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PERFORMANCE OF THE H-E ALGORITHM DURING THE CENTRAL AMERICAN RAINY SEASON OF 2001

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Abstract

Significant portions of Central America experienced flooding in recent years from Hurricanes Mitch (1998) and Keith (2000), Tropical Storm Chantal, and Hurricanes Iris and Michelle (2001), making quantitative measurements of precipitation in this region very important for predicting and mitigating the effects of flooding. However, a number of the raingauges in the already sparse network have been lost in natural disasters or discontinued because of maintenance costs. In addition, large areas of the region are inaccessible, making direct rainfall measurements extremely difficult. Therefore, satellite precipitation techniques represent a valuable alternative for estimating precipitation over the region for flash flood forecasting, as well as for daily and monthly precipitation estimates for hydrological, climatological and agricultural studies.

In this study, the performance of the H-E algorithm was evaluated during the Central American rainy season of 2001 that included Tropical Storm Chantal (August) and Hurricane Iris (October), tropical waves, low-pressure systems and "normal" rainy days with at least 26 mm/day. Comparisons during the rainy season are based on daily and 6-h precipitation totals. Satellite estimates were compared to rain gauge data, the only ground truth data available in the area.

The results indicate that satellite techniques are a promising tool for estimating daily precipitation over Central America for extreme events such as hurricanes. However, "normal" rainy days need to be classified in more detail over smaller areas to obtain a more useful validation. The use of other precipitation algorithms such as the GMSRA and the Blended GOES/Microwave Rainfall algorithm for "normal" rainy days will be investigated in the future. Future work also includes the development of cloud top temperature/rain rate curves for different types of precipitation systems over the tropics and modifications to some of the correction factors in order to improve the estimates.

1. Introduction

The Central American weather services have had access to Geostationary Operational Environmental Satellites (GOES) digital data since July 2001 as part of the Hurricane Mitch Project which began in 1999. Since then, satellite precipitation techniques represent a valuable alternative for estimating precipitation over the region because the rain gauge network has been decreasing over the years and radar data is not available over the area.

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This study was part of a regional effort to validate the performance of some precipitation algorithms over the region. The results previously obtained (Alfaro and Scofield, 2001) showed that the best precipitation estimates were obtained with the Hydro-Estimator (H-E) algorithm. Therefore, in this study, the performance of the H-E was evaluated during the Central American rainy season of 2001, in order to use the estimates for flash flood warning systems in the near future.

The methodology and the data used in this study will be described in the next two sections. The results and discussion are addressed in section 4. Future work is described in section 5.

2. Methodology

Satellite and rain gauge comparisons for the Central American 2001 rainy season were done in this study. Daily and 6-h rain gauge totals were used. The satellite precipitation estimates were obtained with the H-E algorithm.

2.1 Hydro-Estimator (H-E)

This technique is a variant of the original Auto-Estimator (A-E) developed by Vicente et al. (1998). Among the main differences, the cloud growth rate correction factor from the A-E is not used in this algorithm (Scofield and Kuligowski, 2001). Instead, the H-E uses a modified temperature gradient correction in order to screen out non-raining pixels. The H-E uses the same temperature/rain rate relationship as the A-E, but adds a second variable which relates the pixel temperature to that of its surroundings. The mean cloud temperature and standard deviation are calculated for a 35-pixel radius surrounding the test pixel. Then a Z score is calculated as Z=(Mean-T)/SD, in which Mean is the mean cloud temperature mentioned above, T is the temperature of the test pixel and SD is the standard deviation.

In this algorithm, the moisture correction factor of the A-E has been split in two separate factors: PW (precipitable water) and RH (relative humidity). The PW factor is used to change the base rainfall rate - both to lower the basic rate in arid areas and to enhance it in very humid ones. The RH factor is purely subtractive; in dry areas, it causes rainfall from the cloud to “evaporate” before reaching the ground. This approach leads to notable improvements in areas with low PW but high RH. The orographic factor is the same as that used in the A-E.

