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1. INTRODUCTION

The lack of spatially continuous and accurate long-term precipitation datasets over Africa has prompted the creation of a daily climatology of gridded rainfall, to cover the entire continent. While rain gauge and satellite-based precipitation data is available for the region, these products by themselves are not sufficient to capture rainfall at both high temporal and spatial resolutions. The use of a technique developed to merge daily rain gauge observations with satellite estimates is applied here to create a 1982-present climatology of daily precipitation over the African continent. To accompany reprocessed climatological data, a daily rainfall estimate product is created using a corresponding algorithm, which will enable the calculation of anomaly fields. Both products are available via anonymous ftp and are updated at regular intervals as data is processed. The motivation for creation of this product is to allow more accurate monitoring of regional and large-scale climatic and hydrometeorological trends for the U.S. Agency for International Development / Famine Early Warning System Network (USAID/FEWS-NET) humanitarian aid program. This paper will describe the technique used to create the precipitation climatology and will present preliminary results from the first seven years of data reprocessing.

2. INPUT DATA

The availability and consistency of long-term satellite-based precipitation estimates over the African continent was a major constraint in choosing input data to be used in the creation of the rainfall climatology. The operational daily precipitation estimate method (RFE2.0), currently used by the Climate Prediction Center's FEWS-NET Africa group (Xie and Arkin 1996) and modified to formulate the climatology algorithm, incorporates geostationary infrared as well as polar orbiting microwave SSM/I and AMSU-B satellite data as inputs. Of these satellite inputs, only Meteosat IR data is available from the early 1980s in a continuous, calibrated format. Furthermore, the RFE2.0 precipitation

estimate method uses full resolution IR inputs on a half-hourly basis. While Eumetsat's Meteosat satellite data is potentially available to the Climate Prediction Center, obtaining full spatial and temporal resolution products from 1982 would not be time efficient and would delay production of the precipitation climatology to a much later date.

An alternative is to use full spatial resolution (4km) IR data with a three-hour temporal separation as input to the daily climatology. In particular, the Meteosat 2 through 7 satellites' 10.5-12.5 μ m wavelength window channel is used to determine brightness temperature. This data will later be used as cloud top temperature input to determine the GOES Precipitation Index (GPI) (Arkin and Meisner 1987). The GPI technique and a comparison between 3-hourly and half-hourly input data will be discussed in section 3.

The second and final meteorological input used in creation of the daily climatological precipitation estimates is 24-hour accumulated rainfall, as obtained from Global Telecommunications System (GTS) automated rain gauge data. While approximately 7500 gauges exist globally, the African continent contains roughly 1300 stations, from which between 800-1200 report each day. Herein lies the fundamental problem this daily precipitation climatology attempts to overcome: The ratio of rain gauges which provide easily accessible, daily, near real-time observations to area in Africa is approximately 1:23,300 km². Even after considering that this does not account for the Sahara Desert, which occupies around a quarter of the continental land mass, the spatial representation of rain gauges throughout the continent is not nearly adequate enough to allow for detection of local, regional, or even some large scale hydrological and climatic phenomena. Though the real-time availability of GTS data is less of an issue when constructing the past precipitation estimates, timeliness is desired when constructing near real-time estimates to be used in anomaly products.

While the use of Meteosat IR and GTS rain gauge data as inputs to daily precipitation estimates enables the creation of a 20-plus year climatology, concessions are made that limit the accuracy of the product. Possibly the highest impact on dataset accuracy is due to the exclusion of daily microwave rainfall estimates. Figure 1 shows the differences between daily precipitation estimates using IR+GTS only and those using IR+GTS and SSM/I+AMSU microwave inputs. It can be seen that although the climatology-method rainfall estimate matches well in spatial extent with the

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Daily Precipitation Estimates for October 17, 2003

