Experimental Drought Monitoring and Flood Forecasting over Africa Using TMPA Precipitation: A Prototype for a Global Forecasting System

Huilin Gao, Michele Minihane, and Dennis Lettenmaier, Dept. of Civil and Environmental Eng., University of Washington; Nathalie Voisin, Pacific NW National Laboratory
Alok Sahoo, Ming Pan, Justin Sheffield, and Eric Wood, Dept. of Civil and Environmental Eng., Princeton University

1. Introduction

Droughts and floods are pervasive natural hazards. Both the number of events and the economic losses per event have been increasing over recent decades. A global analysis of large floods from the Dartmouth Flood Observatory (DFO, www.dartmouth.edu/~floods) shows that almost half (47 percent) of these evens have been in Africa and Southeast Asia. In July 2011, east Africa's worst drought in 60 years alone had put 11 million lives at risk. However, these undeveloped areas have especially low densities of in situ precipitation stations (see Figure 1).

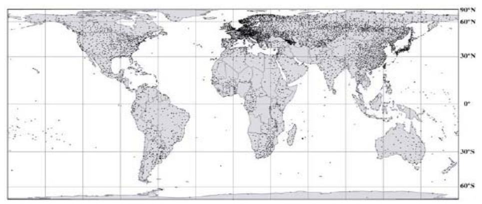


Figure 1: GTS precipitation Stations (Rudolf and Rubel, 2005: http://gpcc.dwd.de)

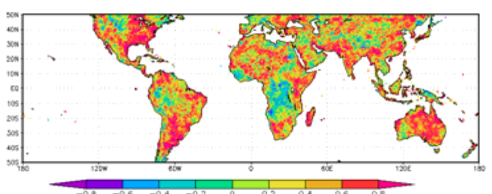


Figure 2: Correlation between SPI-12 derived from TMPA-RP and TMPA-RT

Improvements to satellite precipitation retrieval algorithms from the TRMM and other measurements, including polar-orbiting radiometers, have resulted in the potential for global coverage at temporal frequencies (~ 3 hourly) that potentially allows for global drought and flood monitoring and prediction through hydrologic modeling. Such a near real-time system would be extremely valuable for decision making, as large scale observations of hydrologic variables are lacking worldwide, especially in Africa.

The TMPA research product (TMPA-RP), which is lagged some months behind real time, has been used in many studies as a high quality dataset because of its calibration against monthly gauge observations. However, the adjusted product is often inconsistent with the original real time (TMPA-RT) product over data sparse regions (see Figure 2). Therefore, the motivating science question for this project is: *Can TMPA (and eventually GPM) precipitation products provide the basis for successful global monitoring and prediction of large droughts and floods with usable skill, particularly in parts of the world where in situ networks are too sparse to support more traditional methods?*