2.2 Comparisons

The validation of the satellite precipitation techniques were done based on comparisons of the satellite estimates with the only available “ground truth” data over the region: daily and 6-h rain gauge measurements.

First, a rain gauge image was produced by assigning a rain gauge value in a 4-km radius surrounding each rain gauge. The value was found by taking the average of all gauges within 4-km of the point, weighting each by the cubic inverse of their distance from the center of the pixel. In order to take into account the relatively large instrument footprints, navigation errors and errors in the rain gauge location, comparisons were done by comparing each pixel of the rain gauge image with the 9 pixels surrounding it centered in the rain gauge location from the satellite image. The Best Estimated Value (BEV) corresponds to the rain estimate of the 9 pixels that is closer to the rain gauge value (Vila et al., 2001). These comparisons are been denoted as BEV comparisons. The statistical measures used in the validation are the additive bias (or mean error), the correlation coefficient (CORR), the Root Mean Square Error (RMSE), the Probability of Detection (POD), the False Alarm Ratio (FAR), the Critical Success Index (CSI) and the Heidke Skill Score (HSS). The definitions are shown in detail as follows:

$$Bias = \frac{\sum_{i=1}^{N}\left(S_i - G_i\right)}{N} \tag{1}$$

$$CORR = \frac{N\sum_{i=1}^{N} G_i \cdot S_i - \sum_{i=1}^{N} G_i \cdot \sum_{i=1}^{N} S_i}{\sqrt{\left(N\sum_{i=1}^{N} G_i^{\,2} - \left(\sum_{i=1}^{N} G_i\right)^2\right)\cdot\left(N\sum_{i=1}^{N} S_i^{\,2} - \left(\sum_{i=1}^{N} S_i\right)^2\right)}} \tag{2}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(S_i - G_i\right)^2}{N}} \tag{3}$$

$$FAR = \frac{q_2}{q_2 + q_4} \tag{4}$$

$$POD = \frac{q_4}{q_3 + q_4} \tag{5}$$

$$CSI = \frac{q_4}{q_2 + q_3 + q_4} \tag{6}$$

$$HSS = \frac{2\left(q_1 q_4 - q_2 q_3\right)}{\left(q_1 + q_2\right)\left(q_2 + q_4\right) + \left(q_3 + q_4\right)\left(q_1 + q_3\right)} \tag{7}$$

S refers to satellite estimates and *G* refers to ground truth that corresponds to rain gauge data. The q values are obtained from a rain/no rain contingency table (Fortune, 1998), shown as follows:

	Estimated	
Observed (rain gauges)	No rain	Rain
No rain	q_1	q_2
Rain	q_3	q_4

3. Data set

Elevation data at 10-km resolution were combined with Eta model forecasts of the u and v wind components at 850 hPa were used to calculate the orographic correction factor used by the H-E algorithm.

This study used 10.7-μm brightness temperatures and the corresponding grid files from the Eta model from 1515 UTC 20 August to 1445 UTC 22 August 2001 to produce H-E estimates for Tropical Storm Chantal. Similar information was obtained for Hurricane Iris from 8 October to 10 October 2001. Also, the H-E estimates for days between May and September 2001 with daily precipitation from the raingauges higher than 26 mm d^{-1} were examined.

The rain gauge information included daily precipitation data from the National Meteorological Institute of Costa Rica and rain gauge data every 15 minutes from rain gauge networks installed over Guatemala, Honduras, El Salvador and Nicaragua. Also, for Tropical Storm Chantal and Hurricane Iris, data from Belize and the Yucatan Peninsula were used. Total precipitation estimates for 6-h periods beginning at 0000 UTC were obtained for May, July, September and October for comparison with 6-h totals obtained from the rain gauges.