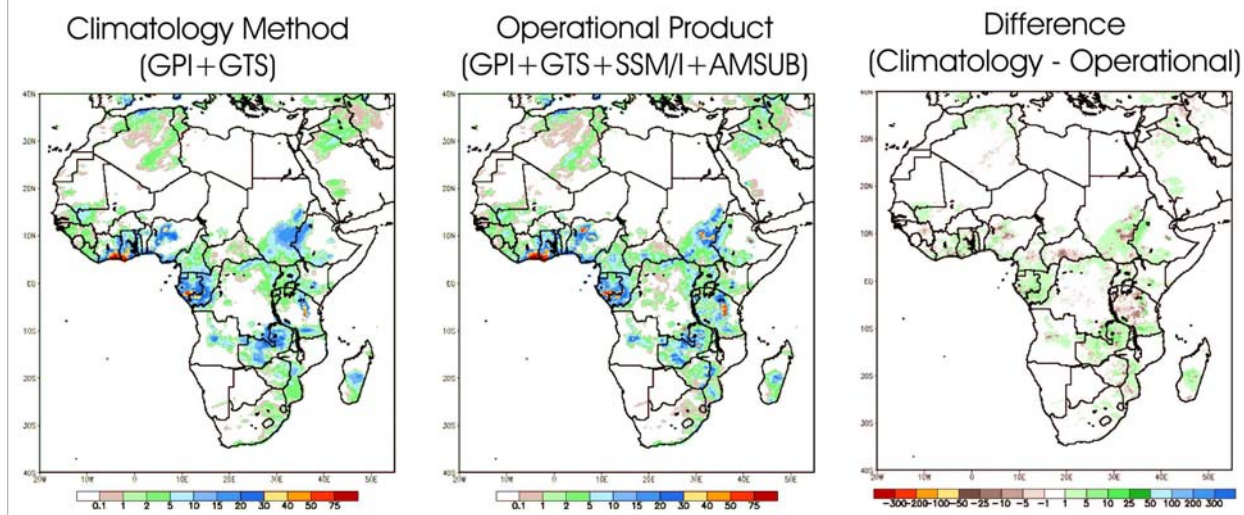


Figure 1: October 17, 2003 climatology method precipitation estimate compared to operational method. Note that the climatology method relates well with the operational method's spatial distribution, though it fails to capture small-scale rainfall events of higher intensity.

NOAA/CPC operational product, the lack of microwave remote sensing techniques lead to a failure to capture locally heavy precipitation events.

3. METHODOLOGY

The methodology used to create the daily precipitation climatology at 0.1 degree resolution is similar to that used by the NOAA/Climate Prediction Center's FEWS-NET group to monitor hydrometeorological trends in Africa, southern Asia, and Afghanistan (Xie et al. 2002). Running daily at the CPC beginning January 2001, the RFE2.0 method was created to replace the previous operational algorithm, used from 1995-2000 (Herman et al. 1997). Initial validation for the RFE2.0 product shows that outputs have reduced bias and mean error compared to CPC's earlier version, attributing to increased input data and a modified algorithm. Validation has also shown that using the RFE2.0 algorithm increases the correlation of estimates to rain gauges (see Table 1).

Table 1: Dec 1999 monthly accumulated rainfall as estimated from the RFE2.0 algorithm, compared to station gauge observations.

Data	Bias (mm/day)	Correlation
GPI Only	2.26	0.345
SSM/I Only	-0.24	0.321
AMSU-A Only	-0.15	0.095
GPI+SSM/I+AMSUA+GTS (RFE2.0 inputs)	-0.15	0.501
GPI+GTS (Climatology inputs)	-0.04	0.467

The RFE2.0 algorithm consists of two major steps that are performed on a daily basis to create the 14-hour accumulated precipitation: 1) Satellite combination, and 2) Gauge merging.

3.1 Satellite Combination

Step 1 takes all daily satellite input datasets and individually compares them to rain gauge data at corresponding latitude/longitude positions to determine the overall error of each input. The errors are converted to weighting coefficients for all inputs so that they are then linearly combined to create one daily, fused satellite estimate. Meteosat IR cloud top temperature data is converted to a standard GOES Precipitation Index (GPI) by assuming that daily rainfall is proportional to the fraction of 24-hour period where cloud top temperatures remain below 235K.

The climatology method differs from the operational RFE2.0 in that only three-hourly Meteosat IR data is used for the satellite-based input. The fact that three-hourly data is used rather than half-hourly does not appear to affect the intermediate GPI estimates.