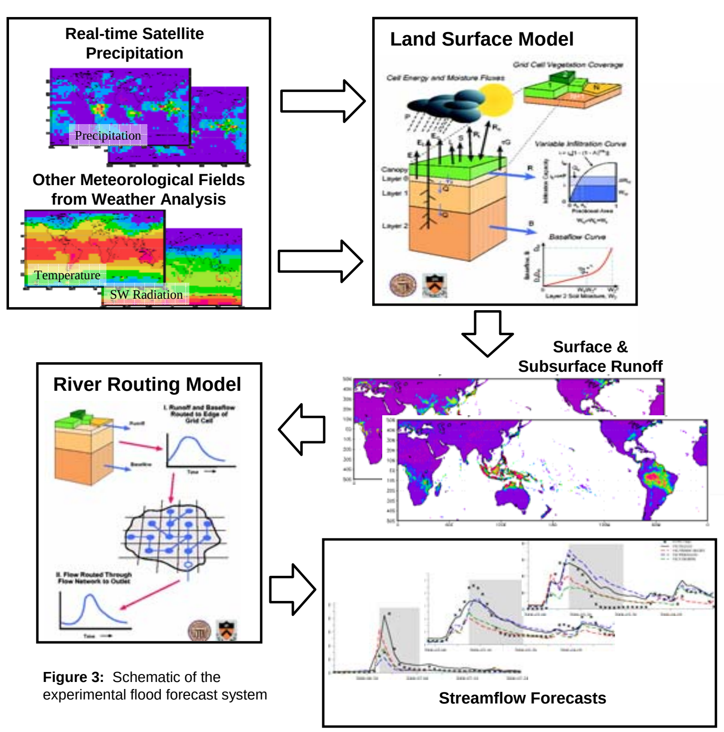


Figure 3: Schematic of the experimental flood forecast system

2. Comparisons between TMPA-RP and TMPA-RT

2.1 Skill in drought monitoring

To test the potential of using TMPA-RT for drought monitoring, we compared the 12-month standardized precipitation index (SPI) from TMPA-RT, TMPA-RP, and CPC unified gauge rainfall for drought events over three African regions (Figure 4). Although the time series share similar patterns, and RT was consistent with the other two datasets over the first two regions, the 2005 drought in Zambia, Angola, and Cameroon was missed, while a false alarm was given in 2009.

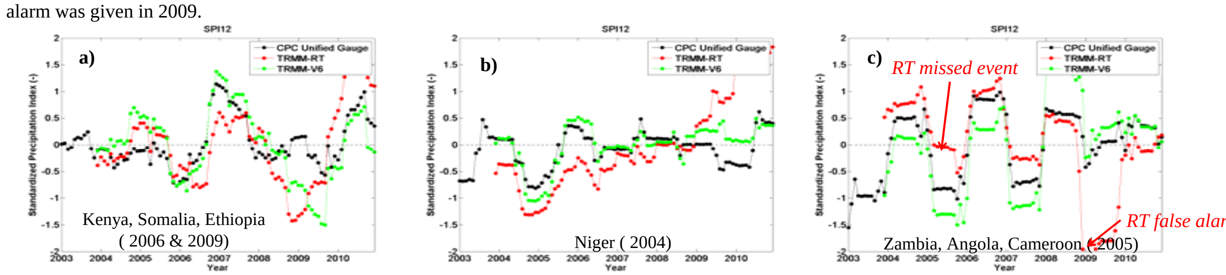
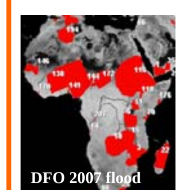


Figure 4: Time series of SPI12 calculated from CPC, TMPA-RT, and TMPA-RT over a) Kenya, Somalia, Ethiopia; b) Niger; c) Zambia, Angola, Cameroon.

2.2 Skill in flood monitoring



TMPA-RT and TMPA-RP were compared against each other during three large flood events (according to DFO) over Africa in 2007. Overall, the largest rainfall events were in agreement in terms of timing. The main difference is that RT tends to overestimate the precipitation amount. This may cause substantial overestimation of surface flow as the soil is often saturated during floods.

Location/river	DFO ID	Began	Duration	Dead	Displaced	Damage	Severity	Affected km^2	Magnitude
Mozambiqque/Mala	003	Jan 3	66	46	165000	71M	1	243400	7.2
Sudan/Nile,Gash, seasonal rivers	116	Jul 3	68	98	200000	300M	1	1591400	8.2
Chad/Bhar Azoum, Bahr Salamat	172	Aug 25	38	38	170000	N/A	1	454400	7.2

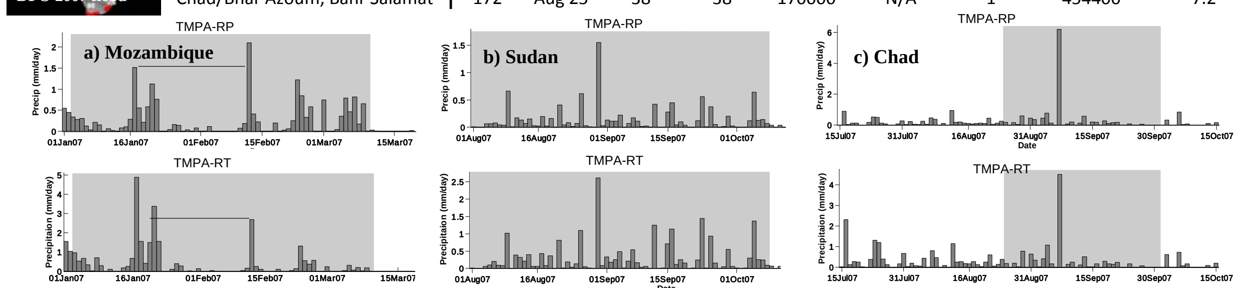
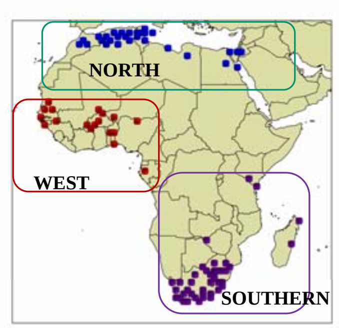


Figure 5: Time series of TMPA-RP and TMPA-RT during the floods in a) Mozambique; b) Sudan; c) Chad.

