THE USE OF MULTISPECTRAL AND MULTITEMPORAL METEOSAT B2-DATA FOR DESIGN OF WATER MANAGEMENT SYSTEMS

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ABSTRACT

Planing and design of water management systems requires long and continuous time series of hydrological data. A montly cloud cover index is determined as a function of the cloud top temperature (IR channel), the "reflectivity" of the cloud (VIS channel) and the state of the environmental mean relative humidity in the upper troposphere (WV channel) using multispectral and multitemporal B2-Meteosat data. This information is transformed into monthly area precipitation. The monthly area precipitation is then transformed by means of lumped non-linear rainfall-runoff model into monthly runoff values.

1. INTRODUCTION

Planinng and design of water management systems requires long and continuous time series of hydrological data. However, in the most developing countries the time series of hydrological data are either full of gaps or are not availble at all. Water resources engineers, in their studys are very often obliged to use data which are insufficiently representative. Thus hydrologists are urgently seeking new ways of augmenting their convetional data supplies. Satellite remote sensing is being explored as one possible answer to the data acquisition problems.

The idea of the research project presented in this paper can be described as follows: At the beginning of the design of a water resources project-if no hydrological data are available- a hydrological network will be installed which will collect data (ground truth) during the planning period of usually one to three years. On the basis of these data a mathematical model can be developed which connects the ground truths to data obtained from satellite imagery. After calibration and validation of the mathematical model it becomes possible to reconstruct historical river flows with the aid of the mathematical model on the basis of satellite data alone for the period of time for which satellite information is available. This way, the very short time series of hydrological data can be extended considerably thus allowing an estimate of the future performance of the water project in terms of reliability indices.

2. STUDY AREA AND DATA USED

Due to the fact that the mathematical hydrological model discussed here is mainly meant for planning water management systems in developing countries, it seemed adequate to choose a test area in the tropics.

In the Tano basin daily records from 23 raingauges for the period from 1983 to 1984 are available. The raingauge density is 1 gauge per 700 sq. km and their distribution over the catchment is reasonably uniform. Additionally measured monthly runoff values and monthly rainfall for the periods from 1969-1972, 1975-1976 and 07/1984-04/1985 are also available.

The so called B2 Meteosat data were used which contain only every sixth pixel in a line and every sixth line in all three Meteosat spectral channels (VIS: 0.4-1.1 μm; IR: 10.5-12.5 μm; Water Vapour (WV): 5.1-7.1 μm). The time resolution was chosen to be 3 hours.

3. ASSESSMENT OF MONTHLY AREA PRECIPITATION ON THE BASIS OF MULTI-SPECTRAL AND MULTITEMPORAL SATELLITE IMAGERY

A number of scientists have already used data from geostationary satellites to compute precipitation (e.g. Arkin 1979; Griffith 1978). Many of their schemes are, however, based on the individual tracking of clouds entities throughout their lifetimes. These methods require substantial computing capacity and are applicable only over limited areas in space and time periods. For the reconstruction of long hydrometeorological time series the method for deriving rainfall estimates has to be relatively simple. Arkin (1979) has shown that the fractional cloud cover colder than a certain cloud top threshold temperature is proportional to the accumulated rainfall amount. This approach constitutes a feasible solution for the research project presented here.

There are, however, some limitations in the Arkin scheme. The threshold cloud top temperature is the only parameter taken into account, although two clouds with the same cloud top temperature and with comparable sizes produce different rainfall amounts depending on the state of their environmental humidity (Krüger and Schultz, 1982). Clouds in a moist environment produce considerably more rain than those in a dry environment. The influence of the humidity on the rainfall activity is also emphasized by Adler and Mack (1984). Poc et al. (1983) and Schmetz et al. (1988) found a relationship between the radiance of the WV channel of the Meteosat satellite system and the mean relative humidity in the upper troposphere. The mean relative humidity in the upper troposphere obtained from the WV channel can be used as an indicator for the humidity state of the environment of clouds or clouds systems(Papadakis and Schultz, 1990).

Furthermore high and thin ice cirrus clouds with very low cloud top temperature certainly produce no rain. The brightness characteristics in the VIS channel and temperature characteristics in the IR channel allow the distinction between non-precipitating cirrus clouds and those with rainfall activity.

In order to overcome the above mentioned limitations of the Arkin method, a monthly cloud cover index (CCI) is estimated as a function of a certain cloud top threshold temperature (IR channel), certain threshold "reflectivity" of the cloud(VIS channel) and the state of the environmental mean realtive humidity in the neigbourhood of the cloud in the upper troposphere(WV channel). Consequently the CCI is transformed into monthly rainfall values (Papadakis and Schultz, 1990).

