THE ROLE OF SATELLITE REMOTE SENSING IN PRECIPITATION FORECASTING, RAINFALL ESTIMATION, AND WATER MANAGEMENT

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ABSTRACT

Infrared data from the U.S. GOES geostationary satellites are used to operationally estimate precipitation amounts. Two techniques have been developed: the Interactive Flash Flood Analyzer (IFFA) and the Convective Stratiform Technique (CST). IFFA, a semi-objective decision tree approach, has been used operationally for more than 10 years. Estimates of potential rainfall amounts are calculated for heavy rain or flash flood producing weather systems with a 70% storm total accuracy. The newer CST is an objective (computer-based) analysis system that produces estimates for all rain events. Water Vapor data is providing new insights to the development of analytical techniques to forecast heavy precipitation or flooding events. Most of today's meteorological satellites are also equipped to interrogate remote data collection platforms that are used extensively by hydrologists. Programs are underway to incorporate these satellite based observations and estimates into hydrometeorological models for water management activities ranging from river containment to hydroelectric power generation.

Key Words: Hydrology, Water Management Application, Remote Sensing Application, Atmospheric Remote Sensing, Precipitation

1. INTRODUCTION

Water is one of our most important natural resources. It is the essence of life and yet, unmanaged it can be catastrophic. The importance of precipitation is well known to the populations of arid lands. Today, as populations grow or resettle into new areas, communities are becoming acutely aware of the need to conserve or even ration water. Recent droughts and resultant rationing of water in large populated states such as California and New York have clearly illustrated that precipitation is a valuable resource. Many hold the view that in the next century water shortages will eclipse our concerns about oil or fuel reserves.

On the other hand, heavy precipitation can be disastrous. In the United States, flash floods are the leading cause of deaths and destruction. A significant effort has been made to improve the forecasting of heavy precipitation. In addition to long-range forecasts, short-term 0-12 hour outlooks or Nowcasts are also issued. These Nowcasts are used to prepare weather watches and warnings and to facilitate preparedness and evacuation activities by local officials. Recently, a pilot project has been undertaken to incorporate satellite-based precipitation estimates into a hydrometeorological forecast model for the management of the Nile River. This is the first step to manage, end to end, water, our most precious natural resource.

2. SATELLITE OBSERVATIONS

The primary U.S. satellite system employed in the monitoring and estimation of precipitation amounts is the Geostationary Operational Environmental Satellite (GOES) operated by the National Oceanic and Atmospheric Administration (NOAA), National Environmental Satellite, Data, and Information Service (NESDIS). Data, taken at half-hour intervals in the visible, infrared (11.5um), and water vapor (6.7um) wavelength bands are used to compute estimates of precipitation. The METEOSAT system, operated by the European community is similarly instrumented and its data will be used in the Nile River Forecast System. The GMS system, operated by the Japanese Meteorological Agency, provides frequent interval data in the Infrared and visible wavelengths. Techniques have also been developed to employ data from polar orbiting satellites (Barrett and Martin, 1981). The less frequent passage of these satellites limits the use of the data for short-term events such as flash floods, but can be used to provide estimates for daily rainfall and longer-term climate observations. Microwave sensors, especially those operating in the 85GHz range, are providing exciting new data for precipitation estimation. The "all weather" capabilities provide better definition of active areas of precipitation within storm systems.

## 3. FORECASTING PRECIPITATION AND ESTIMATING RAINFALL

The focus of weather forecasting in the next decade is on the short-term (0 to 3 hours) forecast or outlook, frequently called the Nowcast. New observational systems such as doppler radars, wind profilers, automated surface observing systems and advanced GOES satellites are being procured to support the requirements of Nowcasting. Regional numerical forecasts generating hourly updates are planned to support the forecasting of mesoscale weather events and the issuance of severe weather and flash flood watches and warnings.

