VALIDATION RESULTS FOR DAILY PRECIPITATION ESTIMATES OVER SOUTH AMERICA

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ABSTRACT

A long-standing problem of great interest among the meteorological and hydrological communities has been how to represent the spatial distribution of precipitation at small scales in regions without radar coverage and with only a sparse rain gauge network. In this case, satellite-derived quantitative precipitation estimates (QPE) are an extremely powerful tool for obtaining rainfall patterns that can be used by distributed hydrologic models to produce forecasts of discharge that can be used by crop growth models and other applications. To optimally use these data for forecasting and research applications, it is important to evaluate the errors in satellite-based rainfall estimates.

In 2003 the International Precipitation Working Group (IPWG) began a project to validate operational and semi-operational satellite rainfall estimates over Australia and the US in near real time. A European verification page was added in 2004. In June 2006, the Cooperative Institute of Climate Studies (CICS) at the University of Maryland started a new validation page devoted to the South American region (http://cics.umd.edu/~dvila/web/SatRainVal/dailyval.html). This study is focused on the preliminary results of large-scale validation of daily rainfall estimates over South America. The retrieval of several satellite precipitation estimates are compared against daily accumulations on 1°x1° areas (accumulation period starting at 12:00Z) using a gauge analysis performed by the Climate Prediction Center (NOAA/CPC) for South America. Only those grid cells with at least one rain gauge are included in the statistics. For comparison purposes, 1-day forecasts from a limited number numerical weather prediction models like GFS (NCEP) and US Navy global models are also verified.

1. INTRODUCTION

Global rainfall estimates from a variety of operational and semi-operational algorithms are easily and freely available via internet. These data, available in digital format, are provided by national meteorological centers, government institutions and university research groups. The temporal and spatial scale varies from hourly rainfall estimates at a scale of ~10 km to daily accumulations on larger areas (typically 0.25 to 1 degree) and these analyses are frequently available a few hours of real time image acquisition.

These estimations are potentially valuable not only for weather forecasters but also a wide range of users including hydrologists, emergency managers and climatologists among others.
Nevertheless, this kind of products are relevant in those regions where no conventional rainfall measurements are available (i.e., unpopulated regions, oceans, etc.).

To use these products appropriately it is important to have an idea of their accuracy and expected error characteristics because some users may require precise information about location and time of a given rain event but may be less sensitive to rain rate errors, while others may need very accurate volume estimation over certain area but are less concerned about where and when the rainfall was located. Error distributions given in the form of maps, time series, intensity distributions and validation statistics can help to know if the estimates are sufficiently trustworthy for a particular application.

In 2003 the International Precipitation Working Group (IPWG) began a project to validate operational and semi-operational satellite rainfall estimates and NWP models over Australia and the US in near real time. A European verification page was added in 2004 (Ebert et al, 2007). The primary focus of these efforts is to provide both users and algorithm developers information about the quality of rainfall retrievals for different precipitation regimes around the globe compared against more conventional daily rainfall measurements from rain gauge networks and radar in near real time. On June 2006, the Cooperative Institute of Climate Studies (CICS) at the University of Maryland started a new validation page devoted to the South American region (http://cics.umd.edu/~dvila/web/SatRainVal/dailyval.html).

This study is focused on the preliminary results of large-scale validation of daily rainfall estimates over South America. The retrieval of several satellite precipitation estimates are compared against daily accumulations on 1°x1° areas (accumulation period starting at 12:00Z) using a gauge analysis performed by the Climate Prediction Center (NOAA/CPC) for South America.

2. VALIDATION DATA AND COMPARISON METHODOLOGY

While validation / intercomparison study is an ongoing project of IPWG, an evaluation of 2006 extended winter season (May – September) over South America has been carried out. At the time of writing, rainfall estimates from nine satellite algorithms are being evaluated in this study. Three NWP models are also included: two global and one regional mesoscale model.