Empirical relationships between the observed monthly rainfall and the spectral information obtained from Meteosat data are estimated for the follow cases:

i) The monthly area precipitation (P) and the CCI obtained from the three spectral channels with values of $T \leq -20^0C$ and $R \geq 80$ digital counts for the IR and VIS channel respectively and three mean relative humidity intervals of $0<H_1 \leq 30\%$, $30< H_2 \leq 80\%$ and $H_3>80\%$ for the WV channel(Fig. 1):

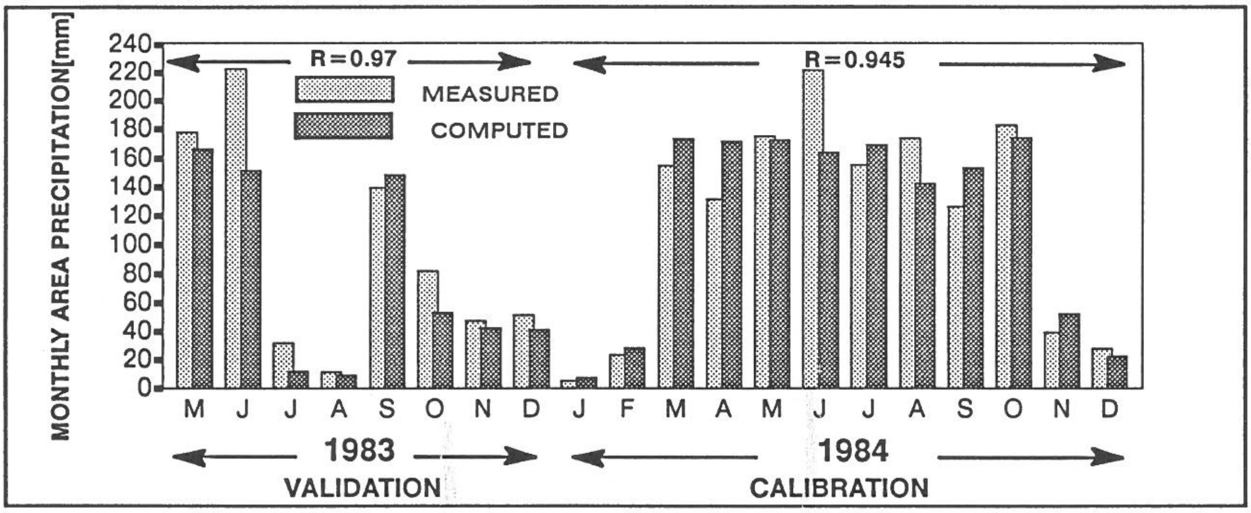

Fig. 1 Comparison between observed and computed monthly rainfall on the basis of three spectral channels (IR, VIS, WV).

ii) The monthly area precipitation(P) and the CCI obtained from two spectral channels (IR, VIS) with values $T \leq -20^0C$ and $R \geq 80$ digital counts for the IR and VIS respectively(Fig. 2):

