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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

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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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SUMMARY

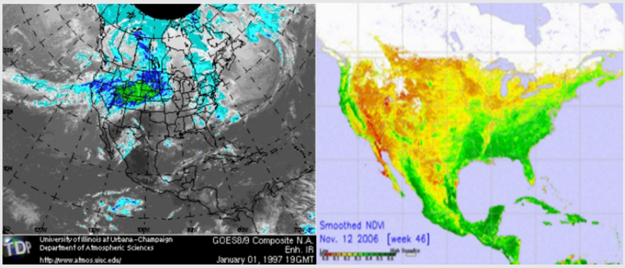
Agroecosystems differ spatially in their performance depending on the characteristics of the soil, terrain, hydrology and climate, but also of culture, societies, markets, processing capacities, proximities, etc. Fields of a homogeneous region, further tend to vary in performance due to varying farmer, 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

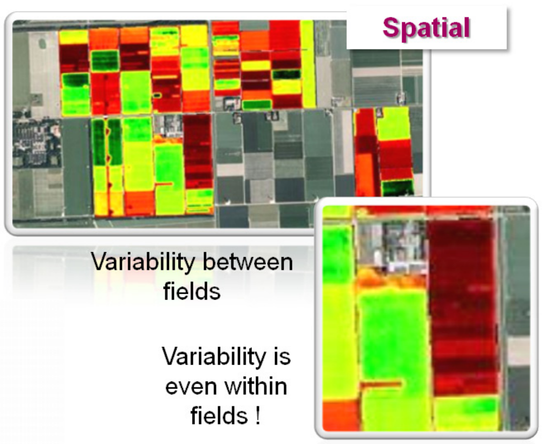
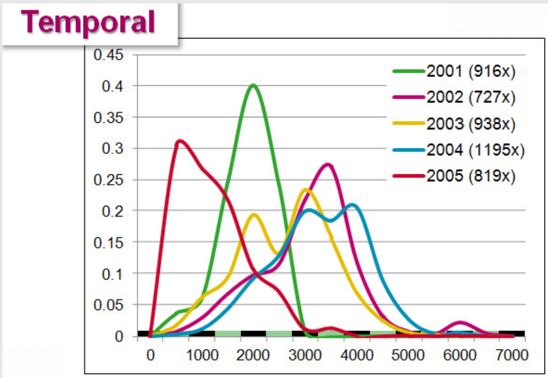


Figure 3: Frequency distribution of rain-fed durum wheat yield variability (kg/ha), Andalucía, Spain



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).

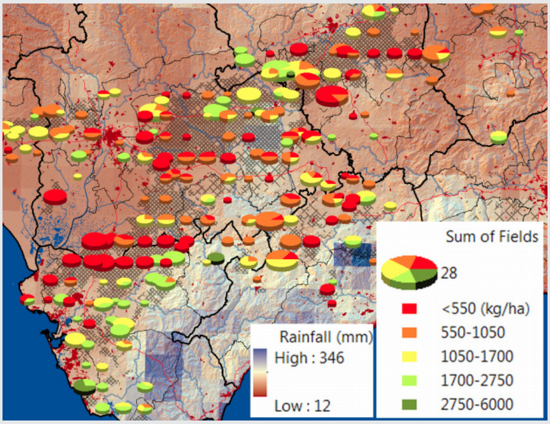
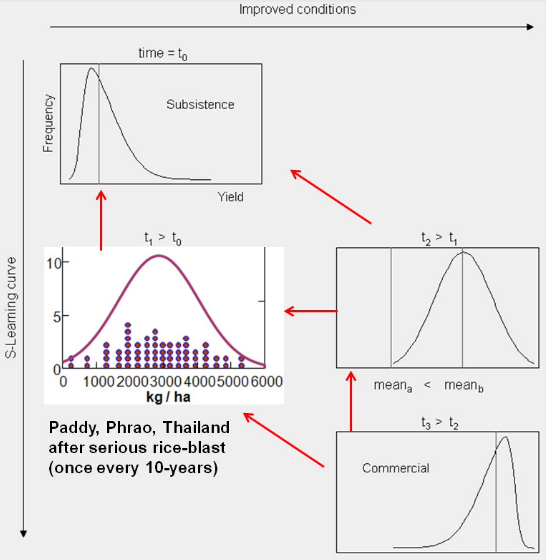


