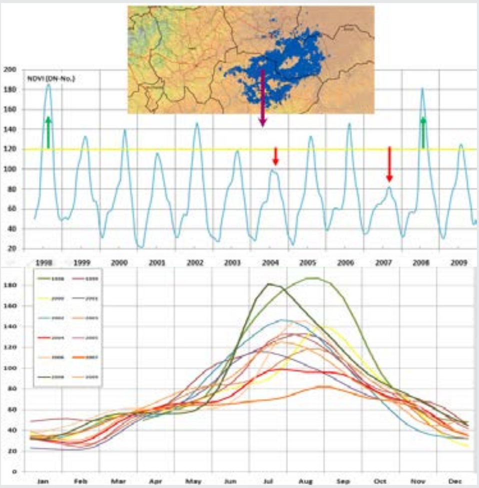
The availability of long-duration NDVI imagery exists from 1981 onwards [(2)], thus fulfilling an essential data requirement by actuaries of insurance companies. The validation and annotation of historic events (1981 onwards) by strata (meso units) forms part of an assessment of how NDVI must be used in that particular area to render an insurance scheme

2 The University of Arizona has developed a consistent 30-year record of Enhanced Vegetation Index and Phenology products using the Advanced Very High Resolution Radiometer (AVHRR), the Systeme Pour l'Observation de la Terre (SPOT) Vegetation instrument, and the Moderate Resolution Imaging Spectroradiometer (MODIS) to create a 30-year record that can be extended into future missions. In July 2012, the VIP project released version 2 of its vegetation index products. The product suite is comprised of daily, 7-day, 15-day, and monthly temporal intervals covering the period 1981 to 2010 (https://lpdaac.usgs.gov/about/news_archive/version_2_nasa_measures_vegetation_index _products_releasde).

functional. Simultaneously, because of the very high dynamic nature of weather, strata will internally show variable 'future' performances due to stochastic weather conditions. In fact, superimposing the anomaly product (Figure 12) on the mapping product (Figures 13 and 14) will provide the locations of anomalies by meso unit. Figure 15 suggests, indeed, that the anomaly product (based on variability from the mean) acts independently from the prepared map (based on long-term means).

Given that stratifying NDVI imagery by class provides estimates over time of standard errors (SEs: applicable to all pixels classified to that class) is a desirable additional advantage. Use of these SEs provides excellent opportunities to make micro-insurance designs area-specific without reducing transparency for farmers. Through mobile technology and the Internet, opportunities arise to monitor the status of insurance policies on an area-by-area basis. Such a scheme is actually already operated by the Spanish Pasture Insurance System (Sanz et al., 2012; http://www.agroseguro.es).

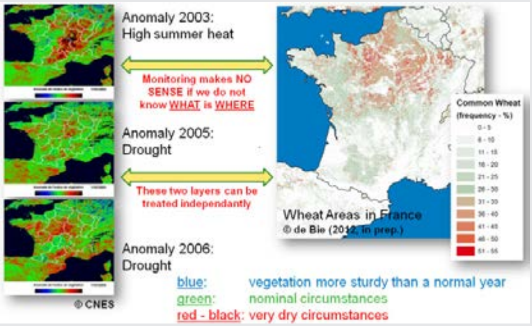
Figure 14: NDVI map unit in Mongolia containing extensive rangelands. The greenness behaviour of years (1998–2009) showing good and bad years, the annual curves are superimposed to indicate how variable and indicative NDVI data are.



5. FINAL NOTES

Index-based micro-insurance schemes focusing on actual rainfall data do not fully use the potential of knowledge gained by the agronomy community in recent years or the possibilities to use earth observation data to generate indices that relate better to crop performance and that cover the entire globe. If the objectives of index insurance schemes are to reach agricultural policy objectives and to develop long-term sustainable schemes, the argument is raised that NDVI products, which became the de facto standard for 20+ years in the early warning community, must be studied in further depth.

Figure 15: Wheat strata in France created through NDVI stratification and field data with anomaly animations for three different years



The presented risk sources shed light on the causes of yield performance variability. It is shown that most are captured by defining meso units, thus isolating weather and farm variability as remaining sources. Often, farm variability is wrongly related to basis risk; it relates to local variability in yields that must remain linked to competition between holdings. This supports the idea the insurance products written at meso level such as farmer associations, MFIs and seed companies may be able to overcome some of the challenges faced when implementing micro-level index insurance.

It is argued that NDVI supports the definition of meso units and that anomaly products show, by grid cell, for meso units where and when performance was below a set threshold. Thresholds must be unique for meso units, not administrative areas, and insurance companies must make the status of the index transparent through, for example, the Internet [3].

3 http://www.agroseguro.es/indices/servlet/agro.pastos.controlx.PastosServlet?cluster=S

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In the wake of the Sahelian droughts and the resulting food insecurity crises of the 1970s and mid-1980s, the international community and national governments alike have focused on early warning systems as a mechanism to prevent famines and avert acute malnutrition. Thirty years later, food insecurity still prevails in many areas of the globe, amidst rapidly evolving geopolitics. A different and innovative way to tackle the problem of the fluctuating food availability attracted the attention of development agencies and governments in developing countries some fifteen years ago: index-based crop insurance. Many pilot projects have experimented about every possible insurance design under diverse conditions, involving farmers, cooperatives, micro-credit institutions, governments, commercial banks, insurance and reinsurance companies. However, the indices, which play a pivotal role in the insurance schemes, also constitute one of their main weaknesses. Very little crop modeling and forecasting knowledge is put to use in index design, and only occasionally do remote sensing data and advanced statistical methods play a part. This volume explores the overall picture of index-based insurance, from index design to its socio-economic environment, identifying at each stage current challenges to scaling from pilot project to real world implementation.

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