CONTRIBUTION OF METEOROLOGICAL SATELLITES TO AGRICULTURE AND HYDROLOGICAL HAZARD WARNING IN THE SEMI-ARID TROPICS

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Abstract

Meteorological satellites provide regular and frequent views of the earth and are promised to continue for many years. They are therefore the preferred source of data for monitoring various aspects of the long-term water balance Within the overall programme of Local Applications of Remote Sensing Techniques (LARST), data from Meteosat and NOAA series of satellites are now used for flood prediction and drought monitoring in Africa. Operational experience will be used to illustrate the needs for ready access to raw data, for establishing suitable algorithms and validating them locally, and for good communications with users outside meteorology Given these factors, remote sensing can play a major part in forecasting natural hazards.

1. Introduction

Meteorological satellites give daily, global coverage in the visible (VIS), near infra-red and thermal infra-red (TIR) bands. Spatial resolution ranges from about 1km for the visible bands of the polar orbiting satellites to 5km for the thermal infra-red bands of the geostationary satellites; with corresponding image frequencies of 2 to 48 per day. The primary purpose of these satellites is to give information on atmospheric and surface properties for use in numerical and subjective weather forecasting. These forecasts themselves make a valuable contribution to the prediction of both severe weather hazards and to the weather which may influence attempts to alleviate the effects of natural disasters. However, the purpose of this note is to describe some of the valuable applications of operational meteorological satellite data which had not been anticipated when the satellites were designed and first launched.

At the University of Reading, efforts have been made to develop methods for using the meteorological satellite data for water balance studies in seasonally arid areas. This has led to operational applications in drought monitoring and river flow forecasting in Africa The basis of both of these applications is the use of the thermal infra-red bands of the geostationary meteorological satellite METEOSAT to estimate area rainfall. These techniques will be briefly described in the next section, followed by more detail on the specific applications in subsequent sections.

2. Rainfall estimation

Techniques for estimating rainfall from satellite data generally rely on the identification of particular cloud types in the TIR or visible VIS bands or observe the emission or scattering of microwave radiation by raindrops Descriptions of the range of techniques can be found in Liberti (1993), Barrett (1990), and Engman and Gurney (1991). Only the microwave frequencies offer any direct linkage between the rain itself and the measured radiances, but such data are not yet operationally available in real-time so we are at present confined to the VIS and TIR data. Both polar orbiting and geostationary satellites give information in these bands. While the polar orbiting satellite has higher spatial resolution, the more frequent data from the geostationary satellite allow the development and decay of rain producing clouds to be followed. An additional restriction in many areas is that much or most of the rainfall occurs at low sun angles or after sun-set In such cases the VIS data are of little value.

The most widely used operational satellite rainfall monitoring methods use TIR images to identify storm clouds and ascribe a rain rate to these clouds. Most of these methods identify a threshold temperature such that clouds with tops colder than the threshold can be assumed to be raining. The threshold temperature and rain-rate are determined empirically. This approach gives good results if the rainfall is predominantly associated with convective activity; it is less successful in the case of frontal or monsoon-type precipitation The stochastic nature of the rainfall cloud temperature relationship also means that the rainfall estimates must be averaged over a large number of pixel values to give reliable results The averaging may be spatial and/or temporal.

The care needed to select the appropriate temperature threshold and rain-rate depends on how the estimates are to be used. For large scale monthly estimates of rainfall over the tropical oceans a fixed threshold and rain-rate may be appropriate (Arkin and Arduanuy, 1989). However, over continental areas, where the physical and dynamical structure of storms varies with

