Final Report ending 31 December 2003

Development of a Tropical Cyclone Rainfall Climatology and Persistence (R-CLIPER) Model

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Two tropical cyclone (TC) rain CLIPER (R-CLIPER) models were developed as part of this project. The first was based upon 53 years of U.S. rain gage data and was completed at CIRA (DeMaria and Tuleya, 2001). This project was supported by the Insurance Friends of the National Hurricane Center. The gage data set includes 125 U.S. landfalling storms from 1948 to 2000. There were about 1,000,000 hourly rain gage reports within 500 km of the storm center. Only storms that were hurricanes at landfall are included (46 storms). There were about 560,000 hourly gage reports within 500 km of the storm center for these cases. The gage data was stratified into 50 10-km wide annuli surrounding the storm center and mean rainfall rates were computed for each annuli (Fig. 1). In order to handle storms after they made landfall an inland-decay model was developed using the rain gage data set by stratifying the results by time after landfall (Fig. 2). The rainfall climatology was reduced to a linear fit of the mean rainfall rates by radius (r) and time (t) after landfall defined as:

$$R(r,t) = (ae^{-\square t}+b)e^{-(r-rm)/re} \quad (1)$$

where parameters a and □ are defined from the fit to the gage data in time and b by the fit to the gage data by radius, where r_m is the radius of maximum rainfall (which is at the origin) and r_e is 500 km. This approach results in a circularly symmetric rain distribution that can be combined with the forecast track to produce a swath of rain along the forecast track before and after landfall. The climatology was combined with the operational track forecasts through the automated tropical cyclone forecast (ATCF) system used at TPC/NHC to compute an integrated rain distribution for each forecast interval to produce the R-CLIPER (Fig. 3).

The gage-based R-CLIPER model was implemented at NHC in September 2001 with the help of Michelle Mainelli (TPC) as part of that project. Michelle wrote a program to plot the rainfall totals in N-AWIPS. However, because the hourly gage data is sparse, particularly within 100 km of the storm center, it is difficult to obtain a large enough sample to stratify the data by storm intensity.

The second TC R-CLIPER model was developed to overcome this limitation through inclusion of a global satellite-based TC rainfall climatology based on rain estimates from the NASA Tropical Rain Measurement Mission (TRMM) satellite (Lonfat et al 2003); in particular the microwave imager (TMI). To date, this climatology includes global TMI rain estimates in 482 storms from 1 January 1998 to 31 December 2002, yielding 3979 events, where 65% of the events were tropical storms, 24% were category 1-2 hurricanes, and 11% were category 3 or higher. The climatology provides a mean rain rate and the rain rate probability distribution in a storm-centered coordinate system composed of 50 10-km wide annuli in four quadrants. The results are stratified as a function of storm intensity (Fig. 4), which shows that the mean rain rate increases by a factor of 4 (3 in day^{-1} for tropical storms versus 12 in day^{-1} for category 3 and higher TCs) within 50 km of the storm center with increasing intensity. Figure 4 also indicates that the radius of maximum rainfall (r_m) also decreased with increasing intensity (i.e., from 55 km for tropical storms, to 45 km for category 1-2 hurricanes, and to 28 km for category 3-5 hurricanes).

A comparison of the satellite-based to the gage-based climatology for all hurricanes and tropical storms depicted in Fig. 1 denotes a surprising similarity between the two mean rainfall rate curves with radius and intensity. The major difference is the high variability of the mean rainfall rate at radii<100 km in the gage climatology, particularly for tropical storms, which is caused by the low number of points in those annuli. There is also a lack of a minimum in the mean rainfall rate at small radii for the gage-based climatology. Despite these slight differences, this comparison gives a good indication of the veracity of both climatologies.

The satellite-based R-CLIPER uses the TMI rain climatology partitioned by storm intensity developed by Lonfat et al (2003) to provide the storm-centered mean rain rate distribution out to 500 km radius (r_e) from the storm center as a function of radius:

$$R(r) = (R_0) + (R_m - R_0)(r/r_m) \qquad r<r_m$$
$$= R_m \exp(-(r-r_m)/r_e) \qquad r>r_m \qquad (2)$$

where parameters R_0, and R_m, are the mean rainfall rates at r_e and r_m, respectively. The climatology was combined with the operational track forecasts through the ATCF in the same manner as the gage-based climatology to compute an integrated rain distribution for each forecast interval to produce the R-CLIPER.