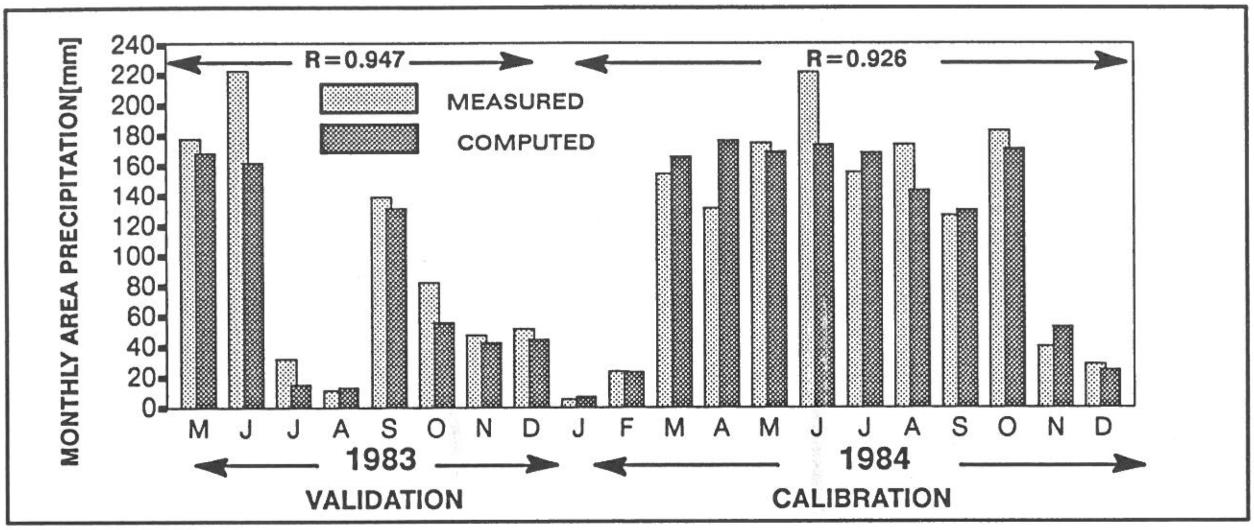

Fig. 2 Comparison between observed and computed monthly rainfall on the basis of two spectral channels (IR, VIS).

iii) The monthly area precipitation (P) and the CCI obtained from two spectral channels (IR, WV) with values for the IR channel and mean relative humidity intervals as by (i) (Fig.3):

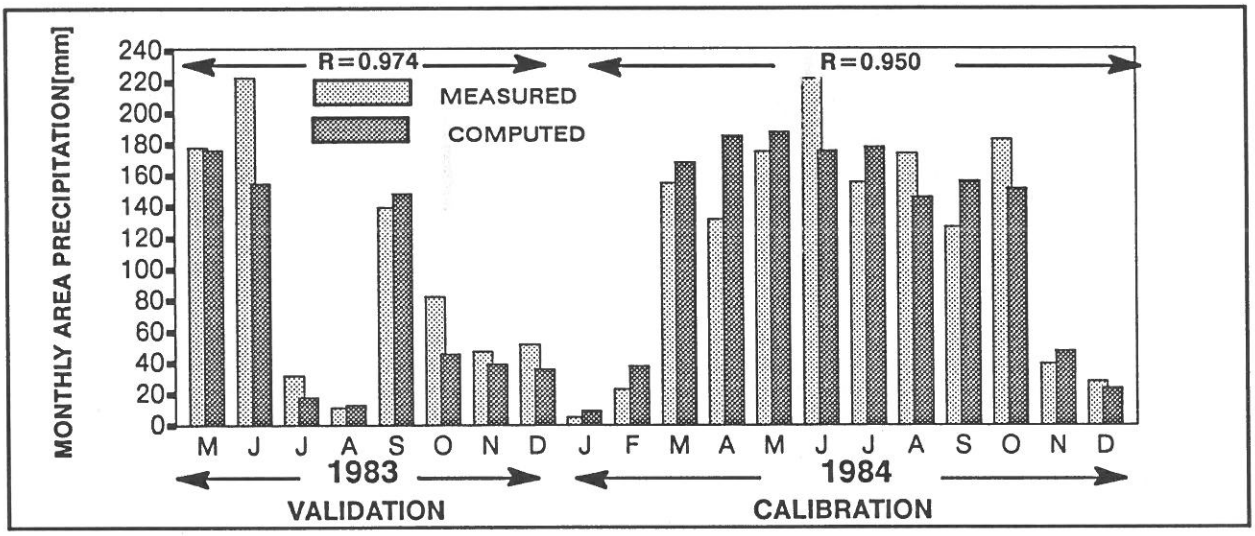

Fig. 3 Comparison between observed and computed monthly rainfall on the basis of two spectral channels (IR, WV).

iv) The monthly area precipitation (P) and the CCI obtained from one spectral channel (IR) with values for the IR channel as by (i) (Fig. 4):

