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# Satellites as the Panacea to Transboundary Limitations for Longer Term Flood Forecasting?

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**Abstract:** *This article presents a brief overview of the challenges associated with long-term flood forecasting, as experienced by many flood-prone developing nations, due to transboundary limitations. The potential of satellite rainfall data to overcome such limitations is highlighted. The article also discusses the limitations of rainfall estimates from space-borne platforms due to their high degree of uncertainty in measurement. This is contrasted by the vantage of space that makes them immune to transboundary limitations of real-time sharing of rainfall data across boundaries. Since the availability of satellite rainfall is expected to magnify with the proposed Global Precipitation Measurement (GPM) mission in 2013, it is important for flood forecasting agencies in developing countries to initiate a range of error propagation studies in order to assess the true worth of globally available satellite rainfall data.*

**Keywords:** *Floods, long-term forecasting, satellite rainfall estimation, international river basins, transboundary rivers, multi-user decision support.*

## Introduction

A challenge faced by many lowermost riparian nations in flood-prone international river basins is the availability of in situ hydrologic data across geopolitical boundaries. This information is used for issuing early flood warnings. It is estimated that about 40% of the world's population lives in such international basins, accounting for about 60% of the global freshwater flows (Wolf et al., 1999). About 33 countries have more than 95% of their territory locked within such basins (Giordano and Wolf, 2003). Many of these locked nations are therefore forced to cope with a large proportion of the flood mass generated beyond their borders. Some examples of such flood-prone nations are: (1) Bangladesh in the Ganges-Brahmaputra-Meghna (GBM) basin, which comprises three other nations (Bhutan, Nepal and India) (Paudyal, 2002), (2) Cambodia in the Mekong River basin (other riparian countries: Myanmar, Laos, Vietnam and Thailand) and (3) Senegal in the Senegal River basin (comprising Senegal, Mali, Mauritania and Guinea), among others.

Floods can be forecasted at a point downstream, as long as the river flow at some point upstream is known. This information must be used in conjunction with a hydrological/land-use model for estimating the transformed runoff from rainfall. Based on the combined information of river flow and transformed runoff (that eventually drains into the channels), simple regression forecasts can give fairly accurate short-term estimates of river discharges. However, for many flood-prone nations situated within international river basins, the challenge of issuing effective flood forecasts for a Decision Support System (DSS) can be particularly difficult to overcome due to certain transboundary limitations. Two specific challenges in this regard are: (1) when surface measurements of rainfall and other land surface parameters are largely absent due to inadequate resources or complex terrain (Hossain and Anagnostou, 2004) and (2) when there is no cooperative agreement among riparian nations to share hydrologic information (rainfall, in particular) in real-time for proactive flood management (Webster et al., 2004; Paudyal, 2002). The first condition is commonly observed within tropical basins of Asia, Africa and South America. These basins lack the financial resources for adequate real-time monitoring of hydrological conditions (i.e., mainly rainfall). The second condition, barring a few exceptions (such as the Mekong River Commission–MRC), is endemic in most flood-prone developing nations and severely limits the lead-time in skillful flood forecasting. Bangladesh, for example, does not receive any upstream river flow or rainfall information in real time from India during the critical monsoon season. Bangladeshi authorities, therefore, measure river flow at staging points where the two major rivers enter Bangladesh (Ganges and Brahmaputra) and at other points downstream. On the basis of these data, it is only possible to forecast flood levels in the interior and the south of Bangladesh with two to three days lead time (Flood Forecasting and Warning Center, Bangladesh: www.ffwc.net; Webster et al., 2004). Another example is Senegal, which lies in the Senegal River basin. Despite the establishment of the Senegal River Valley (SRV) Authority, which was set-up as early as 1972 (by the four riparian nations) in order to coordinate water resources management across political boundaries, the floods of 2003 have exposed some of the limitations of long range flood forecasting due to the absence of a real-time rainfall monitoring network in the basin.

**Satellites as the Panacea?**

Since rainfall is the single most important determinant of the state of surface runoff leading to large-scale floods, and because runoff is lagged from rainfall, it is logical to expect that satellite remote sensing of rainfall, along with other satellite-derived surface parameters like elevation, vegetation, soils and river network, can potentially address the current challenge of improving the accuracy and range of flood forecasting for many flood-prone nations constrained within international river basins. A longer forecasting range would have the consequentially beneficial impact of enhancing the utility of a DSS that ingests these warnings. For example, 7- to 10-day forecasts are much more useful than daily forecasts in agricultural decision support, as they inform farmers of the potential benefits of delayed sowing or early reaping of crops. A 21-day forecast is considered most ideal for South and Southeast Asian nations (ADPC, 2002). Extended forecasts also assist in economic decision-making through the early disbursement of rehabilitative loans to the regions that are more likely to be affected by floods (Ninno et al., 2001).