Gage Comparisons:

An important use of the R-CLIPER is to provide a benchmark for the evaluation of other more-general QPF techniques. To evaluate the R-CLIPER forecasts it was run on a number of past storms to provide some statistics on model performance and to develop different data products useful to the hurricane specialists. At the NOAA Hurricane Conference in December 2001 a meeting with representatives of the NWS Hydrometeorological Prediction Center (HPC) and TPC/NHC selected suitable cases to test R-CLIPER. These discussions resulted in the selection of five storms:

Andrew (1992); fast moving major hurricane
Fran (1996): classical mature hurricane making landfall
Danny (1997): small, weak, slow-moving hurricane
Floyd (1999): major trough interaction with weakening hurricane

Allison (2001): strong slow-moving tropical storm.

We evaluated the R-CLIPER model on the five storms selected. The R-CLIPER was modified to use the 6-h best track positions for each of the storms shown in Fig. 5, and was run at HRD. The TMI-climatology version of the R-CLIPER was used for all five cases. Figure 6 shows the storm total rain for all five cases and Table 1 lists the R-CLIPER peak storm-total rainfall after landfall for each case along with the gage estimated peak storm-total rainfall.

The results from the five cases in Fig. 6 give good examples of the distribution of storm total rainfall that the R-CLIPER produces. It is clear from Fig. 6 that when storms move slowly, as in Danny, the rainfall increases, while as a storm intensifies the swath of rain is slighter narrower as in the Andrew and Floyd examples. Even though Allison was moving slowly, the rainfall was still relatively light because it was only a tropical storm.

An interesting observation is how sensitive the storm total rain distribution is to changes in storm track direction. All cases presented in Figs. 6 have large increases in storm total rain amounts when the track direction changes. This result is caused by two effects: (1) when the storm turns to a new direction it usually slows down increasing the duration of the rain; and (2) there is a increase on the inside of the turn due to the increased duration caused by the shape of the track. These two effects occur whether there is other influences present or not, and they may explain increases in storm total rainfall we have seen from the gage data when there is no apparent cause, such as topographic lifting or a frontal zone. **Hence, as a rule of thumb, forecasters should look for local increases in storm total rain when the track is predicted to turn or slow down.**

Figure 6 and Table 1 also show that while the storm total distributions make sense in terms of the storm speed and intensity, the R-CLIPER performs relatively poorly when compared to a single measure of the rain distribution such as the peak storm-total rainfall. Using this measure of the rainfall distribution, the R-CLIPER often produces less than half the gage-estimated peak storm-total rainfall, and in the case of Allison less than 15%. This tendency to underestimate the storm-total rainfall is also evident when comparing the probability distributions from gages and the R-CLIPER.

Comparisons of the gage and TMI R-CIPER showed small differences in the rain totals from the best-track version of the program (not shown). The major differences were caused by the lack of intensity information used by the gage R-CLIPER, in particular in weak storms and slow moving storms after landfall. The gage R-CLIPER only has one rain by radial distance curve for all storms, which is close to that for CAT1-2 hurricanes in the TMI R-CLIPER. Hence, weak storms tend to show larger rainfall totals. Also, the decay model employed by the gage R-CLIPER only uses time inland as a factor in determining the rain total. Hence, a slow moving storm tends to underestimate the rainfall amounts. The major advantage to the TMI R-CLIPER is the simplicity afforded by its use of the forecast storm intensity as an additional factor (to storm motion) in the rain estimates. Keeping these slight discrepancies in mind, the rest of the gage comparisons use the TMI R-CLIPER.

Figure 7 shows the cumulative distribution function (CDF) of all of the storm total rain estimates over the U.S. from the available gages (top) and the R-CLIPER (bottom). The number of gages varied from case to case, but they covered the region affected by the storm. The R-CLIPER estimates (R_C) represent the area covered by the swath shown in Fig. 2 that was over the United States. Assuming the gage estimates (R_G) are representative of the areal rain distribution covered by the R-CLIPER, the CDF for the gage estimates and R-CLIPER were compares using the probability-matching method (PMM, e.g. Calheiros and Zawadski, 1987; Rosenfeld et al 1993). The PMM finds the set of pairs of R_G, and R_C at which the cumulative probabilities of the two are equal. The assumption is that the area covered by that cumulative probability rain amount is equivalent for both the gages and the R-CLIPER (a big assumption considering how representative each gage is of the large area covered by the R-CLIPER, especially for small R_G).