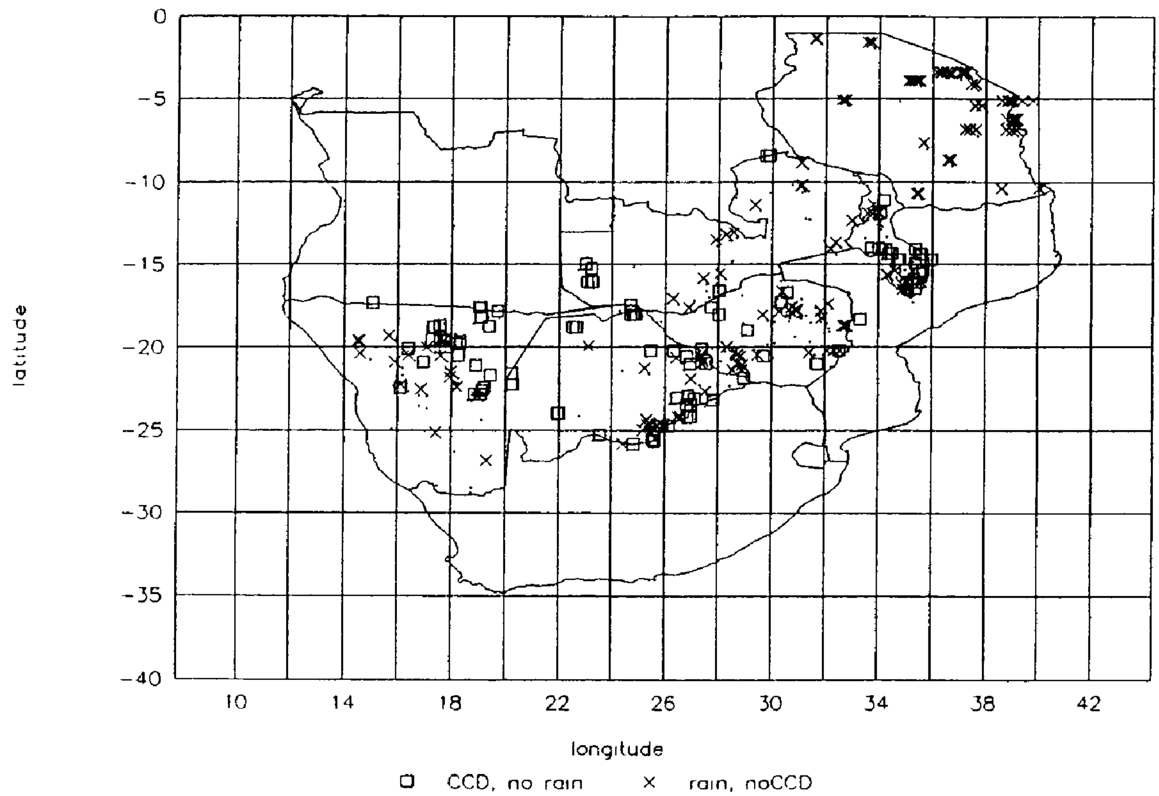

Figure 1. Comparing cold climate cloud based and raingauge indicators of rainfall for southern Africa.

location and season, the threshold and rain-rate should change accordingly. At Reading we have made extensive studies of the relationship between cloud top temperatures and rainfall over most of non-equatorial Africa, where the assumption about the convective nature of rainfall systems is usually true.

Figure 1 shows a plot of ten-day totals of rainfall and cold cloud duration over southern Africa in the month of November from 1990 to 1992. Each raingauge observation is recorded either as an error if there were no coincident rain and storm cloud, or as correct if they were coincident. In the illustration storm clouds are defined as those with tops below -50 C. It shows that over north-eastern Namibia and western Zambia a colder threshold is needed, while a warm threshold may be appropriate over Tanzania. A series of such plots using different thresholds allows the best threshold to be decided for each part of the region on a monthly basis "best" being defined as that which minimises the errors and divides them equally between rain without cloud and cloud without rain. When the appropriate threshold is decided further sub-division may be needed to define areas in which the storms have similar rain-rate Details of the procedures are given in Milford and Dugdale, 1990a.

3. Applications

Drought monitoring

Rainfall estimates based on the methodologies outlined above have been used to monitor the progress of the rainy season in semi-arid and seasonally arid Africa for several years. They have been implemented by the Food & Agriculture Organisation of the United Nations and the United States Agency for International Development programmes to support the famine warning services, and, through the Overseas Development Administration many countries have been equipped with their own satellite data receiving and processing equipment for local use.