The time scale of primary interest to this study is daily rainfall, largely because the bulk of the rain gauge observations available for use in algorithm validation are 24 h accumulation (12:00 UTC; in this case). In this study, the CPC Realtime Daily Analysis is used as ground truth. This analysis is prepared using GTS daily reports and additional reports provided by different institutions in Brazil (CPTEC, INMET, FUNCEME and SIMEPAR) and INAMHI of Ecuador. The spatial resolution is 1 degree x 1 degree while the regional domain extends from 60 S to 15 N and from 30 W to 90 W. The analysis technique used to grid the original data is a Modified Cressman (1959) Scheme (Glahn et al. 1985; Charba et al. 1992). Some quality control processes like duplicate station check, minimum number of stations (above 500 for South America) and data check (buddy check, standard deviation check against climatology) are also performed before carry out the analysis.

One of the main concerns about this analysis is the lack of rainfall data in certain regions of South America in near real time. While some regions are largely unpopulated (like Amazonian
region and the Andes), communication issues and sparse national rain gauge GTS collections are also influencing the data flow to perform a more accurate rainfall analysis over South America. Figure 1 shows the time percentage (during 2006 extended winter season) when the rainfall data was available in real time to perform the analysis. In this case, we are considering only those cells with, at least, one rain gauge inside. While large regions over South America are poorly covered with real time rain gauge networks (i.e., southern South America), some other regions not only have sparse real time networks but also the reception of this data is very irregular along the time (i.e., northern South America).

![Figure 1](image)

**Figure 1:** Frequency (in %) of occurrence for a given cell to be considered in the validation process. Threshold value: 1 rain gauge per cell (1x1 degree)

To avoid comparisons of satellite rainfall retrieval with precipitation analysis in those regions with no rain gauges, a daily masking process is performed to mask out those cells with no rain gauges (at least one) inside them. This situation generates a different number of valid grid cells every day. Even though, most of the time, the number of grid cell is above 400 (Figure 2, blue line), it is important to point out that the statistical parameters are largely influenced by the number and the position of those cells considered in each particular day.

In order to understand how different models work in different rainfall regimes, the region was divided in sub regions for this particular study: one located southward 22 S and eastward 65 W called southeastern South America (hereafter, SSA) and other in northeastern Brazil (eastward 54 W, hereafter NEB). The election of these two regions was based in two criterions: differences in the rainfall regimes and rain gauge data availability. Figure 3 shows the average monthly total precipitation from May to September over South America (Willmott & Webber, 1998).
Figure 2: Time series of the number of grid cells considered in this validation process for each day considering 1 rain gauge per cell. The mean observed precipitation is also plotted in the left axis.

Figure 3: Average monthly total precipitation from May to September over South America

Over SSA the average monthly total precipitation remains almost constant during this period; the most relevant forcing is due to transient activity, which accounts for much of the total
precipitation of this region (Vera et al., 2002). Over NEB, as shown by Kousky (1980), monthly rainfall reaches a maximum along the eastern coastal areas in May-Jul due to convergence between the mean onshore flow and the offshore land breeze. On the other hand, monthly rainfall reaches a maximum in the northern part of the region (Ceara) during March-April and for the southern part of the region (Bahia), the maximum occurs in November-December.

In both cases, the number of valid grid cells is, on average, 100-150 grid points for SSA and 150-200 grid points for NEB.

3. VALIDATION RESULTS

The South American daily rainfall validation page includes several graphics and statistical parameters for each model. Figure 4 shows the results for CMORPH (Joyce et al., 2004) for June 25, 2006. The rain maps and scatter plot show how accurate is the correspondence between estimated and observed rainfall. Like other similar validation pages, categorical statistics such as frequency bias, Probability of Detection, False Alarm Ratio, Equitable Threat Score and Heidke Skill Score (see Wilks, 1995 for definitions) are used to estimate different aspects of the estimation quality. To quantify errors in rain amount; mean error, mean absolute error, RMS error and correlation coefficient are also computed.

![Figure 4: South American daily rainfall validation page for CMORPH.](image)

a. SSA region
As it was mentioned above, the most relevant forcing is due to transient activity, which accounts for much of the winter precipitation of the region. The activity of cold fronts coming from southwestern Pacific Ocean, off the Chilean coast, sweep the region from southwest to northeast in a periodically generating a synoptic time series pattern of daily mean rainfall. This behavior can be observed in Figure 5 (green line).