4. Results and discussion

Central America has a mountain range that extends from Panama to Guatemala. On the Pacific side of the range, there is a rainy season between May and November. The Caribbean side does not have a well-defined dry season. The rainy season includes precipitation from convective, orographic, and stratiform clouds and stratiform events with embedded convection. The complexity of the terrain also produces very localized convective rainfall.

The analysis for the Central American 2001 rainy season takes into account days during May through October. Tropical Storm Chantal, Hurricane Iris and a tropical wave case were included in the analysis. The rainy season was abnormally dry in some of the countries like Nicaragua and Honduras during some months. According to a report of the National Meteorological Institute from Costa Rica, most of the rain fell on a few days that was comparable to the monthly average. Months such as June, July and August had an average of 20 dry days in some parts of the country, which is very low according to the records from this institute.

In order to evaluate the skill of the Hydro-Estimator for the rainy season in Central America, days with rain gauge measurements higher than 26 mm d^{-1} were chosen to do the comparisons. The results obtained are shown as follows.

4.1 Tropical storm Chantal

Chantal became a tropical storm on 17 August. It made landfall near the Belize-Mexico border late on the 20^{th} with winds of 112 km h^{-1}, according to the National Hurricane Center (http://www.nhc.noaa.gov/2001chantal_text.html). It then weakened to a depression and dissipated over southeastern Mexico on the 22^{nd}. The analysis of this storm included data from Belize and the Yucatan Peninsula on 20 and 21 August. Satellite estimates and rain gauges used in the comparisons for 20 August are shown in Fig. 1. The statistical measures for rainfall thresholds of 26 and 52 mm d^{-1} are shown in Table 1.

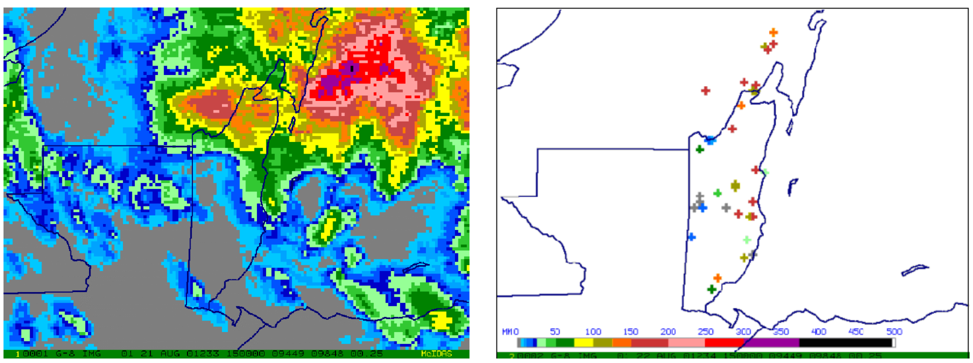

Figure 1. *H-E estimates for tropical storm Chantal corresponding to daily precipitation ending 1245 UTC 20 August 2001 (left). Location of the rain gauge measurements used in the comparisons and color table used in the figures are shown to the right.*

Thres (mm/day)	Num	Bias	Corr	RMSE	POD	FAR	CSI	HSS
26.0	171	-21.02	0.58	49.71	0.96	0.20	0.77	0.71
52.0	146	-29.69	0.48	51.02	0.92	0.13	0.81	0.81

Table 1. *Results of BEV comparisons with H-E estimates for tropical storm Chantal for 20 and 21 August. Results in second row correspond to a threshold rain gauge value of 26.0 mm/day. Results for a threshold rain gauge value of 52.0 mm/day are shown in the 3rd row.*

Chantal show better results for the RMSE, POD, FAR, CSI and HSS values compared with hurricane Keith (Alfaro and Scofield, 2001). A HSS value of 0.81 for a threshold value of 52 mm d^{-1} is obtained for Chantal.

Rain gauge values for stations over Honduras, Guatemala, El Salvador and Nicaragua were used to do 6-hour total comparisons. The 6-hourly totals were obtained at 0000,0006,0012 and 0018 UTC.