Figure 5: X-axis: trend over time (improved conditions and technology availability); Y-axis: adoption rate of available technologies following the S-learning curve define the path from subsistence to commercial farming. The remaining variability between yields obtained in an area (normal or skewed) relates 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.

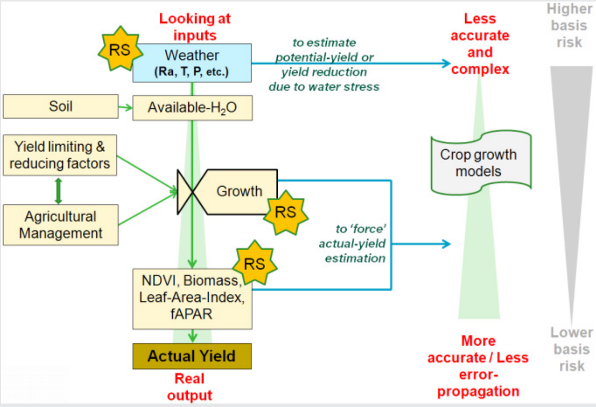
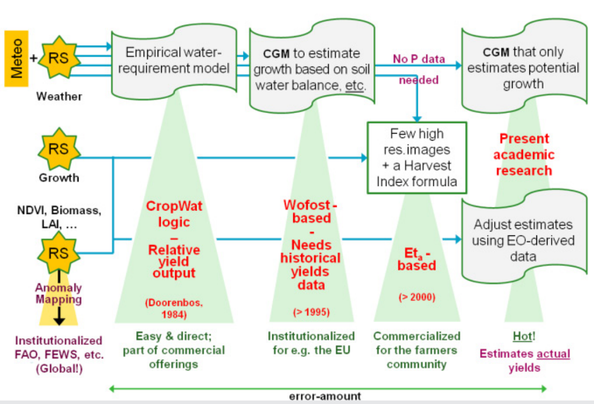


Figure 7: Evolution in crop yield assessment methods



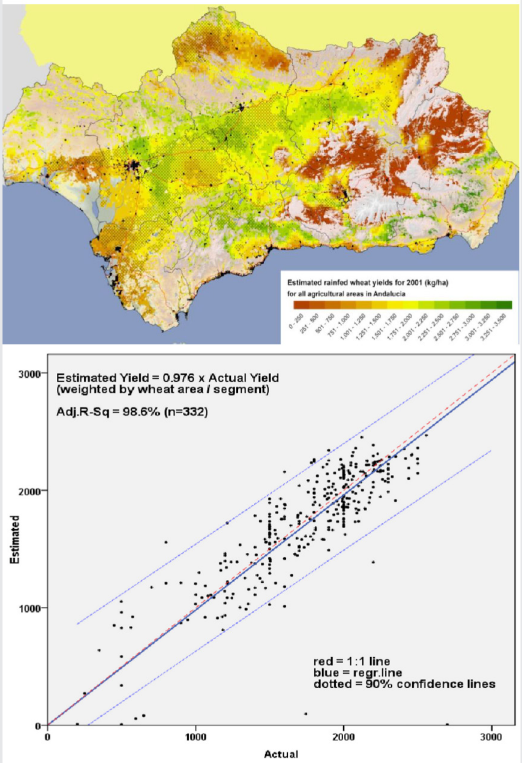


Figure 8: Top: actual durum wheat yield estimates for Andalucía (2001, 1 km resolution), using a RS-based forcing technique (heat flux) with crop growth models; bottom: validation graph (R2 = 98 %, 332 700 m x 700 m areas) indicating that, at local level, variability remains (farm variability; Khan, 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.