2.3 Evaluating TMPA-RT with TMPA-RP over gauged locations



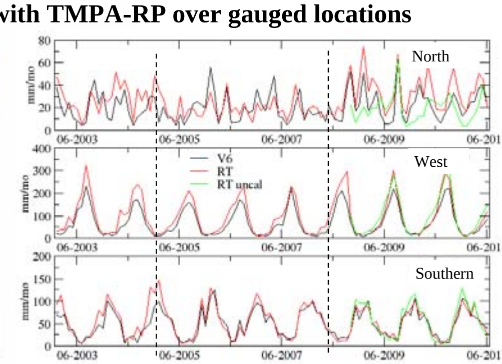


Figure 6: Region averaged time series .

To best evaluate the TMPA-RT product, we chose to compare it with TMPA-RP only over the grid cells where monthly gauge observations were used for calibrating the research product. Since there was a switch in the stations used in the RP product adjustment in April 2005, we only used stations that were included in both data sets from 2002 to 2011. These locations were then clustered into three regions (North, West and Southern Africa). Regional averaged time series are shown in Figure 6.

Major modifications with TMPA-RT occurred first in Feb 2005, when additional microwave sensors were included, and the calibration scheme was changed. This change had brought the most significant improvement of RT. A subsequent change occurred in Oct 2008, when the RT calibration scheme was changed again. In general, Figure 6 shows that the Oct 2008 change in calibration was beneficial in the southern domain, but not in the other two. In the west region, the overestimation by RT during the wet season still dominates. For the north region, the uncalibrated product actually out-performs the calibrated product.

When the two datasets are used for calculating SPI for drought monitoring, discrepancies are noticeable from the spatial images over gauge sparse regions, even for the most recent years. Figure 7 shows, for example, that while there was agreement for the drought in Figure 4a, regions like the Zambezi basin may have an opposite (wet) phase. Such results suggest that further adjustments of the RT product may be necessary to resolve the nonstationarities that have resulted from algorithm changes before the TMPA products can be used for real time monitoring and forecasting purposes.

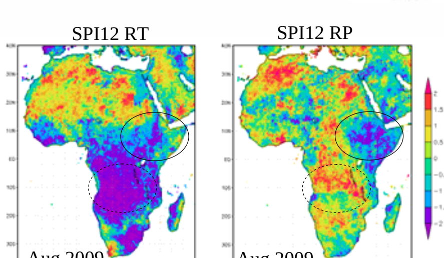


Figure 7: Spatial pattern of SPI from RT and RP in Aug 2009.

3. Towards a global forecast system

3.1 The African drought monitor

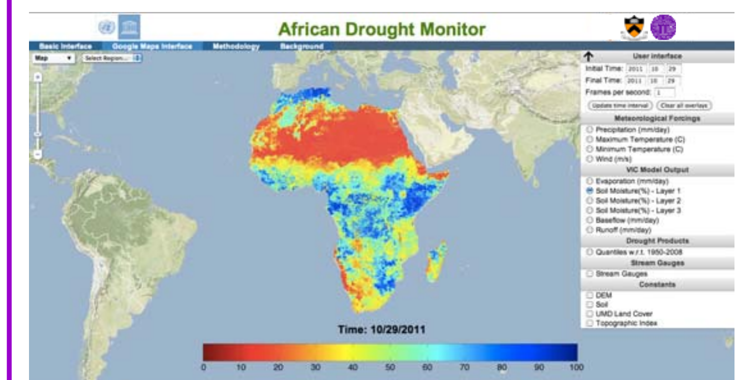


Figure 8: Drought monitor webpage (http://hydrology.princeton.edu/~justin/research/project_global_monitor/)

An African Drought monitor is operated by the Land Surface Hydrology Group at Princeton University to support the International Hydrology Program of UNESCO. The goal is to provide near-realtime (2-3 days behind real time, depending on data availability) drought monitoring products based on large-scale hydrological model using the Variable Infiltration Capacity (VIC) output.