3.2 Gauge-Satellite Merging

Since the output of the first step contains bias passed through from the original inputs, a second step is introduced to remove it by blending the first-step-output with the gauge data through the method of Reynolds (1988). In this blending process, the first-step-output is used to define the relative distribution, or 'shape', while the gauge data are used to determine the magnitude of the precipitation fields, respectively.

Analyzed values of daily precipitation at grid points are computed by solving a Poisson's equation in which the forcing term is determined by the first-step-output and the boundary conditions are derived from gauge data.

The technique used to create climatological precipitation estimates is virtually identical to the RFE2.0 method, though a slight difference exists. To promote accuracy in regions exhibiting problematic merged analyses, a daily threshold of 300 mm rainfall is used. Upon exceeding this constant, the erroneous precipitation grids are replaced by satellite-only estimates.

3.3 Near Real-Time Estimates and Data Availability

To accompany the 1982-present climatological rainfall data, a daily, near real-time product is created at the CPC. The methodology used to produce this data exactly matches that of the climatological product and is available with a delay of approximately twelve hours after the 24-hour period. Both products will be available via the internet and anonymous ftp for download.

4. PRELIMINARY RESULTS

As of October 2003, climatological precipitation estimate reprocessing has been completed for the period from January 1994-December 2001. The operational creation of daily and ten day (dekadal) accumulations, means, and anomalies have commenced and are available on a near real-time basis. Figure 2 shows October 11-20 current, mean, and 7-year difference precipitation products which are available operationally.

Short to medium term precipitation trends can be inferred from ten day rainfall products, and meteorological hazards such as flooding and short term dryness may be captured on this time scale. For example, Figure 2c captures excessive rains from a cold front in southern Africa as well as short-term dryness in the Greater Horn region of Somalia and eastern Ethiopia.

A longer term period is examined in Figure 3, which depicts September 2003 precipitation anomalies from two different methods used by the NOAA/CPC FEWS-NET group. Figure 3a shows precipitation differences using the rainfall estimation method discussed here, while the Figure 3b shows a difference between the operational RFE2.0 method and a 1961-1990 rain gauge climatology provided by the Australian Bureau of Meteorology. Note that the inconsistency of mean time periods is accepted here due to the fact that this paper presents a preliminary assessment of the climatology product. A more rigorous comparison will be undertaken in the future. Though both products shown use accumulated rainfall for the month of September to determine the anomalies, substantial differences can be seen between the graphics. A mountainous and rugged area, central Ethiopia (shown at the eastern edge of both graphics) is a region where orographic precipitation is a considerable percentage of total rainfall. It has also been theorized that both the operational RFE2.0 and climatological RFE2.0 estimation methods fail to capture this type of precipitation on a routine basis. Thus, the fact that a systematic bias exists in the rainfall estimation algorithm leads to the marked differences between products shown in Figures 3a and 3b. While the product shown in Figure 3b shows a large negative