An illustration of an application is given in Figure 2. Here the duration of storm clouds for ten-day periods over part of southern Africa are compared for December 1991 (which corresponds to a severe drought) and 1992 (a more typical season). It clearly shows the shortage of rain in Zimbabwe in 1991 and the early onset of the retreat northwards at the end of December.

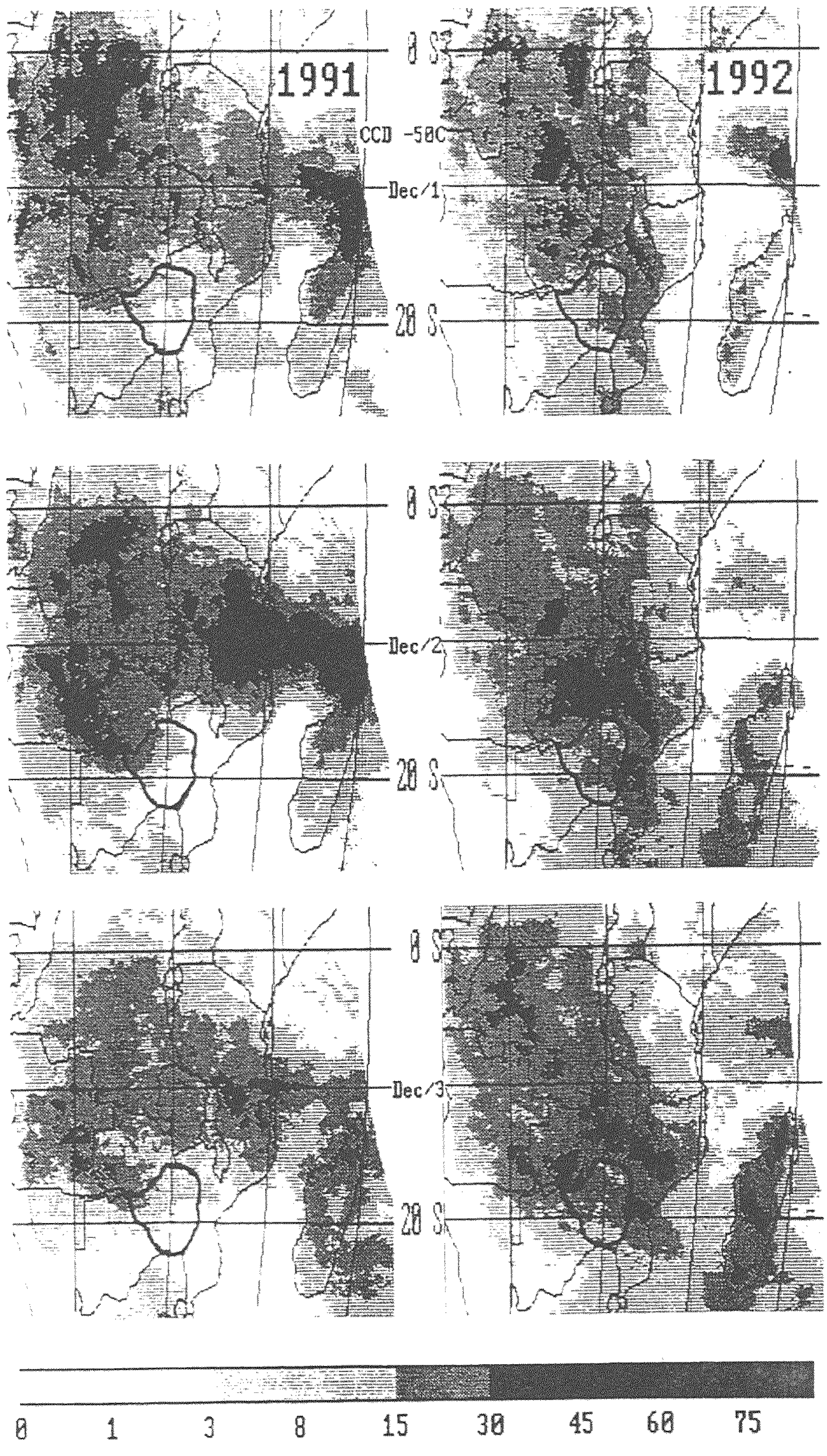

Figure 2 CCD images for the three dekads of December 1991 and 1992 in southern Africa. Zimbabwe is shown in heavy outline