### 3.1 The Heavy Precipitation Estimation Program

For more than a decade, NESDIS has produced half-hourly precipitation estimates from satellite data. A decision tree technique that employs visible and Infrared satellite data is used to determine rainfall amounts (Scofield and Oliver 1978, Scofield 1987). Variables such as changes in cloud top temperatures and areal coverage plus environmental conditions (e.g. atmospheric water content) are used to determine precipitation amounts. Thunderstorm complexes are responsible for the heaviest rainfalls (Xie and Scofield, 1989). Figure 1a shows a large area of thunderstorms over the eastern portions of Texas (T) that produced more than six inches of rain in a 24 hour period in December 1991. The Infrared data are displayed with
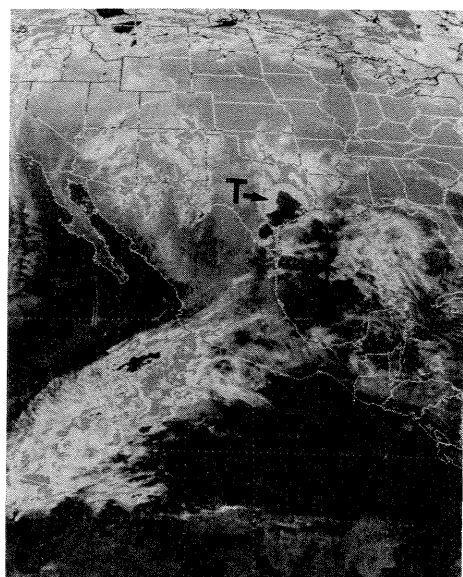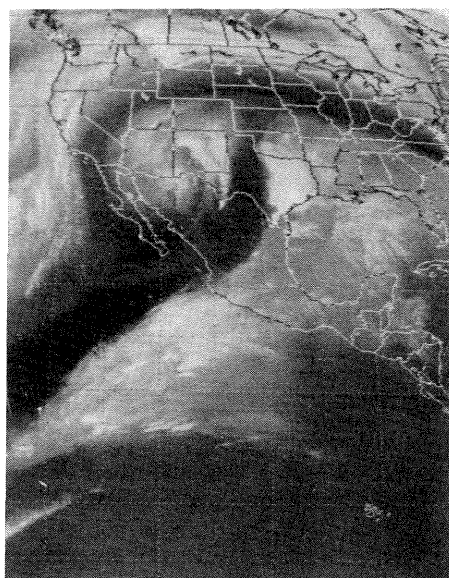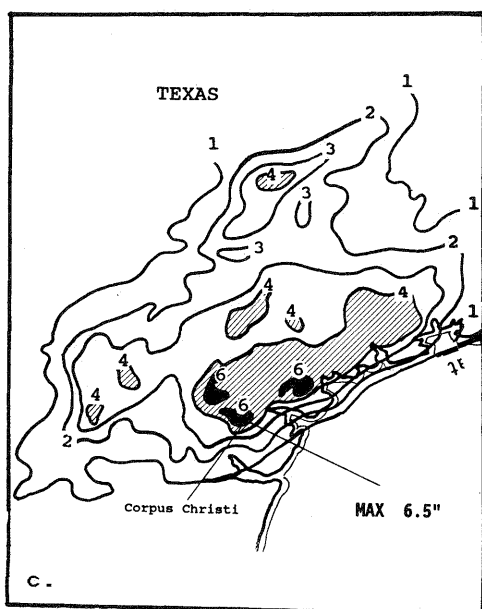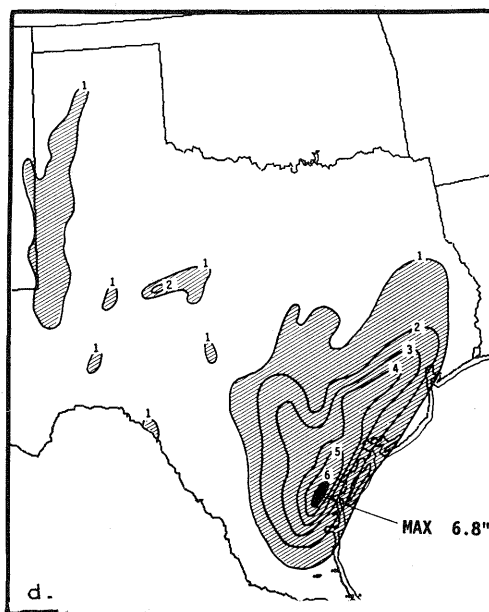
Figure 1.   a) Enhanced Infarred, GOES-7, 0100UT, December 22, 1991. b) Water
Vapor Imagery, GOES-7, 0000UT, December 22, 1991. c) 24 hour Satellite Derived
Precipation estimates ending at 1200UT, December 22, 1991. d) 24 hour observed
rainfall ending 1200UT, December 22, 1991.

darkest gray shades depicting warm radiating surfaces, such as the ocean, and lighter tones representing cooler land and cloud features. An enhancement curve has also been applied to delineate cloud tops that are colder than - 50C; these appear dark gray in Figure 1a. Subsequent changes in the cold cloud top temperatures and areal coverage of these temperatures are the basis for the estimates produced by the Interactive Flash Flood Analyzer (IFFA) program (Scofield, 1987, Borneman, 1988). The satellite derived precipitation estimates for this event can be seen in Figure 1c and the observed rainfall amounts are shown in Figure 1d.