![Figure 5: Mean observed (red solid line) and estimated rainfall (red line, CMORPH) for SSA. The number of valid grid cell is also included in the right axis (blue line).](image)

As it can be observed in Figure 5, CMORPH has a slightly tendency to overestimate precipitation, especially for heavy rain events. This behavior is also observed in the scatter plot (observed vs estimated daily mean rainfall, Figure 6) of other estimation models like Experimental TRMM Real-Time Multi-Satellite Precipitation Analysis (3B42RT) (Huffman et al, 2006) and AMSU (Ferraro et al, 2005) but it’s less evident in Hydroestimator (HYDROE), an IR based model, with the larger dispersion among the analyzed algorithms. In case of the Global Forecast System (GFS), a well known global numerical weather prediction model, it tends to underestimate precipitation but, also exhibits the lower dispersion of this group. Larger overestimations observed in AMSU algorithm, a high frequency microwave scattering-based model, may be due to less frequent NOAA time sampling.

The frequency bias measures whether the rain was estimated too often or too infrequently. The ETS quantifies how well the occurrence of rain was detected or predicted, while the POD and FAR clarify the nature of the errors. Figure 7 shows how these statistics vary with increasing rain threshold. The bias score shows that all satellite rainfall algorithms (AMSU, CMORPH and HYDROE) tend to underestimate the frequency of light rainfall; heavy rainfall events are overestimated. The NWP behavior is fairly different. The bias score remains positive for all rain thresholds. Nevertheless, ETS is pretty similar for all estimations showing a similar quality for all estimations. The accuracy decreased for heavier rain, primarily due to the rapid increase in the number of false alarms. The detection ability (POD) of the NWP models decreased with increasing threshold. This is because the convective nature of precipitation makes it difficult for the models to predict precisely when and where rain will occur. In contrast, the observations-based satellite algorithms were able to detect high rain intensities fairly well.
Figure 6: Scatter plots of observed vs. estimated daily mean rainfall values for SSA. Correlation coefficients are also included. From left to right and top to bottom: Experimental TRMM Real-Time Multi-Satellite Precipitation Analysis (3B42RT), Global Forecast System (GFS), AMSU rainfall retrieval algorithm (AMSU) and Hydroestimator (HYDROE).
Figure 7: Performance of rainfall estimates during winter as a function of rain threshold for SSA. The plots show the frequency bias, the false alarm ratio, the probability of detection and the equitable threat score.

b. NEB region

In this region, from a climatological point of view, monthly rainfall reaches a maximum in the northern part of the region (Ceara) during March-April, while for the southern part of the region (Bahia), the maximum occurs in November-December and for the eastern coastal areas it occurs in May-Jul. In this particular period, most of the winter time (between June and August) the daily mean precipitation was very low (Figure 8, green line) and, by the end of the studied period, several rain events generate some rainfall near the coast as can be shown for September 9, 2006 (Figure 9). Due to the process that generates this kind rainfall (warm tops with very little ice in its structure), the satellite-based techniques could not retrieve the precipitation observed by the rain gauge network.
Figure 8: Mean observed (red solid line) and estimated rainfall (red line, CMORPH) for NEB. The number of valid grid cell is also included in the right axis (blue line).

Figure 9: NEB daily rainfall validation for CMORPH on September 9, 2006
4. SUMMARY AND CONCLUSIONS

The South American validation page has been producing results for the last five months and will continue validating different algorithms in the future in quasi real time. This study offers some preliminary results of an IPWG validation study of daily rainfall estimates from several high resolution satellite precipitation products and numerical weather prediction models over South America. Results for 2006 extended winter season for two different regions confirm that the performance of satellite precipitation estimates and the model QPFs are both highly dependent on the rainfall regime. Generally speaking, the more the precipitation regime tends toward deep
convection, the more (less) accurate the satellite (model) estimates are. Users can look forward to improvements in both model and satellite-based precipitation estimates. Continued research toward better understanding of cloud and precipitation processes will lead to improved model parameterizations and more accurate satellite precipitation algorithms. Model QPFs will also benefit from the use of enhanced observations, advanced data and assimilation methods. New sensors on future satellites, including high frequency microwave sensors on geostationary satellites and a dual frequency precipitation radar on the GPM core satellite, will contribute toward more accurate satellite precipitation estimation. More validation results performed with historical dataset for different regions and precipitation regimes along the year must be carried out in order to get a better estimation, useful for users and developers, of how well different techniques works over the continent.

5. BIBLIOGRAPHY


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