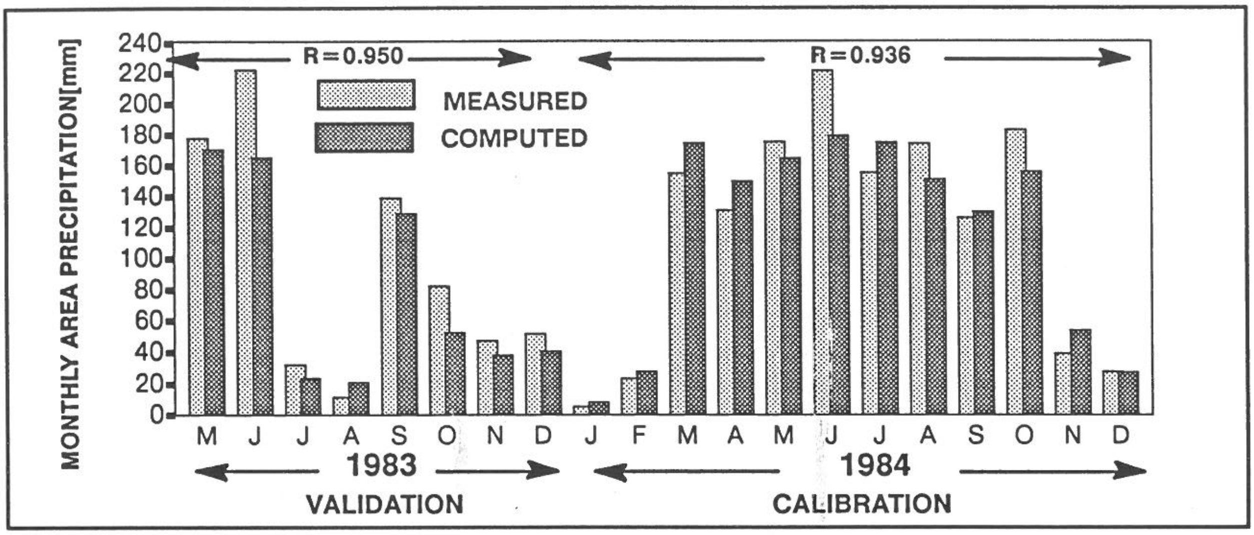

Fig. 4 Comparison between observed and computed monthly rainfall on the basis of one spectral channel (IR).

4. RAINFALL-RUNOFF MODEL

Since a detailed topographical survey and roughness parameters are unknown for the Tano basin, a conceptual model is used to describe the nonlinear behavior of the catchment. The chosen model is a cascade of n equal nonlinear reservoirs with arbitrary storage-outflow relationship whose first two derivatives at a reference outflow define the remaining model parameters (Napiorkowski, 1983). The outflow was shown to be linear in the parameter (b) representing the second order derivative so this parameter can be rapidly optimized for the choice of the first two parameters, number of reservoirs (n) and the first derivative (a), e.i. reservoir time constant. The Second-Order State Model (SOSM), which was shown to be equivalent to the first two terms of the Volterra series, is used within the discrete framework (Napiorkowski and Kundzewicz, 1986) justified in view of the inherently discrete problem that we are forced to deal with in practice.

The objective is to solve the problem of identifying the three parameters (a, b, n) of the SOSM for the watershed described. The data of rainfall and corresponding runoff observed in 1969-1972 are used. The optimal values of the parameters and the optimized fit of the SOSM are shown in Fig.5.

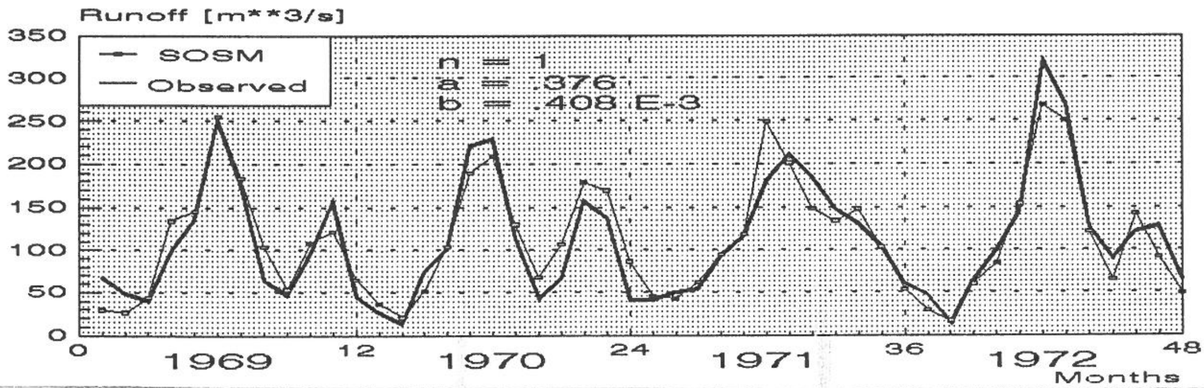

Fig. 5 Model calibration.

The model thus obtained was tested by applying the data in the years 1975-1976. The resulting fit is shown in Fig.6 and can be considered to be adequate.

