Regional Scale Satellite Data Sets for Agricultural, Hydrological and Environmental Applications in Zambia

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ABSTRACT

Many applications in the areas of agricultural, hydrological and environmental resource management require data over very large areas and with a high imaging frequency - monitoring crop growth, water stress, seasonal wetland flooding and natural vegetation development. This precludes the use of fine resolution data (Landsat, Spot) on the grounds of cost, accessibility and low imaging frequency. Meteorological satellites have the potential to fill this need, given their very wide spatial coverage, and high repeat imaging. The Remote Sensing Unit (RSU) at the Zambia Meteorological Department routinely receives, processes and archives imagery from both Meteosat and NOAA AVHRR satellites. Here I wish to present some examples of applications of these data sets that arise from the RSU work - relationships between rainfall and vegetation development as assessed by satellite, derived information and seasonal patterns of flooding in the Barotse floodplain and the Kafue flats. I also wish to outline ways in which a more widespread use of this data by the Zambian institutions can be achieved.

1. INTRODUCTION

NOAA-AVHRR

The National Oceanic and Atmospheric Administration (NOAA) satellites are a series of polar orbiting satellites which provide two images a day covering an area around a receiving station whose maximum extent depends on the receiver characteristics. The satellite of interest at the Remote Sensing Unit of the Zambia Meteorological Department is NOAA-14, providing data during an early afternoon pass and a night time pass about 12 hours later. The NOAA satellites provide data in five spectral channels - two measure solar reflected radiation, visible (VIS, channel 1 at 0.7μm), and near infrared (NIR, channel 2 at 1.1μm) wavelengths, two measure terrestrial emission radiation in thermal infrared wavelengths (channel 4 at 11μm and channel 5 at 12μm) and another measures a mixed signal of reflected solar radiation and terrestrial emission during the daytime pass and pure terrestrial emission during the night-time pass at mid-infrared wavelengths (channel 3 at 3.7μm). The NOAA data captured at the Remote Sensing Unit of the Zambia Meteorological Department has a spatial resolution at nadir of 1.1 km. The variety of spectral channels available, medium spatial resolution, and daily frequency make the NOAA-AVHRR data popular in a variety of environmental monitoring applications.

METEOSAT

The METEOSAT geostationary meteorological satellite images cover all of the African continent with a nominal resolution of 5.5km and are acquired every half-hour. This may seem a rather coarse spatial resolution but its data are used for regional scale, fast moving phenomena (rainfall, cloud motion) where temporal resolution is the crucial factor.

Through much of Africa, rainfall is the most important meteorological factor in determining agricultural production and hence the economic well being on a local or national scale. Accurate real-time information on rainfall should therefore be valuable in providing an overview of the development of the current rainy season, highlighting areas where crop shortfalls or localised flooding are likely. Unfortunately, the raingauge network in Zambia is too sparse to provide this overview and is still reducing further as government funding on public services continues to be small. The use of rainfall estimates based on METEOSAT satellite data should be of great benefit. In particular, its thermal infrared imagery can be used to detect storm clouds. A satellite derived parameter known as CCD (Cold Cloud Duration – an indicator of rain bearing convective cloud activity) is used to provide useful quantitative rainfall estimates. These estimates can easily be produced in near real-time and provide full area coverage irrespective of the remoteness of a region given the temporal and spatial characteristics of the METEOSAT satellite.

The problem remains of how to communicate this information to local institutions that need to use it. I argue in favour of local reception facilities as they provide more timely information, ensure that local staff are familiar with remote sensing technology, improves their scientific background, promotes technical independence of local institutions and can provide information not usually available from international dissemination centres. Locally produced information has a better chance of reaching a wider local user base and is more flexible to varying use demands.

Aiming at improving this situation a joint project took place between the TAMSAT group, Department of Meteorology - University of Reading, UK and the Zambia Meteorological Department (ZMD). Zambia was suitable for simple rainfall estimation algorithms based on METEOSAT thermal infrared (TIR) imagery and ZMD had the basic technical capacity (METEOSAT and NOAA-AVHRR receivers) already in place.

From an input consisting of dekadal raingauge data, daily and dekadal images of storm cloud duration (CCD), plus NOAA-AVHRR day time and night time imageries, the system is able to produce a set of outputs.