Results obtained for these comparisons for threshold values greater than 0, 7 and 26 mm/6 h are very poor. They are shown in Table 2.

Thres (mm/day)	Num	Bias	Corr	RMSE	POD	FAR	CSI	HSS
0.0	375	6.56	0.36	18.12	0.93	0.35	0.62	-0.09
7.0	271	8.76	0.25	21.22	0.90	0.53	0.44	0.27
26.0	101	10.59	0.07	30.80	0.40	0.79	0.16	0.15

Table 2. *Statistical measures obtained for 6-hourly rain gauge comparisons for Chantal for 20 and 21 August 2001.*

4.2 Hurricane Iris

Iris was a small but severe Category Four hurricane on the Saffir-Simpson Hurricane Scale that devastated southern Belize in October 2001. It reached its peak intensity of 232 km h^{-1} with a pressure of 948 hPa just before making landfall in southern Belize during the evening of 8 October (http://www.nhc.noaa.gov/2001iris_text.html).

Similar comparisons to those obtained for Chantal were calculated for Iris. Rain gauges from Belize and the Yucatan Peninsula were used in the comparisons. Results obtained for daily precipitation comparisons on 8 and 9 October 2001 for Hurricane Iris are shown in Table 3.

Thres (mm d^{-1})	Num	Bias	Corr	RMSE	POD	FAR	CSI	HSS
26.0	451	-0.49	0.21	36.76	0.61	0.41	0.43	0.45
52.0	161	-1.78	0.18	52.54	0.54	0.48	0.36	0.48

Table 3. *Results of the BEV comparisons for Hurricane Iris. Results shown correspond to daily rain gauge measurements greater than 26 and 52 mm d^{-1} during the 48 h ended 1500 UTC 9 October 2001.*

Due to the few rain gauges available over Belize, in order to gain comparable points in the analysis, the comparisons for hurricane Iris included stations in the Yucatan Peninsula, where warmer IR temperatures were observed. This fact could have an important influence on the results obtained since the center of hurricane was over Belize.

Comparisons for 6-h totals were not obtained because the rain gauge network used for such these comparisons is mostly over Honduras but the heaviest precipitation produced by Iris was concentrated in Belize and the Yucatan Peninsula.

4.3 Tropical wave over Costa Rica

A tropical wave moving west at 18.5 km h^{-1} crossed Costa Rica on 18 July 2001. The ITCZ was located close to 10°N with a low pressure system over Costa Rica (8° N, 85 °W). Thunderstorms were observed along the Atlantic Coast and to the north of Costa Rica early on that day. In the middle of the country lighter rain was observed.

The coldest IR brightness temperature values were observed to the northeast of Costa Rica and to the southeast of Nicaragua. Only daily rain gauge data were available over Costa Rica, with most stations located in the middle of the country. The results of BEV comparisons for 18 July are shown in Table 4.

Thres (mm d^{-1})	Num	Bias	Corr	RMSE	POD	FAR	CSI	HSS
26.0	119	-7.45	0.35	25.46	0.88	0.23	0.70	0.60
52.0	69	-12.04	0.14	31.75	0.64	0.29	0.51	0.54

Table 4. *Daily BEV comparisons for a tropical wave over Costa Rica on 18 July 2001 for the 24h ended 1245 UTC.*

For the tropical wave case, the results were most likely influenced by the location of the gauges over Costa Rica; most stations are over the middle of the country where mainly light rain was observed and warm top clouds were observed.

Previous results (Alfaro and Scofield, 2001) showed that better results are obtained when the rain gauge network is split: one using stations over cloud-top temperatures colder than 200 K, which are associated with heavier rain and the other one using stations over the warmer tops.