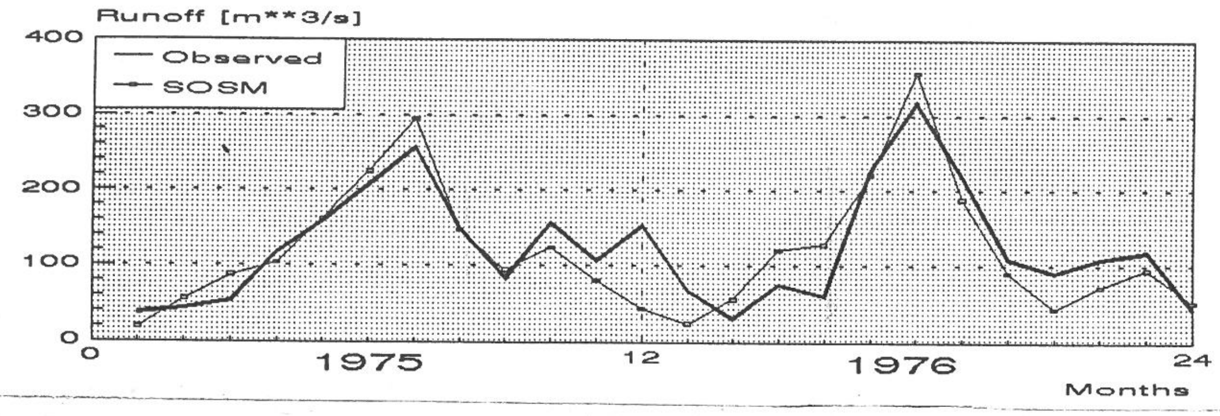

Fig.6 Model verification.

Consequently, the rainfall based on satellite information is transformed to monthly runoff for the period when both the satellite data and runoff were available, namely 07.1984- 04.1985. The resulting fit is shown in Fig.7 and is found to be satisfactory.

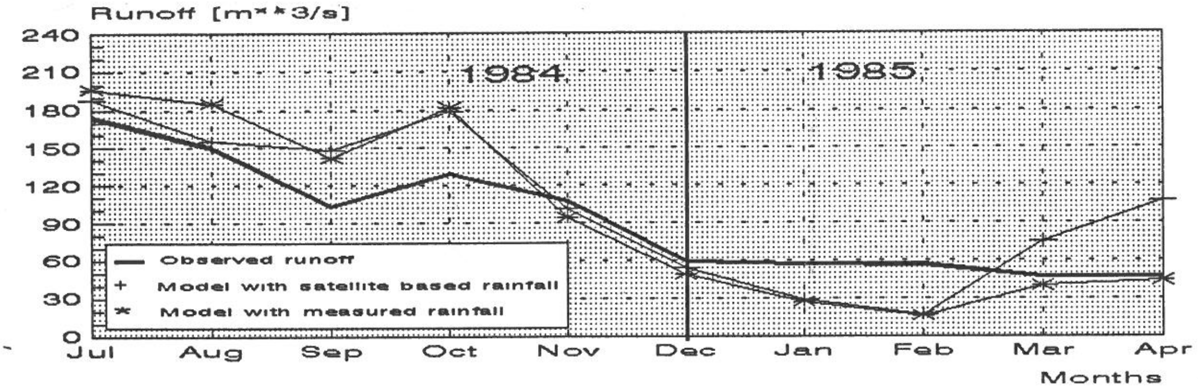

Fig.7 Comparison of observed runoff and that predicted by the SOSM

5. CONCLUSIONS

It was the aim of the study to find out how well a historic time series of monthly runoff in a river basin can be reconstructed on the basis of satellite data alone with the aid of a non-linear rainfall runoff model. The remote sensing data base for this study was a time series of Meteosat data. From the study the following conclusions can be drawn:

-The relationship between monthly rainfall and monthly cloud cover index obtained from satellite spectral information is non-linear.

-From the three spectral channels which were used in the analysis (VIS, IR, WV) the IR data are the most important in this case. The addition of information from the VIS channel to IR data renders no improvement due to the fact (after further analysis) that the rainfall activity in the area under consideration dominates in the night time where no VIS information is available. The addition of WV data to IR data shows a slight improvement (r=0.95 as compared to r=0.93). The use of all three spectral channels (IR, VIS and WV) renders no improvement.

-When the water vapour channel is used, it can be seen from the equations 1,2, 5 and 6 that the contribution of the low humidity values 0–30% is zero. Also the contribution of the humidity higher than 80% is mostly rather small probably due to frequent cloud contamination by cold non-precipitating cirrus clouds.

-In the analysis only Meteosat B2 data were used (only each sixth pixel in a line from each sixth line). Although poor, it seems that this resolution will do for catchments of the Tano river size.

-The satellite-based monthly precipitation, when transformed by the non-linear SOSM, generates monthly runoff values that are accurate enough for hydrological purposes.

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