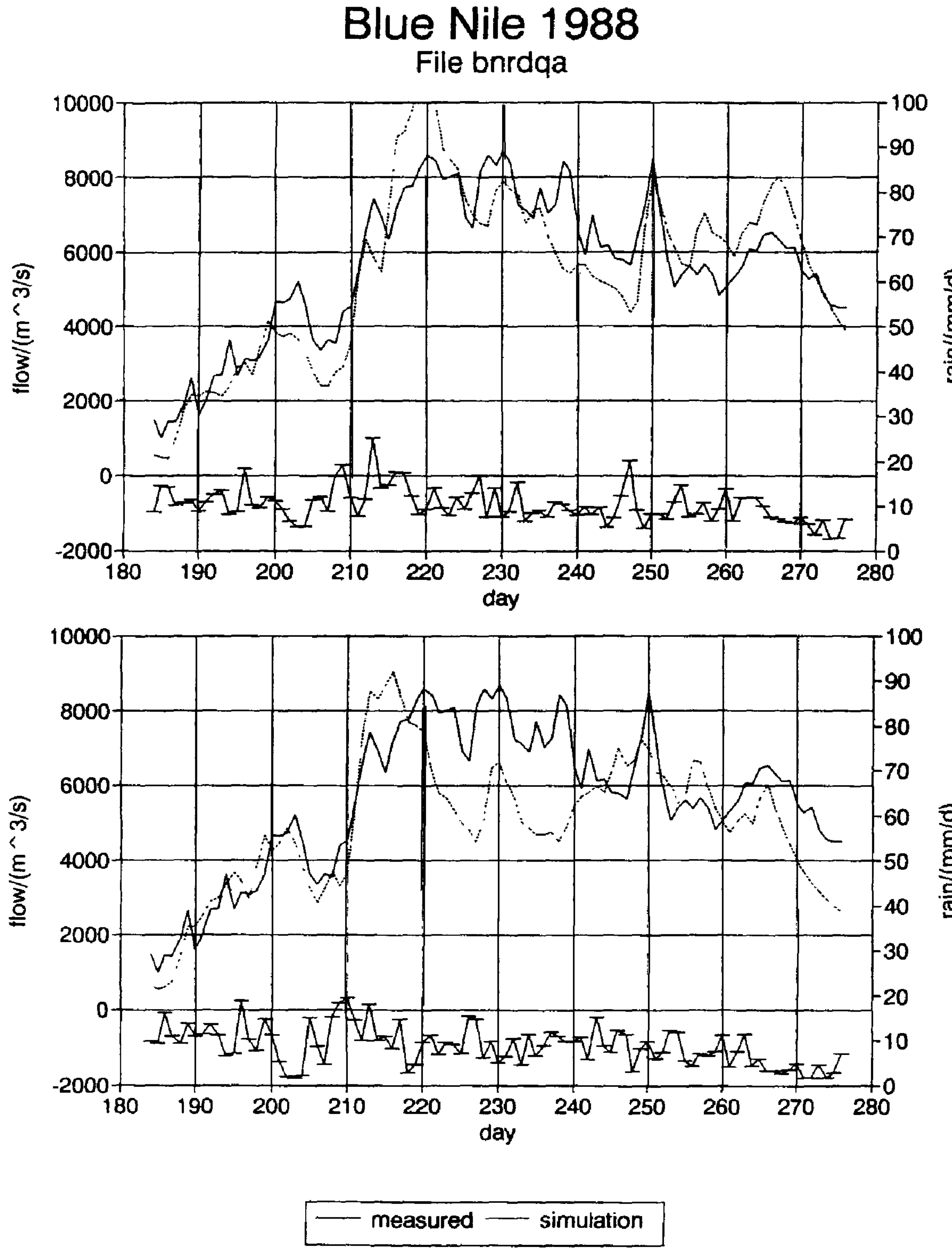

Figure 3 Hydrological models compared to measured flow rates for the Blue Nile. The top graph shows a simulation using all available rain gauge data, whilst the bottom graph simulation is based on CCD estimation. In both cases the lowest curve shows the rainfall values used in the simulations.