4.4 Daily precipitation estimates from May through September, 2001

The cases considered in this section evaluated the H-E performance in those rainy days in which meteorologically extreme events do not occur; however, daily rain gauge precipitation values greater than 26 mm/day were still observed on occasion. Satellite precipitation estimates during August and September were based on 42 images; the eclipse period; therefore, satellite estimates could have been higher if all 48 images were available.

H-E daily precipitation estimates from May through September were compared with rain gauge measurements available mainly over Costa Rica and Honduras. The results obtained for each month for daily precipitation totals are shown in Table 5. Corresponding results for Chantal are shown in the first row of the table for comparison.

Case	Num	Bias	Corr	RMSE	POD	FAR	CSI	HSS
Chantal	171	-21.02	0.58	49.71	0.96	0.20	0.77	0.71
May	514	-29.11	0.36	57.47	0.66	0.54	0.37	0.39
June	283	-0.19	0.47	36.47	0.82	0.52	0.43	0.44
July	519	-9.93	0.35	30.01	0.76	0.53	0.41	0.47
August	270	-12.44	0.24	27.60	0.65	0.83	0.16	0.19
Sept	565	-8.63	0.28	25.48	0.62	0.76	0.21	0.22

Table 5. *Statistical measures obtained for daily precipitation estimates from the H-E during the Central American rainy season of 2001. The rain gauge threshold value is 26 mm d^{-1}.*

Similar results are obtained for a threshold value of 52 mm d^{-1}. Daily precipitation estimations for all months show lower correlation coefficients, POD, CSI and HSS values as well as higher FAR values compared with those for Chantal.

Predicting precipitation for low values during the rainy season is not challenging since the probability of rain is very high, therefore the HSS values obtained for some cases are not meaningful when compared with POD, FAR and CSI. Previous results show that the H-E dry bias is more pronounced for warmer tops which predominate over the rain gauge locations used in these comparisons.

The results suggest that for a normal rainy day in the area, the H-E performance for daily precipitation is poor, however, daily precipitation estimates for extreme events such as hurricanes, tropical storms and tropical waves, show very good results. Further classification (as a function of cloud-size/pattern/temperature) within tropical systems restrict the comparisons because of the sparsity of rain gauges. However, innovative uses of TRMM data could solve this problem in the future.

5. Future work

The impact of the correction factors used by the H-E needs to be investigated. The complexity of the terrain over Central America requires a more detailed map over the area that will be used in the orographic correction in the near future.

Future work also includes adapting the cloud top temperature-rain rate curve to different types of cloud systems based on case studies over the region. Precipitating cloud systems range from convective to stratiform (or a combination) and have unique cloud pattern/size/temperature (Scofield, 1985; Shi and Scofield, 1987). The use of BEV comparisons, GIS and TRMM data - to help categorize precipitating systems over small areas - can be helpful tools in this respect.

A recently developed pattern recognition methodology for convective systems (Vila and Toledo, 2001) could be used in the future to classify clouds and adjust the Z-score employed in the H-E. The possibility exists that the amount of over- and underestimations could be reduced. The reason for this reduction is that the Vila/Toledo methodology may be more realistic in calculating the mean and the standard deviation that is used in the Z-score calculation.

A study on the validation of the Blended GOES/microwave (Turk et al., 1998) is underway at this moment at the University of Costa Rica along with the comparison of the two versions of the H-E running in the server of the National Meteorological Institute of Costa Rica at this moment. One version corresponds to the H-E used in this study and the other one is a version which has been used for precipitation in Florida. Rain gauge data from Costa Rica and the USGS over Central America will be used in these studies; however, the use of TRMM data will be investigated too.

The availability of satellite data in Central America marks the beginning of a more cooperative relationship between the satellite community and the national weather services of these countries. Such interaction will undoubtedly benefit all Central American countries and improve understanding of meteorology over these areas. The successful conclusion of the hurricane Mitch project established a bridge between NESDIS and Central America for continued collaboration. This interaction will ensure promising, new satellite algorithms for the Central American community.

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