Figure 8 shows the PMM gage and R-CLIPER storm total rain estimates for each of the five cases, and for the combination of all five. The comparison shows that the R-CLIPER underestimate varied from 70% in Hurricane Andrew to nearly a factor of three in Hurricane Floyd. However, Table 1 indicates that both storms had <126 gages to represent an area affected by rain of $>10^6$ km^2. The sample area for a standard gage over 1 h, where the rain cells are advected over the gage at 20-25 m s^{-1} is approximately 10^4 m^2, so it would take more than 10^8 gages to represent the same area. This discrepancy in sample area is a major issue for all rainfall validation approaches. A major reason why we worked with HPC to devise other means of evaluating the rain forecasts, such as using the gage-corrected Stage-IV radar products produced by the Office of Hydrology (OH) available since mid-summer 2001. These products were used to evaluate the 2002 and 2003 operational R-CLIPER forecasts (we have since been able to acquire Stage-II uncorrected radar estimates back until 1996 and will be evaluating all but the Andrew cases for a manuscript describing the R-CLIPER development).

Because of the paucity of gage estimates in the five cases we combined all five cases to produce a single PMM comparison between the gages and the R-CLIPER (Fig. 8b). When all five cases are combined together a factor of two estimate applies at all amounts, with slightly worse underestimates at $R_G<2$ inches. At $R_G>2$ inches the underestimation is almost exactly a factor of two. This result, while a bit discouraging, indicates a rather robust relationship between the R-CLIPER and the gage storm total estimates. **Hence, all of the operational runs in 2002 and 2003 presented R-CLIPER rain forecasts by doubling the estimates.**

Operational Results:

During the 2002 hurricane seasons the gage and TMI versions of the R-CLIPER were run operationally on the JHT computing facility for 584 forecasts in 32 storms in the Atlantic, eastern and central Pacific basins. In 2003 the TMI version of the R-CLIPER was run operationally for 469 forecasts in 34 storms, with the storm total output doubled before plotting to account for the differences seen in the gage-CLIPER comparisons. Table 2 lists the number of operational forecasts run in each basin for the gage and TMI versions of the R-CLIPER. Overall, there were about the same number of forecasts run in the Atlantic and east Pacific basins, resulting in roughly 20 forecasts per storm. However, the number of forecasts varied from storm to storm. The maximum number of forecasts run were in Hurricane Kyle (2002) in the Atlantic basin (85), and the fewest was 1 in a number of cases.

Figure 9 shows a comparison of the OH Stage IV gage-corrected radar and TMI storm total rain maps for the forecasts in 2002 for select cases: Tropical Storms Fay and Gustav, and Hurricane Lili approximately 12-18 h prior to landfall. Figure 10 shows a similar comparison for select 2003 cases: Tropical Storm Bill, and Hurricanes Claudette and Isabel. The maximum storm rainfall in each case is well represented by the R-CLIPER forecasts. In some cases, such as Isabel, the forecast swaths are surprisingly similar in shape and magnitude to the swath of storm total rain from the hourly Stage IV product. Whereas, in others, such as Fay, Lili, and Claudette, there are clear differences in the location of the maxima, and even in the number of maxima, suggesting more than a simple rain model with a peak along the track is needed (e.g. one with asymmetries). The major discrepancy between the R-CLIPER and Stage-IV product is the area covered by rain <1", suggesting that the simple multiplication of the R-CLIPER output by the factor of two may not be the best solution for all of the rain. This issue is a major problem for all rain estimation techniques, not just tropical cyclone rainfall, and needs a lot more attention beyond the work in this JHT project.

Issues Remaining:

(1) More work is needed to understand why the R-CLIPER underestimates the gage amounts by a factor of two. We checked the algorithm developed by Mark DeMaria from the TMI climatology of the mean rain amount in each annulus to derive the rain estimates for each storm category. The algorithm slightly underestimated the rain estimates because it assigned the values derived for the three intensity ranges defined by Lonfat et al (2003) to the middle of each intensity range. The storm intensity statistics from Lonfat et al suggest that the rain estimates are more representative of the lower edge of each intensity range. We altered the algorithm to reflect this difference and reran the comparisons with only a slight change (the results presented in Figs. 2-4 use the new version of the algorithm).