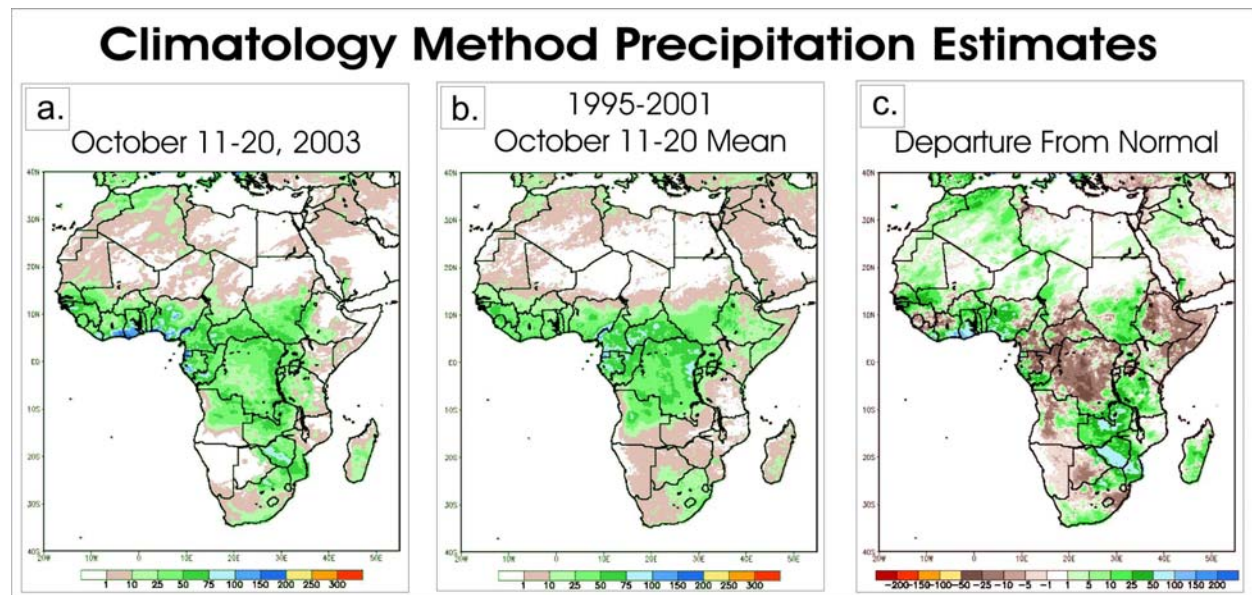


Figure 2: Climatology method precipitation estimates for the October 11-20, 2003 period compared with 1995-2001 mean. Depicted are a) Accumulated precipitation from October 11-20 2003; b) 7-Year mean precipitation for the October 11-20 period; c) Precipitation anomaly for the period.

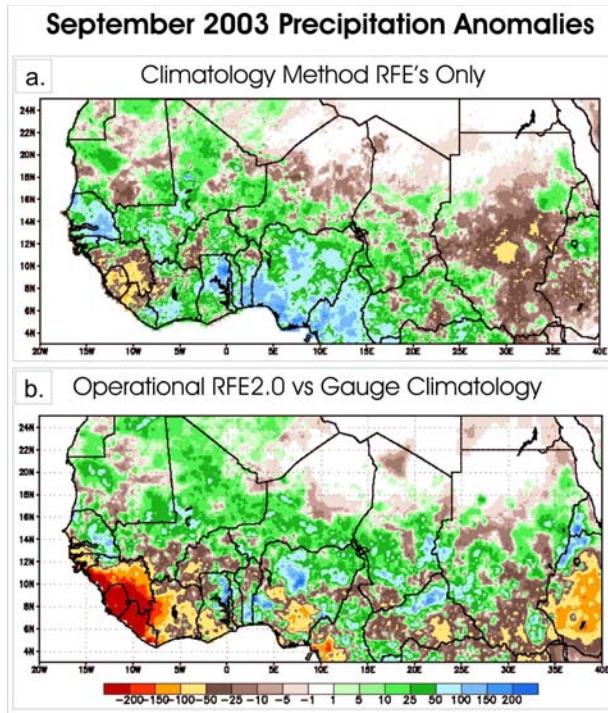


Figure 3: Shown are: a. September precipitation anomaly product using climatology-method RFE only (2003 minus 1995-2001 mean); and b. Operational RFE2.0 monthly accumulation difference from 1961-1990 rain gauge monthly mean. Note the relative differences related to dataset compatibility between images in Ethiopia and Guinea/Sierra Leone/Liberia.

rainfall anomaly due to the failure of the RFE2.0 algorithm to capture warm cloud rainfall, Figure 3a exhibits a smaller difference due to the comparison of data with similar characteristics. A comparable trend can be seen in western Africa due to the inadequacy of both rainfall algorithms along coastal regions where warm cloud effects dominate.

Though a rigorous validation effort to determine the overall accuracy of the rainfall estimate climatology has not yet commenced, it is apparent that initial results have shown promise and have already been proven useful in monitoring efforts for the area.

5. CONCLUSIONS

A new daily, gridded precipitation estimate climatology is being produced to cover the African continent from 1982-present at a resolution of 0.1 degree. Likewise, a near real-time product is created using a consistent methodology to enable construction of various rainfall anomaly datasets. This suite of data will enable more accurate monitoring of medium to long term climatic trends throughout the continent and will provide a continuous dataset for use in hydrological models.

See <http://www.cpc.ncep.noaa.gov/products/fews> for

further details and new efforts.

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