The Potential of Satellite Rainfall Estimates for Index Insurance

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1. Introduction

Most agricultural index-based insurance schemes are triggered by rainfall data rather than crop data. This is because it is preferable to trigger with objectively measurable weather events as it reduces the 'moral hazard' associated with subjective assessments of crop failure and allows evenhanded dealing with marginal and successful farms (Osgood et al., 2007; Skees et al., 2005). The traditional source of rainfall data has been raingauge measurements. In many developing countries (such as those in sub-Saharan Africa) index-based agricultural insurance would be extremely useful because of the high dependence on subsistence agriculture in marginal crop growing conditions. However, precisely in these areas, the number of raingauge stations is often very limited and the distribution of raingauges very uneven, with most stations located in the main cities. As a result, the gauge data may not represent the rainfall over the farmers' plots where the information is needed most. Even where gauge data exist, there are other limitations including short historical time series, missing data, reading errors and poor representation of growing conditions because of poorly sited gauges.

The alternative to surface rainfall measurement is satellite rainfall estimation (RFE). RFE is the technique of obtaining rainfall information from data collected by environmental satellites. Different techniques exist to estimate rainfall from satellite thermal infrared (TIR) and passive microwave (PMW) sensors and combinations of the two. The main advantages of RFE, particularly with regards to index insurance, are:

i. it can provide spatially continuous data over most of the globe;

ii. it is ideal for scaling-up; and

iii. it is tamper-proof.

The two main constraints on using RFE are

i. the uncertainty involved in the estimation of the rainfall; and
ii. the short period of record typically associated with newer satellite derived time series.

With regard to uncertainty, it is important to realize that satellites do not measure precipitation directly; rather rainfall amounts are inferred from microwave and/or thermal infrared brightness temperatures. Often no attempt is made to quantify the uncertainty of the satellite estimates over the region where RFE is needed most. With regard to the limited period of record, TIR data archives go back at most to the late 1970's and microwave archives to the late 1980s. Although these data sets are now becoming sufficiently long, most commonly used satellite-based rainfall archives make use of data inputs which differ significantly from year to year. While this is often done to improve the accuracy of individual measurements, it can result in a loss of homogeneity in the long term time series making it difficult to extract the necessary statistics for the calculation of agricultural risk. Furthermore, the use of data from multiple sensors limits the time series to those years for which all sensors were operating.

However, recent research shows that it is possible to overcome these constraints. It is possible to quantify the uncertainty of the satellite-based rainfall estimates and also that long, homogeneous rainfall time series can be generated for critical areas such as sub-Saharan Africa. This makes satellite-based rainfall indices an attractive

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proposition, given the other advantages of good spatial coverage, relatively long time series, and the fact that they are tamper proof

2. Satellite rainfall estimation

A brief summary of the science of satellite rainfall estimation is given here. For more detail the reader may referred to, among many others, two publications (Levizzani et al., 2002; Gruber and Levizzani, 2008). Unfortunately, no satellite yet exists which can reliably identify rainfall and accurately estimate the rainfall rate in all circumstances. However, satellites carry sensors which can 'see' the Earth in a variety of different ways. Some sensors can make indirect estimates of rainfall by measuring cloud thickness or cloud top temperature. Geosynchronous satellites are preferable to polar orbiting satellites because of their more frequent observations. From the sensors available on geosynchronous satellites, the visible and thermal infra-red (TIR) wave bands provide useful information about storm clouds. Storm clouds show up as very bright to the visible sensor while the infra-red sensor can identify storm clouds by their low temperature. Passive microwave (PMW) sensors are attractive because they contain information about rainy areas rather than clouds, but they are not available on geosynchronous satellites. Almost all current rainfall estimation techniques are based on TIR and/or PMW. Most TIR rainfall estimation methods are based on the assumptions that rainfall comes mainly from convective storm clouds, these clouds only rain when their tops have reached a certain minimum height which can be identified by its temperature on TIR image. At a given location, the quantity of rainfall can be calculated from the length of time the cloud top has been below a given temperature threshold.