Also, a better measure of the natural rain distribution may be the mean of the log of the rain amount, or possibly the median (50%) value of the total storm rainfall. However, that will not increase the storm total rainfall by a factor of two, more like an increase of 25%. If one wants to know the peak storm-total rainfall it may be better to forecast the tail of the probability distribution of rain, such as the 95%, which varies little with storm intensity. The tail of the rain distribution is determined by the convective processes, which don't vary much from storm to storm, or by radius from the storm center. This observation fits with Kraft's "rule of thumb" which doesn't include a variation in peak storm-total rainfall with intensity, i.e., you can get just as much rain from a tropical storm or as from a major hurricane of the same speed of motion.

(2) The above discussion brings up another interesting question and issue: what does the forecaster need to predict? Is the forecaster interested in a good measure of the storm-total rain distribution to insure the area and rough mean amounts are correct? On the other hand, is the forecaster interested in the likelihood the storm total rainfall has some probability of exceeding some amount? The answer to these questions would determine what type of products the R-CLIPER should produce. Currently, the operational product is just the swath map over the 72-h forecast window. Because the TRMM TMI TC rain climatology includes information about the probability distribution of rain by occurrence, rain amount, radius form the storm, and storm intensity we can tailor the products to address a number of forecast needs. The type of products the forecasters want needs to be addressed before we can attempt to improve R-CLIPER to produce a more meaningful product.

(3) Finally, we have a problem with the operational R-CLIPER's dependence on the ATCF forecast for a storm. Currently, the ATCF contains no track forecast information once tropical storm force winds are not present on the coast, when TPC/NHC stops producing them. HPC continues to follow the storm's remnants, however, no track forecast is produced

from which to run the R-CLIPER. We talked with HPC to look into using their internally generated centers and storm intensities to run the R-CLIPER using a version of the operational algorithm that resides on the NWS IBM machine. To help in this effort during the 2003 season, JHT made available the R-CLIPER output to HPC for their evaluation. At this time it is still unclear how best to get the R-CLIPER forecasts to HPC. HPC is continuing to evaluate whether to run the model.

Summary:

An operational tropical cyclone rainfall forecast product (R-CLIPER) based on climatological rain gage and satellite microwave estimates was developed and tested. The R-CLIPER uses the operational track and intensity forecasts from the ATCF to produce the rain estimates. A comparison of these forecasts with gage rain estimates in five storms suggested that the R-CLIPER underestimated the gage estimates by nearly a factor of two. However, that result is based on the assumption that the percent of gages with a rainfall amount above a certain threshold is equivalent to the area covered by rain above that threshold. While this assumption was necessary for the evaluation, the paucity of gages used in each comparison remains a source of potential uncertainty and future research using other rain estimate techniques (OH Stage IV gage adjusted radar rain estimates). **Based on the gage intercomparison, the operational R-CLIPER multiplied the output by a factor of two.**

An interesting observation was the R-CLIPER storm total rain distribution to changes in storm track direction. All five cases showed large increases in storm total rain amounts when the track direction changes. This result is caused by two effects: (1) when the storm turns to a new direction it usually slows down increasing the duration of the rain; and (2) there is a increase on the inside of the turn due to the increased duration caused by the shape of the track. These two effects occur whether there is other influences present or not, and they may explain increases in storm total rainfall seen when there is no apparent cause, such as topographic lifting or a frontal zone. **Hence, as a rule of thumb, forecasters should look for local increases in storm total rain when the track is predicted to turn or slow down.**

Two years of operational R-CLIPER runs (over 1000 forecasts in over 60 storms in the ATL, EPAC, and CPAC basins) suggest that the R-CLIPER is producing realistic rain estimates that compare well with the gage and gage-adjusted radar rain estimates. There are still clear differences in the location of the maxima, and even in the number of maxima, suggesting more than a simple rain model with a peak along the track is needed (e.g. one with asymmetries) to produce the peak rain values. However, the simple R-CLIPER should provide a very useful guidance tool and act as a benchmark for evaluating more sophisticated models. A new JHT proposal will address the development of procedures to compare operational numerical model rain estimates with the R-CLIPER.