IFFA estimates are typically computed for storm systems with the potential to produce heavy rains or flash floods. These are then forwarded to field forecast offices of the National Weather Service where local forecasters issue watches and warnings to emergency management officials and the public.

Water vapor imagery, a fairly recent data set, has been identified as an important tool in the outlook for potential heavy precipitation events. Long water vapor plumes such as the one stretching from Hawaii northward to the coast of Washington, appear medium

gray to white in the imagery (Figure 2). The light gray shading indicates the presence of upper level moisture areas; white areas represent deep cloud cover. These plumes transport moist tropical air to high latitudes and frequently set the stage for heavy precipitation. Propagating storms or fronts, add the catalyst to initiate the heavy precipitation (Scofield 1990). These plumes from tropical and subtropical latitudes are found in all geographic areas. For the most part, the position of the plumes, once established is slow to change. This allows meteorologists to anticipate and forecast a longer period (12+ hours) of heavy precipitation and fine tune the local forecasts with ancillary satellite, radar, and local observations. Note that a similar plume was present during the period of heavy rains in Texas (figure 1b).

3.2 Automated Precipitation Estimation

Over the years, the IFFA program has been quite successful, averaging a modest 30% error in the estimation of rainfall amounts. However, even with interactive computers, the technique is manually intensive and limited to the monitoring of one or two areas at a time. Two new techniques are being examined for the future. The first is the Convective Stratiform Technique (CST), a fully automated estimation algorithm developed by Adler and Negri (1988). This would allow meteorologists to

automatically monitor all potential precipitation events and concentrate their attention on the areas with the largest potential for flooding.

The second approach lies in the use of an "expert system" to estimate rainfall. A preliminary attempt to apply neural network techniques to this problem is described by Zhang and Scofield, 1992, in an earlier paper at this Congress. An Artificial Neural Network Expert System for Satellite-Derived Estimation of Rainfall (ANSER) has been trained and tested on thunderstorm complexes that exhibit backward (south or westward) growth characteristics. Preliminary results show less than a 5% error in estimated precipitation amounts. Both of these techniques hold great promise for automated inputs to hydrological models.

4. HYDROLOGICAL APPLICATIONS

Advances in computer technology, Geographic Information System (GIS) applications and data bases, hydrologic models, and weather radar and satellite observations all offer the potential for improved forecasts of river and stream conditions. Data collection capabilities of nearly all of the environmental satellites allow scientists to gather data from ground-based sensors in even the remotest locations of a tributary's watershed or basins. Remote sensing of surface
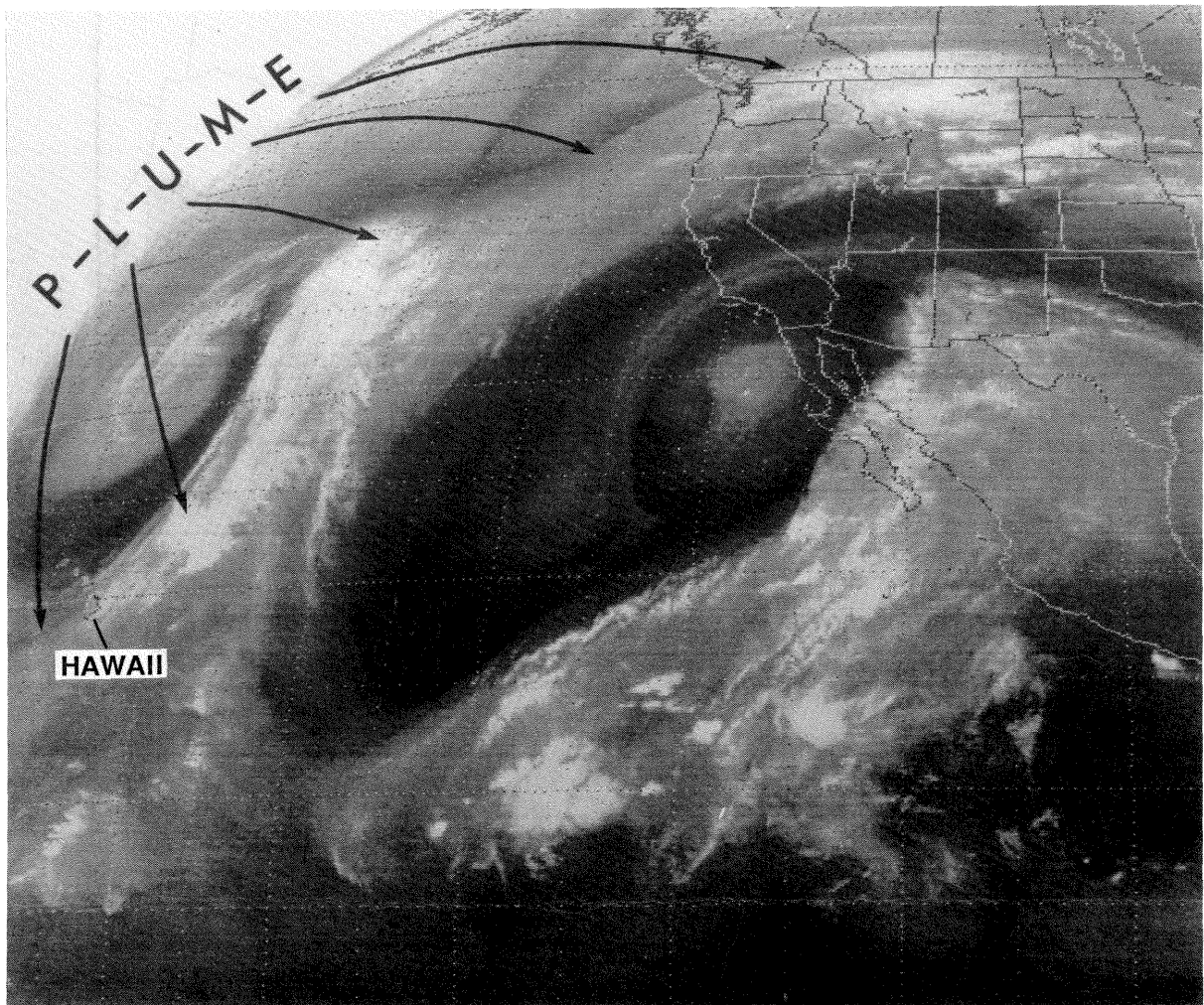