Hydrology
Satellite based rainfall estimates can also be used for flood warning Typically, daily values of catchment average rainfall are required as input to a hydrological forecast model. In many areas of northern Africa where it is not possible to obtain daily, real time, ground based rainfall values, satellite based estimates are a useful alternative which requires only the installation of a satellite dish, plus associated electronics and a dedicated PC. Unfortunately, the requirement for daily rainfall estimates means that the necessary averaging must be done spatially. This restricts the satellite based approach to large catchments (> 10,000km). Furthermore, there is a tendency for TIR rainfall values to underestimate extremely heavy rainfall. This is not a problem for drought monitoring - but is more important if the purpose is flood warning.

Work at Reading University has been focused on the Senegal and Nile rivers. Figure 3 shows the 1988 flood season modelled using satellite based and raingauge based rainfall estimates. The satellite is better in some parts of the season and worse in others - but it should be remembered that the raingauge data would not have been available in real time. Since 1992 there has been an operational flood warning system for the Nile, based at Khartoum. The overall system was installed by Delft Hydraulics and used the TAMSAT methodology for rainfall estimation. So far the system has operated successfully.

Pest control
Many agricultural pests need specific soil moisture and temperature regimes for breeding The desert locust, for instance, requires about 20 mm of soil moisture for egg laying and hatching. This also gives enough vegetation to support the emergent insects. Storm monitoring from Meteosat can indicate where surface based teams can most usefully be deployed to carry out their surveys, and, if necessary, apply control measures (Milford and Dugdale, 1990b).

It is also, in principle, possible to use the full 1km resolution NDVI imagery to identify where, within potential locust breeding areas, vegetation has developed However, the standard form of the satellite-derived NDVI has insufficient discrimination to give unambiguous information at the low NDVI values involved. Research into the application of atmospheric corrections and the following relative changes in NDVI is being undertaken try to solve these problems

Crop modelling
The early identification of large scale crop failure or shortfalls in annual production of crops or pasture can be enhanced by running a continuous crop water use model with the rainfall estimate as an input. Water in excess of current crop requirements is held as soil moisture and depleted in dry periods. The rate of evaporation and transpiration is a function of soil moisture and crop status. Such a model has been applied to the Sahelian zone with very encouraging results. Full details are given in Bonifacio *et al.*, (1993).

4. Conclusions and prospects

Products from the meteorological satellites are already playing a role in mitigating the effects of drought, floods and pests over tropical Africa. The main constraints on the extension of this work are the inability of the current rainfall estimation methods to pick up unusual events and the poor representation of evaporation in the hydrological and crop use models. Evaporation is controlled by both the availability of both energy and water. The main variable in the energy component is solar radiation and algorithms are available for extracting this from geostationary satellite data. It may be possible to use both the NDVI and passive microwave data to obtain a better estimate of the availability of water. Combining these data promises improvements in current estimates of evaporation over large areas

Passive microwave data will become routinely available from polar orbiting meteorological satellites within the next two or three years. This will give some information on moisture in the upper few centimetres of the soil and will be capable of improving the rainfall estimates Much research is needed in placing these microwave rainfall estimates on a sound physical basis and in combining them with the TIR data to give continuous temporal coverage

5. Acknowledgements

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Discussion

Long-term monitoring is not the normal role of a university group, pointed out Dr. Walter (NASA). Dr Grimes and Dr. Williams replied that one of the ways in which the LARST approach works is to identify whether the operational system works, and if not for groups like TAMSAT to do the research to solve any problems. Ms. Morland (UCL) asked how famine warnings are transmitted. As an example Dr. Grimes cited the Ethiopian Met. Service who compared predicted and actual rainfalls every 10 days to identify trouble spots and then pass the information to the agricultural sector.