Presentations made on the R-CLIPER:

- At the IHC in February 2001. A presentation is available on the anonymous ftp site: ftp://ftp.aoml.noaa.gov/pub/hrd/marks/IHC_talk.pdf.
- At HPC in May 2001. A presentation is available on the anonymous ftp site: ftp://ftp.aoml.noaa.gov/pub/hrd/marks/IHC_talk.pdf.
- At an AOML informal seminar in February 2002

- At the 25th Conference on Hurricanes and Tropical Meteorology in May 2002 (Marks et al 2002). A presentation is available on an anonymous ftp site: ftp://ftp.aoml.noaa.gov/hrd/pub/marks/R-CLIPER.ppt
- At the COMAP NWS training course in Boulder, CO in early June 2002. A presentation is available on an anonymous ftp site: ftp://ftp.aoml.noaa.gov/hrd/pub/marks/tropical_met_class/Shuyi_lecture.ppt
- At IWTC-V in Cairns, Australia in early December 2002. A presentation is available on an anonymous ftp site: ftp://ftp.aoml.noaa.gov/hrd/pub/marks/tropical_met_class/Shuyi_lecture.ppt.
- At NOAA Hurricane Conference in January 2003: A presentation is available on the anonymous ftp site: ftp://ftp.aoml.noaa.gov/pub/hrd/marks/rcliper/NOAAHC_talk.pdf.
- At the Simpson's Symposium at the AMS Annual Meeting in February 2003. A presentation is available on an anonymous ftp site: ftp://ftp.aoml.noaa.gov/pub/hrd/marks/rcliper/Simpson_Marks.tar.gz.
- At the IHC in March 2003.

References:

Calheiros, R. V., and I. Zawadski, 1987: Reflectivity-rain rate relationships for radar hydrology in Brazil. *J. Climate and Appl. Meteor.*, **26**, 118-132.

DeMaria, M. D., and R. Tuleya, 2001:Evaluation of quantitative precipitation forecasts from the GFDL hurricane model. Reprints *Symposium on Precipitation Extremes: Predictions, Impacts, and Responses*, AMS, Albuquerque, NM, 340-343.

Lonfat, M., F. D. Marks, S. Chen, 2003: Precipitation Distribution in Tropical Cyclones Using the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager: A Global Perspective. Accepted for publication in *Mon. Wea. Rev.*

Marks, F. D., G. Kappler, M. DeMaria, 2002: Development of a Tropical Cyclone Rainfall Climatology and Persistence (R-CLIPER) Model. Reprints of the 25th *Conference on Hurricanes and Tropical Meteorology*, AMS, San Diego, CA. (ftp://ftp.aoml.noaa.gov/hrd/pub/marks/7D2_Marks.pdf)

Rosenfeld, D., D. B. Wolff, and D. Atlas, 1993: General probability relations between radar reflectivity and rain rate. *J. Appl. Meteor.*, **32**, 50-72.

Table 1.

Storm	R-CLIPER maximum rainfall (in)	Maximum gage rainfall (in)	Location of gage maximum rain	Number of gages
Andrew 1992	7.7 5.0	11.9 7.8	Hammond, LA Broward, FL	126
Fran 1996	4.8	14.2	Luray, VA	170
Danny 1997	15.9	27.0	Theodore, AL	234
Floyd 1999	8.3 4.1	11.9 14.5	Clinton, NC Williamsburg, VA	105
Allison 2001	8.6	36.9	Houston, TX	2263

Table 2. Summary of operational R-CLIPER runs in 2002 and 2003.

BASIN	2002 storms	2003 storms	2002 forecasts	2003 forecasts
Gage version				
Atlantic	14	17	255	275
East Pacific	15	16	280	189
Central Pacific	3	1	48	5
Total	32	34	583	469
TMI version				
Atlantic	14	17	254	275
East Pacific	15	16	280	189
Central Pacific	3	1	48	5
Total	32	34	582	469

Figures

Climatological Rainfall Rates from TRMM and Rain Gauges for Hurricanes and Tropical Storms