2. AGRICULTURAL APPLICATIONS

Dekadal (10 daily) rainfall estimates: These images are derived from a weighted average of gauge and satellite data. Estimates are made for 10-day amounts since daily estimates would be too unreliable.

- A set of gauge rainfall values is interpolated by a geostatistical technique (block kriging) deriving a map of rainfall and its associated error variance map.
- A regression model provides an estimate of rainfall and an associated error from an image of CCD output by METEOSAT.
- A combined estimate is derived as a weighted average of the above estimates. The weights are a function of the uncertainty in each component - where the gauge network is sparse, the gauge-derived estimate has higher error and hence smaller weight than the satellite estimate.
- The merged estimate is therefore weighted more heavily by whatever component is locally more accurate.

(Figure 1 below)

Number of rain days in a dekad : Although CCD images can't provide reliable estimates of daily rainfall, they can provide useful information on the simple yes/no occurrence of rainfall. A logistic model was derived relating probability of rainfall occurrence to amount of daily CCD, calibrated on years of historical data. From this model an image of probability of rainfall is derived. From the images of probability of rainfall we derive categorical images of rainfall occurrence by thresholding at a given probability level, i.e. setting pixels to 1 if above this threshold, or 0 if below. The threshold is derived according to criteria of optimal discrimination of rain/no-rain. From the daily rainfall occurrence images we can trivially derive images of number of rain days per dekad (or whatever period of interest) and length of dry period.

(Figure 2 below)

Sowing rains : These are derived from a combination of the **10 day rainfall** images and the **number of rain days** images, as areas where it rains more than 25 mm from 4 or more rain days in a dekad (definition given by users to ZMD). These images are used to monitor the onset of the growing season and produced up to the end of December.

(Figure 3 below)

Cumulative rainfall : These images are derived from the dekadal (10 daily) rainfall estimates by simple summation.

(Figure 4 below)

Cumulative rainfall departure : It is more informative to provide cumulative amounts in terms of a comparison against a long term mean situation. We use long term rainfall information combined with the cumulative rainfall images to produce cumulative rainfall departures. Values below (above) 100% indicate deficits (surplus) relative to normal. Regions where severe deficits occur particularly at crucial stages of the agricultural season can be easily identified and targeted for assistance.

(Figure 5 below)

The maps above provide a country wide perspective. In many cases a more local perspective is required and for this one can look at data extracted over a small representative region. Figs 6 show a plot used to evaluate the local progression of the rainy season against the long-term normal.

(Figure 6 below)

3. NORMALISED DIFFERENCE VEGETATION INDEX (NDVI)

The main application of vegetation index is the monitoring of vegetation conditions at a national scale. The vegetation index is a function of spectral contrast between the reflected NIR and VIS radiance from a given surface. The contrast is greater for vegetation than for soil and hence the higher a vegetation index the denser the cover and vigour of vegetation.

The channel 1 and channel 2 data which compose the NDVI *[NDVI = (NIR-RED)/(NIR+RED)]* are affected by atmospheric interference of various kinds (water vapour, aerosols and clouds). The effect of these interference is to lower the value of the NDVI. Given that vegetation is a slowly varying parameter, the usual procedure is simply to maximise the value of the index over a period of time, e.g. 10 days, so as to minimise the influence of the atmosphere.
The monitoring of vegetation can be divided into two categories; *beginning of growing period and within seasons monitoring.*

(Figure 7 below)

Beginning of season monitoring: Monitoring the magnitude of the NDVI increase against the dry season level in the first month of the rainy season (e.g. October for Zambia) allows users to detect where the vegetation has started developing in response to the first significant rains. This is of particular importance in areas of rain fed agriculture, which contain the most vulnerable members of the farming community. This information can be usefully analysed in conjunction with early season estimates of rainfall and rain days.

(Figure 8 below)

Within season monitoring: Images of NDVI provide an efficient means of early detection of vegetation stress. Users of this information are those involved in agricultural monitoring and national park management. Particular targets are the areas of rainfed agriculture during critical phases of crop growing period (e.g. early stages, maturing). These are best monitored by tracking a time series of relevant parameters (NDVI) through the season.

Links to Rainfall: The relationship between rainfall and the resulting plant growth are obvious to the observer of nature, though there remains much to be learned about vegetation community dynamic response to rainfall.