To compensate for the sparseness of observation data, either historically or in real time, the VIC model is forced by a combined model/observation dataset of meteorological forcings (precipitation, temperature, etc). Precipitation is currently taken from both the TMPA and PERSIANN datasets. Temperature and wind speed are taken from GTS gauge reports.

The monitor is updated once each day. Available outputs include major water budget components and a drought index calculated from the soil moisture fields and streamflow relative to their seasonal climatology. In December 2011 the monitor will be implemented at the AGRHYMET Center in Niamey, Niger to offer users the opportunity to evaluate the drought products.

Other operational efforts towards monitoring/forecasting hydrological conditions at continental and global scales at Princeton University and the University of Washington include: the experimental Global Water Cycle monitor; the Drought Monitoring and Forecasting system over the US; the experimental Surface Water Monitor for US; and the West-wide Seasonal Hydrologic Forecast System.

3.2 Experimental flood forecasts over Zambezi basin

We are in the process of implementing a global flood forecast system based on the VIC model implemented at a daily time step at 0.25° grid cell resolution. The meteorology forcings during the forecast period will be from downscaled ECMWF output using an adjusted TMPA-RT climatology.

A prototype version of the system has been tested over the Zambezi basin in Africa using three sets of forcings. In this experiment, precipitation is the main driver: the uncertainties in the temperature between PU forcings and ECMWF does not result in significant differences. In our preliminary results, we have found that the origin of the floods in 2007 and 2008 was the Shire basin, both of which were missed by the PU forcings (Figures 10). Therefore, in the forecast system we plan to use adjusted TMPA-RT forcings for spin up and a ECMWF/TMPA for near real-time forecasts (Figure 10).

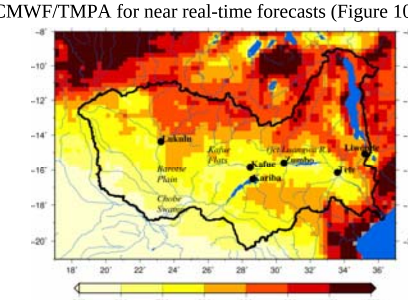


Figure 9: Annual 1998-2008 mean TMPA precipitation (mm/year).

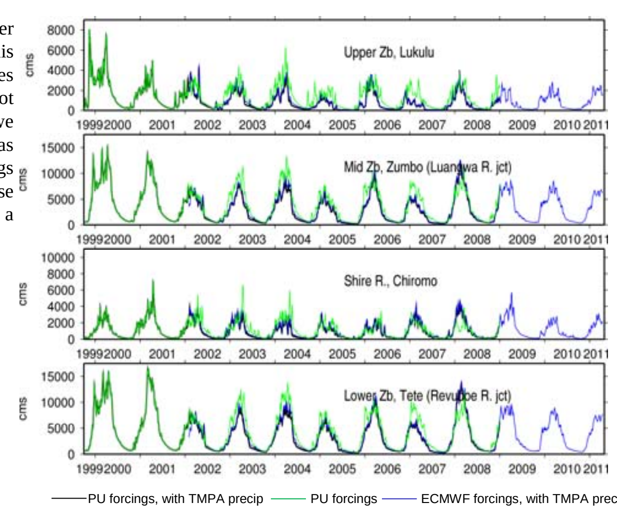


Figure 10: VIC simulated flow at four locations. The model was driven by three sets of forcing combinations.

4. Summary

- The degree of improvements of TMPA-RT algorithms due to calibration using climatology varies under different climatological conditions; post-2008 calibration changes have improved the accuracy over some parts of Africa, but degraded the performance elsewhere.
- An experimental drought nowcast system for Africa has shown potential, however nonstationarities in the TMPA-RT precipitation product complicate the delivery of consistent drought extent and severity products.
- The flood forecast system shows a hint of skill in the Zambezi basin, but nonstationairities in the TMPA-RT product need to be resolved to make a more reliable forecast product possible.
- A global flood monitoring and forecast system, forced with real-time satellite precipitation estimates appears to be feasible and should be able to predict major floods. However, continued research is needed to assess flood monitoring and forecast errors, which remain rather large.

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