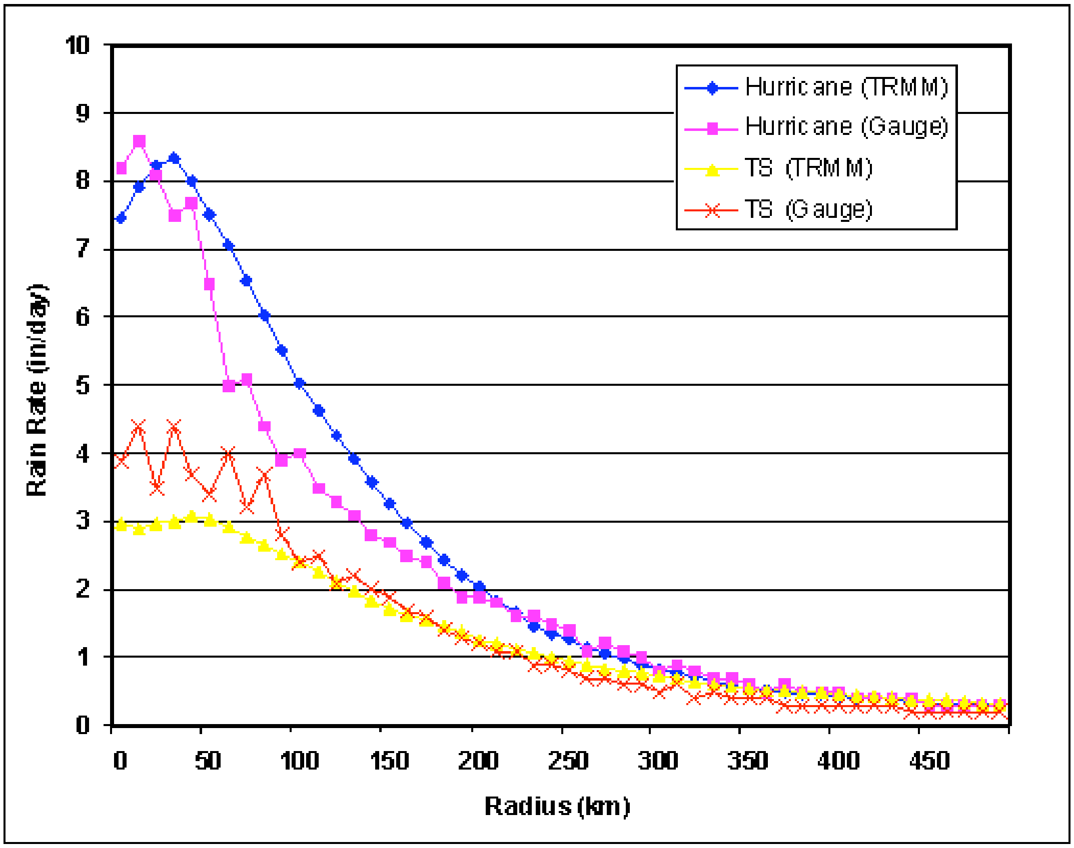


Fig. 1. Gage-based TC rainfall climatology (in day^{-1}) from 1948-2000 and TRMM TMI-based TC rain climatology (in day^{-1}) from December 1997-2000. Comparisons are made for tropical storms and hurricanes.