(Figure 9 below)

This is a challenging and complex area of work where much research still needs to be done. At RSU we have started to build simple descriptions of rainfall vegetation responses, in order to map geographical variations in the nature and intensity of those responses. We are interested to know things like the typical time lag between the first significant rainfall and subsequent vegetation development, relative comparisons of magnitudes of (NDVI, rainfall amount) between different regions, etc,

4. HYDROLOGICAL APPLICATIONS

Rainfall-runoff models: Hydrological applications require knowledge of rainfall patterns and average amounts over large catchments. The data products described so far can satisfy many of need for such applications – average rainfall amounts, fractional wet area, vegetation cover information, can constitute direct input into rainfall runoff models able to provide estimates of river level for catchments which may be poorly instrumented.

Wetlands and Seasonal flood monitoring: Zambia contains wetlands of major importance - Bulozi Floodplain, the Kafue Flats, and Lukanga Swamps among many others. Monitoring these wetlands is crucial for their management and constitutes a major challenge, given their extent and remoteness. Of particular interest is the study of the dynamics of the spatial extent of these wetlands namely during the decay phase following the end of the rainy season.

NOAA AVHRR data can help in this task given that large scale flooded areas can easily be identified from its night-time imagery using the thermal channels and from daytime imagery using a combination of near infrared and thermal channels. Use of night time imagery is preferable, particularly that of channel 3 given that it presents the largest thermal contrast between water and land pixels (Mulando., A., 2000)(fig 10). Routine capture of the night-time imagery started in March 1998.

(Figure 10 below)

Lake Surface Temperature: Temperatures of the water body can be obtained from the NOAA AVHRR satellite obtained at night from a combination of three different channels. The night time images are preferred so that the direct warming of the Lake could be avoided. In addition the images need to be cloud free in order for the correct results to be collected. An image showing the variation of temperature over Lake Kariba is shown below, (Ngoma., S., 2000) (fig 11).

(Figure 11 below)

5. CONCLUSION and RECOMMENDATIONS

I wish to recommend the following:

- encourage comments from all interested institutions on the information produced and suggest other useful information products.
- provision of detailed user specification for existing and suggested products.
- provision of detailed user community specification on the output contents e.g. printed hard copies, numeric values over areas of interest, soft copy in a word document e.t.c.
- identification of areas of interest by the user community that requires close monitoring and provide their geographic specifications.

The above panorama of the RSU output and work shows that good quality data and information products can be generated within country and with moderate resources. It also shows that intensive training done in country and targeted to the projected output is the key to a long-term sustainable activity by local institutions. Having built a basis for routine production of data, we are now in a position to move into a next phase of starting small research projects targeting the information needs of the country and of its institutions.

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God Bless you all

6. REFERENCES

Ngoma., S., 2000, Real-time Lake Surface Temperature monitoring using NOAA AVHRR.

Mulando., A., D., Nawa., K., 2000, Rainfall Estimation in Zambia.

Mulando., A., D., 2000, Flood Mitigation Strategies of the Bulozi Flood Plains, Western Province, Zambia.

Grimes D., Bonifacio R., 1999, Flood and Drought Warning in Southern Africa.