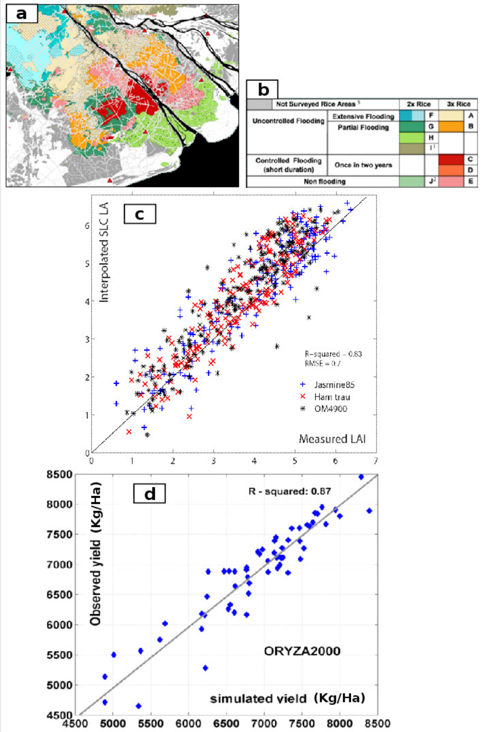
Later, RS-data led to methods to estimate biomass, greenness, and Leaf Area Index (LAI) that all have ‘accumulation’ properties, and methods to measure instantaneous crop growth using the heat balance method (water transpiration (= growth) cools down the leaf surface) that has time-independent characteristics. 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.

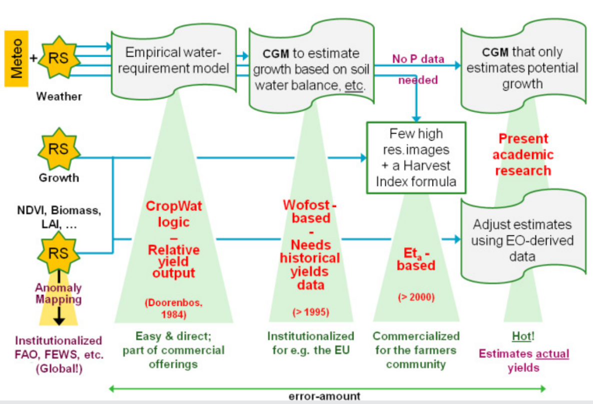


This led to the assumption by insurance companies that a direct relationship between point-based rainfall records (at weather stations) and yields achieved in the area exists. The companies insufficiently considered the lessons learned and progress made during the past 40 years in the fields of agronomy 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)

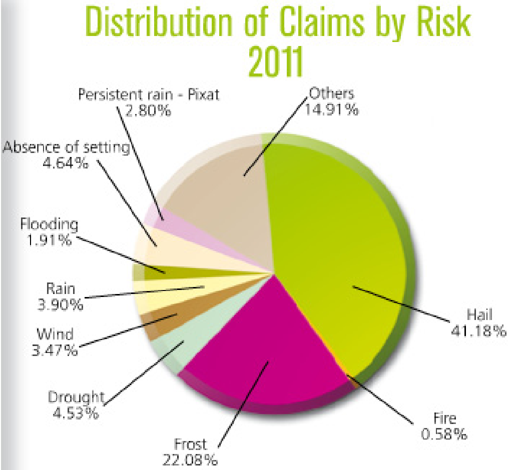
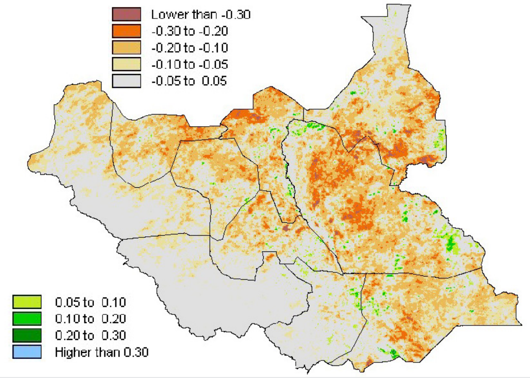


Figure 12: Anomaly NDVI map for Southern Sudan. The product is pixel-based and indicates where land cover greenness is above and below average. It needs to be combined with additional information on cropping systems, farming systems, crop calendars, population coping capacity, vulnerability, etc.