Figure 2.   GOES-7 Water Vapor Imagery taken at 0700UT, November 25, 1990.

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conditions (vegetation and soil moisture) and models of evapotranspiration and snow melt complete the system needed to have a robust end-to-end hydrometeorological forecast system for river and stream stage forecasting as well as reservoir and hydroelectric power management.

4.1 Global Energy Water Experiment (GEWEX)

Insuring water supplies for drinking, irrigation, and hydroelectric power generation, and controlling pollution of water sources/sheds are some of the focuses of research in the GEWEX program. This program, part of the World Climate Research Program (WCRP) has several projects planned. The first is the GEWEX Continental Scale International Project (GCIP) (WCPR, 1990) that plans to test the atmospheric and hydrological components of climate models and provide an opportunity to compare the performance of forecasting models, under real-time conditions. The setting for GCIP is the Mississippi River Basin. This basin, the third largest river basin in the world, includes a wide variety of vegetation, soil conditions, topography and ground water characteristics. Its diverse physical characteristics provide an opportunity for scientists to study meteorological systems, precipitation, runoff and river flow. Satellite observations together with new doppler radars, wind profilers, etc. will be used to determine precipitation, wind fields, and other climate parameters important to hydrometeorological forecasts and climate monitoring. Models and algorithms will be transported to other regional sites for implementation, evaluation, and/or modification under the GEWEX science plan.

4.2 Nile River Forecast System (NFS)

NOAA scientists working under a cooperative agreement with the United Nations Food and Agricultural Organization (FAO) are assisting the Egyptian Ministry of Public Works and Water Resources in the development of a hydrometeorological forecast system to predict the inflow of the Nile River into Lake Nasser. A water balance model that will use satellite precipitation estimates, computed from METEOSAT data, to determine rainfall over the Blue Nile is being developed. Satellite data will be an important observation tool, especially over the data sparse and rugged terrain areas at the headwaters of the Blue Nile. The Blue and White Nile Rivers merge in Sudan to form the Nile River. Using satellite and conventional observations, GIS overlays and hydrologic and streamflow models, the Nile Forecast Center expects to have the capability to predict the water flow for Lake Nasser and the Aswan Dam 90 days in advance.

5. CONCLUSION

The lack of fresh water to serve the ever increasing population and support the food and economic vitality of all nations has already been defined as a major concern for the 21st Century. The mitigation of natural disasters such as the destruction due to flash floods is a major focus of the United Nations program, Decade for Natural Disaster Reduction. These concerns require rapid response, such as warnings on one hand, and

strong resource management on the other. Environmental satellite platforms and sensors, both current and planned, provide valuable spatial and temporal data coverage to support improved hydrologic and meteorological forecasting in the future. Several techniques to employ satellite data have been developed and are operational. From projects such as the NFS and GEWEX greater understanding of the hydrological cycle and more efficient management of this natural resource will emerge.

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