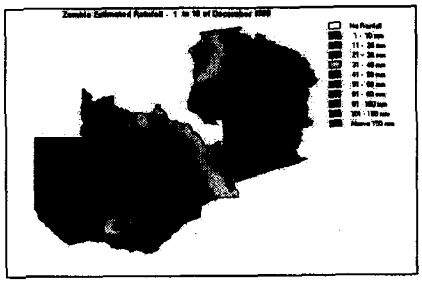

fig. 1 - Dekadal Merged Rainfall Estimate, December 1999

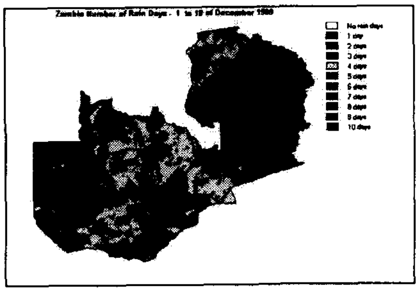

fig. 2 - Dekadal Number of Rain days, December 1999

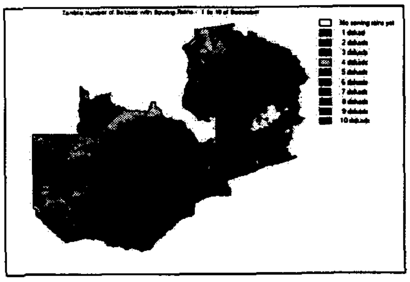

fig. 3 - Number of dekads with Sowing Rains, December 1999

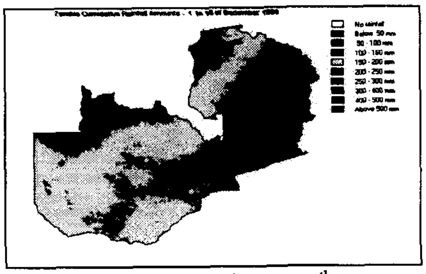

fig. 4 - Cumulative rainfall 1st Oct - 10th December 1999

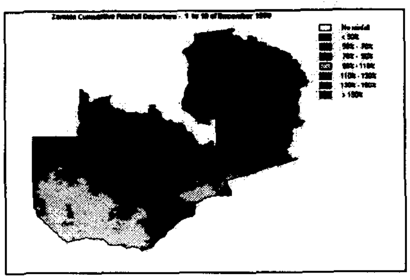

fig. 5 - Cumulative rainfall departure from normal 1-10 December 1999

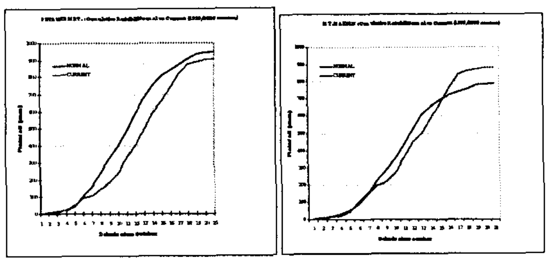

fig. 6 - Cumulative rainfall time series for the current season (red) and the long-term normal situation (blue) for Petauke (left) and Mt Makulu (right). A persistent deficit is evident for Petauke, while Mt Makulu though ending the season with some surplus, actually endured some deficit for most of the season.

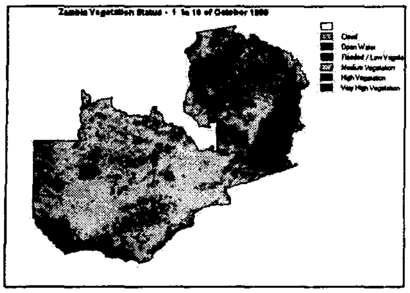

fig. 7 – NDVI image showing the vegetation status beginning of season, 1-10 October 1999

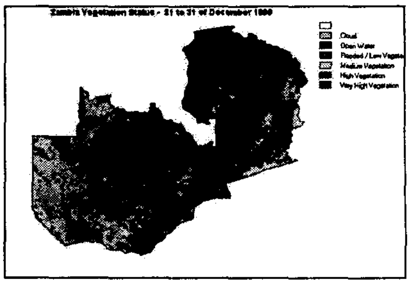

fig. 8 - NDVI image showing the vegetation status within season, 21-31 December 1999

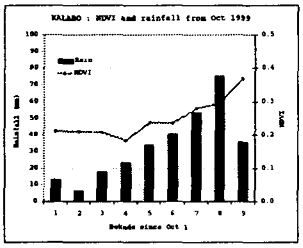

Figure 9 - Rainfall and NDVI time series For a selected location in Zambia for Kariba. October - December 1999

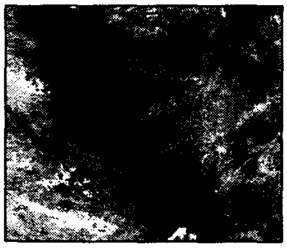

Fig 10 - Image showing flooding extent over Bulozi flood plains. Flooded areas appear darker greys, ground light grey. White is cloud

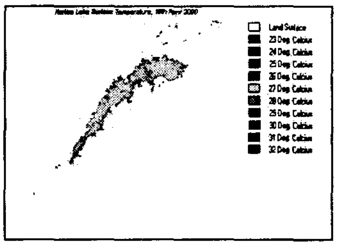

Fig 11 - image showing Lake surface temperature distribution over Lake