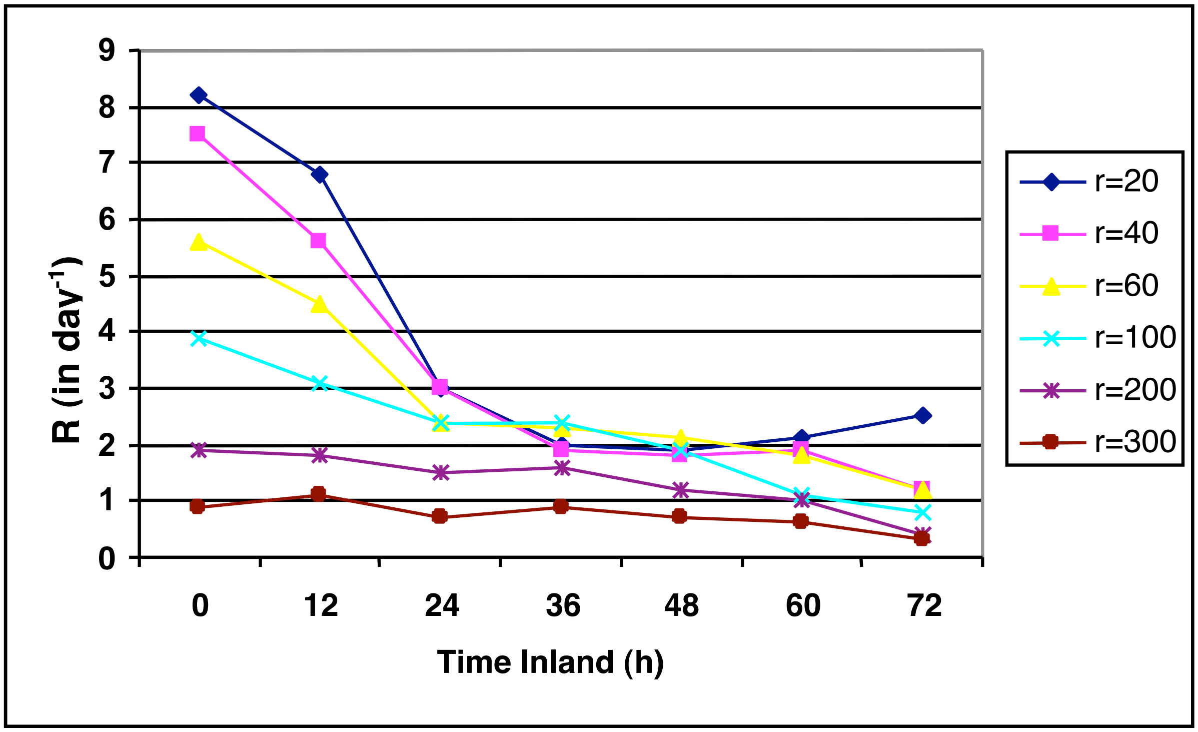


Fig. 2. Comparison of gage-based rainfall climatology (in day^{-1}) for time inland (h) at different radii from the storm center (r).

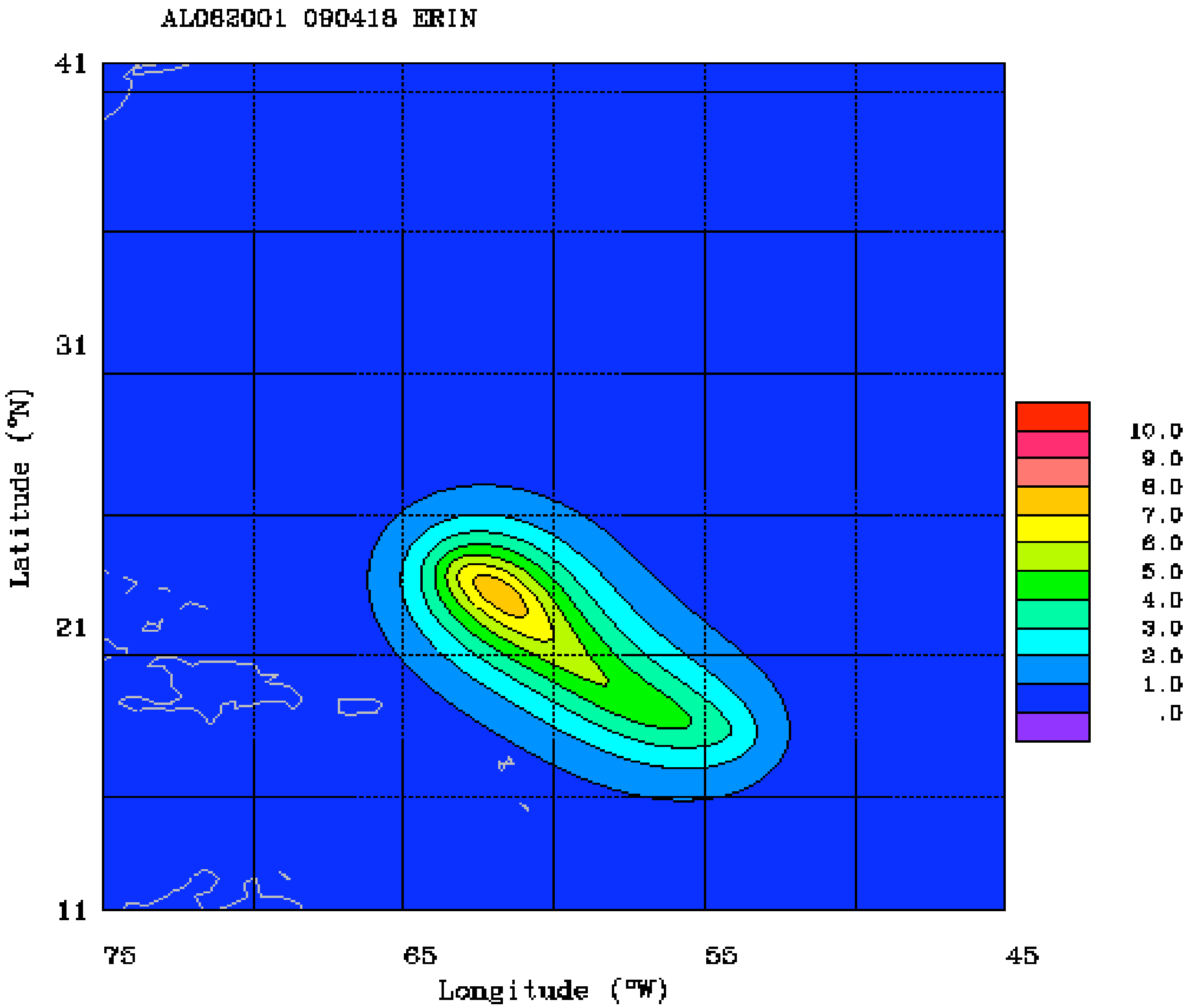


Fig. 3. Rainfall rate (in day^{-1}) forecast from gage-based R-CLIPER accumulated along 72 h NHC track forecast for Erin (4 Sept. 2001 18 UTC).