Limitations of TIR-based rainfall estimates

Local variations in rainfall

Rainfall intensity varies from place to place beneath the cloud. The satellite sees only the top of the cloud, and it cannot pick up this variation in intensity. Thus, the images produced by the satellite do not provide a precise estimate of rainfall for a particular spot on the ground at a particular time.

Effect of warm rain processes

TIR images are used to distinguish raining cloud from non-raining cloud on the basis of their observed cloud top temperature. However, regions near coasts or in mountainous areas may experience rainfall from clouds which do not reach high enough into the atmosphere to register as ‘cold’ clouds. In such cases rainfall would indeed occur but would not appear in the satellite rainfall estimate image.

Effect of Cirrus clouds

Cirrus clouds are high enough in the atmosphere composed of ice crystals rather than water drops. Such clouds appear as very cold to the satellite and therefore would indicate the presence of rain, although in fact the clouds are not deep enough for rainfall to develop.

Limitations of PMW-based rainfall estimates

The main limitations of PMW include background emission from the land surface which varies significantly depending on vegetation type and soil water content (Morland et al., 2001), low repetition rate (typically twice per day) which makes aggregation over daily time periods impossible, and coarser spatial resolutions than that of TIR-based approaches.

Merging satellite rainfall estimates from different sensors and blending with gauge observations

A logical route to optimizing RFE is to merge the information from PMW and TIR, combining the better rainfall identification of PMW with the higher spatial and temporal frequency of the TIR images. Various statistical techniques are employed by different agencies to accomplish this. Another approach towards better satellite rainfall products is blending the satellite rainfall estimates with available gauge measurements. The quality of the final product depends on the quality, number, and distribution of the gauges used.

Future directions for satellite research

The satellite rainfall estimation community is currently working towards the improvement and consistency of PMW algorithms and improving the quality of global climate data sets using PMW inputs. Most of all, this community is excited about a significant future development, which is the Global Precipitation Mission (http://gpm.gsfc.nasa.gov/). This is a satellite mission that will consist of constellation of satellites with advanced PMW and radar instruments. It is expected to increase PMW repeat frequency to three-hourly, and thus improve satellite rainfall estimation significantly. However, this may not be relevant to index insurance immediately. The most relevant research in this respect is the attempt being made to produce historical time series from single and combined instruments. One such example is a project by IRI, University of Reading in UK and National Meteorological Agency of Ethiopia. This project will produce 30-year (1979-2008) time series of locally calibrated rainfall estimates from Meteosat TIR at high spatial and temporal resolution. It will also produce 30-year time series of gridded gauge data and corresponding RFE-gauge blended product. This will offer consistent and homogenous RFE time series as well as improved, but possibly less homogenous, blended product.

Another example is the use of high resolution grids of long term monthly mean rainfall, to substantially enhance the accuracy of RFE retrievals (Funk et al., 2007). These high resolution grids can also be used to downscale coarse long time series satellite estimate products like the 2.5^{o} 1979–near present Global Precipitation Climatology Project dataset (Adler et al., 2003). When blended with gauge data, these down-scaled data create long and accurate depictions of hydrologic conditions (Funk et al., 2007), although it is important to note that for homogeneous time series, the blending must make use of the same set of gauges throughout the series. It is also possible to use block kriging with spatially varying target regions that correspond to desired administrative units (Funk et al., 2008). Block kriging can blend station observations and satellite estimates to provide estimates of the mean rainfall (Grimes et al., 1999). This procedure also produces estimates of the standard errors of the mean estimates (Fig. 1). Teo and Grimes (2007) have shown how district-based area rainfall averages and their associated uncertainties can be used in the context of crop-yield analysis in Africa. A geostatistical framework of this nature could be used to assess optimal scales for index insurance programs. Larger spatial units will have lower standard errors, but the insurance triggers will be less geographically refined. Smaller spatial units will target affected populations more precisely, but at the cost of more missed droughts and false alarms.