Source: WFP, 2010.

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[1] http://www.agroseguro.es/memoria2011/PROGRAMA/MINIMEMORIA_Inglesa_2011/mini_ingles_2011.html

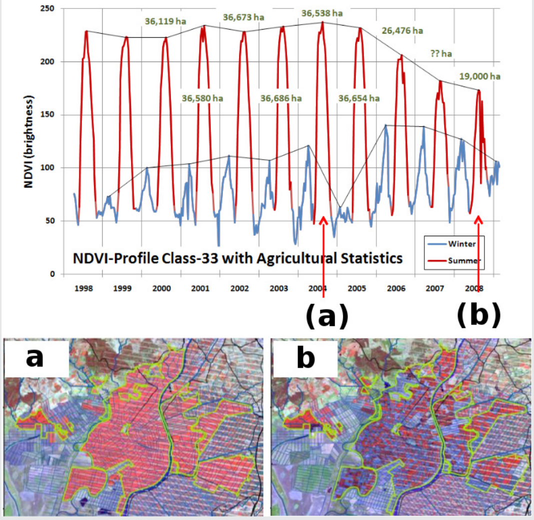

Figure 13: NDVI-derived map unit representing irrigated rice (green line; Sevilla, Spain). The historic NDVI behaviour (1998–2008) with official data on rice area planted. High-resolution imagery (ETM) taken at the peak of the rice crop growing period (a: 2004 and b: 2008).

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

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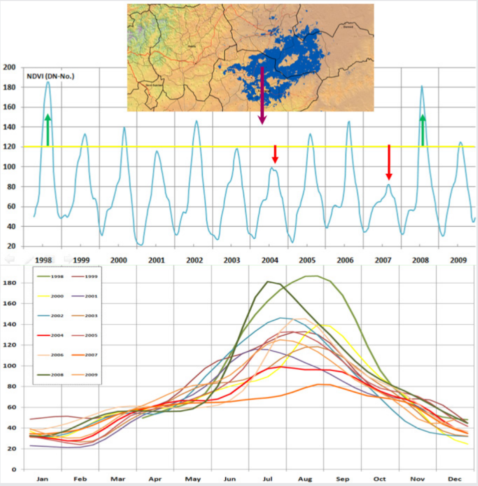
2 The University of Arizona has developed a consistent 30-year record of Enhanced Vegetation Index and Phenology products using the Advanced Very High Resolution Radiometer (AVHRR), the Systeme Pour l'Observation de la Terre (SPOT) Vegetation instrument, and the Moderate Resolution Imaging Spectroradiometer (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).

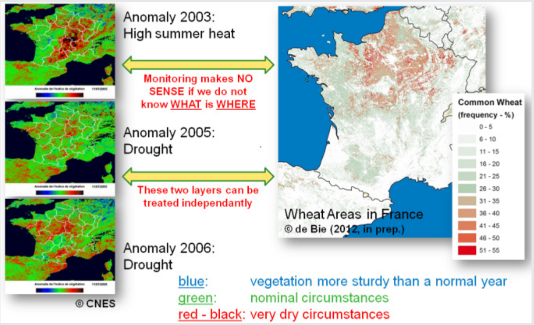
Figure 14: NDVI map unit in Mongolia containing extensive rangelands. The greenness behaviour of years (1998–2009) showing good and bad years, the annual curves are superimposed to indicate how variable and indicative NDVI data are.



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).

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3 http://www.agroseguro.es/indices/servlet/agro.pastos.controlx.PastosServlet?cluster=S

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