Given the unique vantage point of satellites in space (as opposed to ground-based systems), satellite rainfall data has the potential to: (1) extend the accuracy and range of forecasted flood levels in the lowermost riparian nation through early assessment of the surface runoff evolution in the upstream nations and (2) minimize the negative impact of unavailable data and/or high operational costs of in situ networks for developing nations. The hydrologic time lag (between instantaneous rainfall and the transformed downstream runoff, which magnifies as a function of basin area) comprises the fundamental hydrologic principle for anticipating extension of forecasting range with quasi real-time satellite rainfall data. Recently, the Mekong River Commission's River Monitoring network (http://www.mrcmekong.org) has demonstrated the capability for 7-day river flow forecasting in downstream Cambodia on the basis of the ingestion of satellite rainfall over upstream regions in its forecasting system (USAID/OFDA, 2004).

An additional aspect that makes satellite rainfall data an ideal candidate for flood forecasting over international river basins is the anticipated abundance of high-resolution global rainfall measurements (0.1 degree, three to six hourly) from a planned Passive Microwave (PMW) mission known as the Global Precipitation Measurement (GPM; Smith et al., 2006). This mission, combined with high-frequency rainfall estimates available from Geostationary Infrared (IR) sensors, assimilatory data and multiple sensor estimation techniques (Anagnostou, 2005), can be expected to yield global rainfall products of various levels of utility and accuracy. However, these satellite retrievals are subject to errors caused by various factors ranging from infrequent sampling to the high complexity and variability in the relationship of the measurements to precipitation parameters, which, consequentially, have a highly nonlinear effect on the quality of flood prediction (Hossain and Anagnostou, 2004).

A critical aspect associated with the use of satellite rainfall data in an operational flood forecasting setting in flood-prone international river basins is, therefore, the need to assess the performance of satellite data at spatio-temporal resolutions pertinent for rainfall-runoff modeling. Hossain and Anagnostou (2004) have shown that the use of the more frequent IR rainfall, used to bridge between PMW overpasses over a medium sized (~100 km$^2$) saturation-excess watershed, can yield significant improvements in the estimation of water budget and the magnitude of flood wave. However, improvements are elusive for predicting the arrival time of peak runoff. Although studies have begun to address how errors in satellite rainfall retrieval manifest themselves as flood prediction uncertainty, the extent to which this error affects the accuracy of forecasted flow levels, and the consequential impact on decision support applications (e.g., water management and disaster management), remains unknown.

Climate-based approaches have also been initiated for addressing the limitations of flood forecasting over monsoon-affected nations, such as India and Bangladesh (Webster and Hoyos, 2004). These approaches are based on physically sound principles of early detection of weather patterns and intra-seasonal variability. They rely on coupled cloud model observations and the forecasting of rainfall. Although the rainfall derived from these coupled global climate models is not always sufficiently accurate, due to several sources of uncertainty, including coarse resolutions, weak model relationships and sensitivity to initial conditions (e.g., Chen et al., 1998), both types of data (satellite-based and model-based) have worth as an input to flood forecasting models. In particular, the currently available array of satellite rainfall data and the anticipated global availability of higher accuracy PMW rainfall data that is expected from GPM hold much promise for operational flood forecasting agencies.

**Resolving the Myth and Reality**

Now that the future of GPM beckons to the flood endangered inhabitants of large international river basins, we are currently faced with a dichotomous situation. On one hand, the vantage of space and the hydrologic time lag between rainfall and downstream runoff make satellite rainfall and other satellite-derived land surface parameters ideal to address trans-boundary limitations of flood forecasting in international river basins. On the other hand, satellite measurements of rainfall are not perfect and, hence, the uncertainty associated with these measurements has a nonlinear and deteriorating impact on the accuracy of flood forecasts. This dichotomy represents a competing trade-off for using satellite rainfall data for flood forecasting by agencies in developing countries. To resolve this dichotomy, we now require a clear understanding of the implications of the satellite rainfall error on the prediction and forecasting accuracy of river flows. This is vital for achieving better decision support for flood management: though cost-effective satellite rainfall data appears to have promise, the reliability of an operational forecasting system remains unknown. We do not intend to give the reader the idea that rainfall measuring satellites will resolve all water related issues with GPM. Rather, it is important to start using satellites as a cost-effective solution in large river basins where countries are unwilling to share meteorological and hydrological data in real-time with downstream riparian nations.

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