3. Summary

While trends in rainfall, population, and agricultural capacity are placing increasing numbers of Africans at risk of under-nourishment (Funk et al., 2008), the relatively novel use of index insurance offers another tool for mitigating weather-related risks (Osgood et al., 2007; Skee et al., 2005). Satellite RFE fields offer 'tamper proof' spatially extensive estimates with high repeat rates. Short data records and large systematic and random errors may limit use of many standard algorithms, but these obstacles may be overcome by the use of local tuning, high resolution climatologies, additional gauge data, and the retrieval and processing of archived TIR data. While no 'best' system exists at present, the routine use of satellite RFE fields by the early warning community bears a salient testimony to the utility of satellite RFE. Much of the error in satellite retrievals tends to be related to systematic distortions in retrievals. Local tuning and the use of high resolution climatologies can reduce these biases. Thus RFE fields, even where they perform quite poorly, such as within regions of complex terrain (Dinku et al., 2007), can still provide reliable measures of *relative* rainfall amounts. While more research, and more data (both TIR and gauge), can strengthen RFE systems, these satellite fields offer an exciting basis for index insurance products.

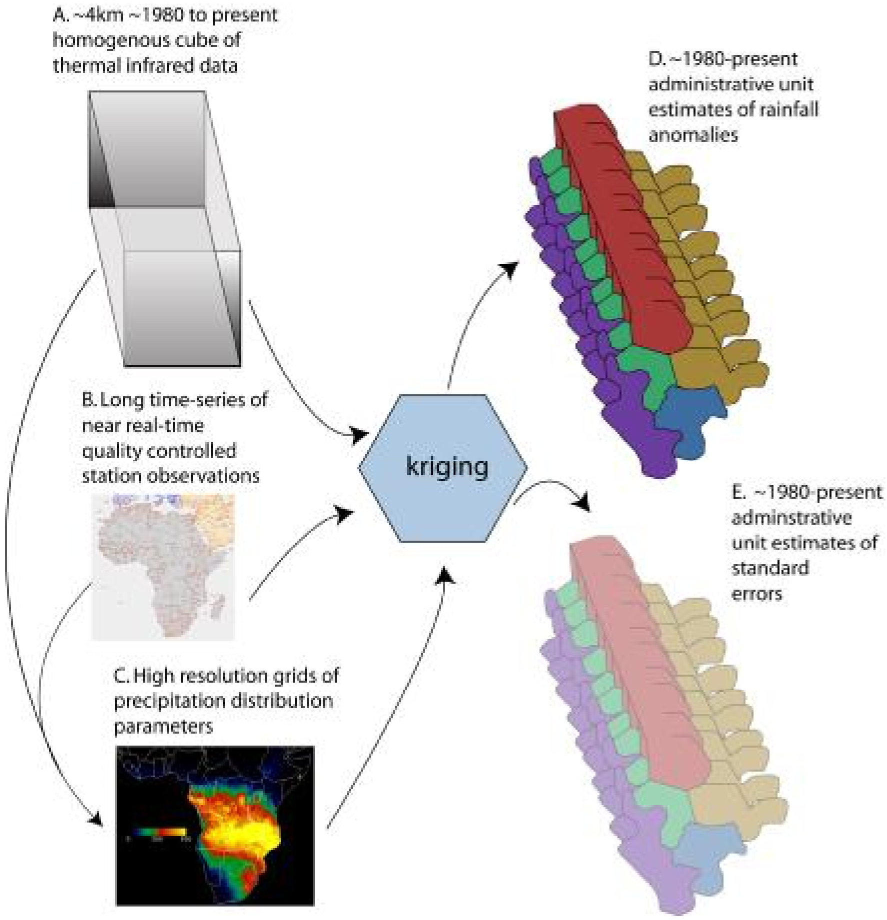

Figure 1. Schema for gauge-enhanced satellite rainfall estimation process based on block kriging. A long high resolution time series of homogeneous TIR data (A) would be combined with gauge observations (B), elevation and slope fields to produce high resolution grids of monthly statistical rainfall parameters (mean rainfall, rainfall frequency, rainfall variance, C). These multiple sources of information can be used to translate satellite and gauge rainfall amounts into relative amounts. Block kriging with a background can then be used to blend the satellite and gauge estimates, producing district level estimates of rainfall (D), complete with associated standard error fields (E).

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