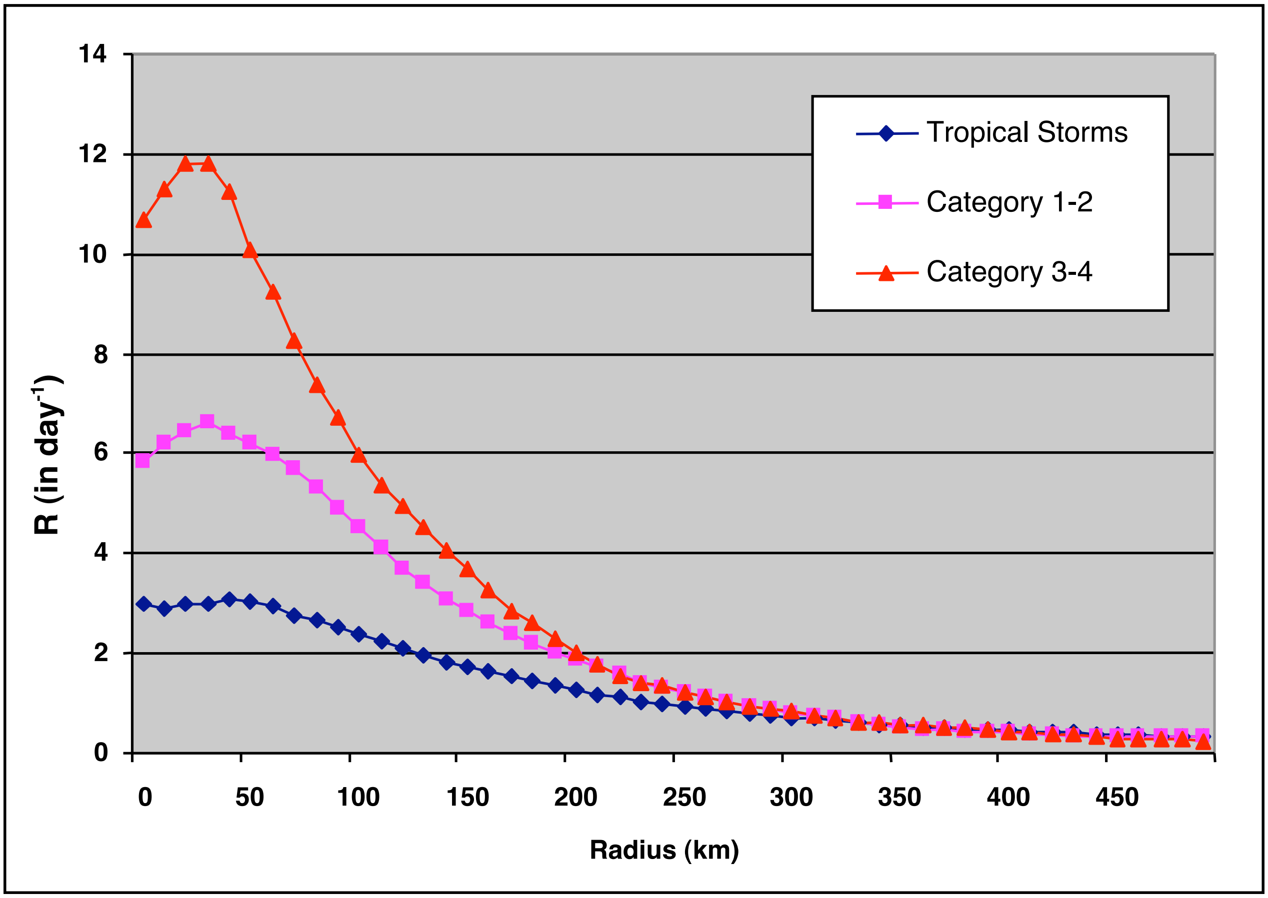


Fig. 4. TMI-based rainfall climatology (in day^{-1}) for tropical storms, Category 1-2, and Category 3-5 hurricanes.

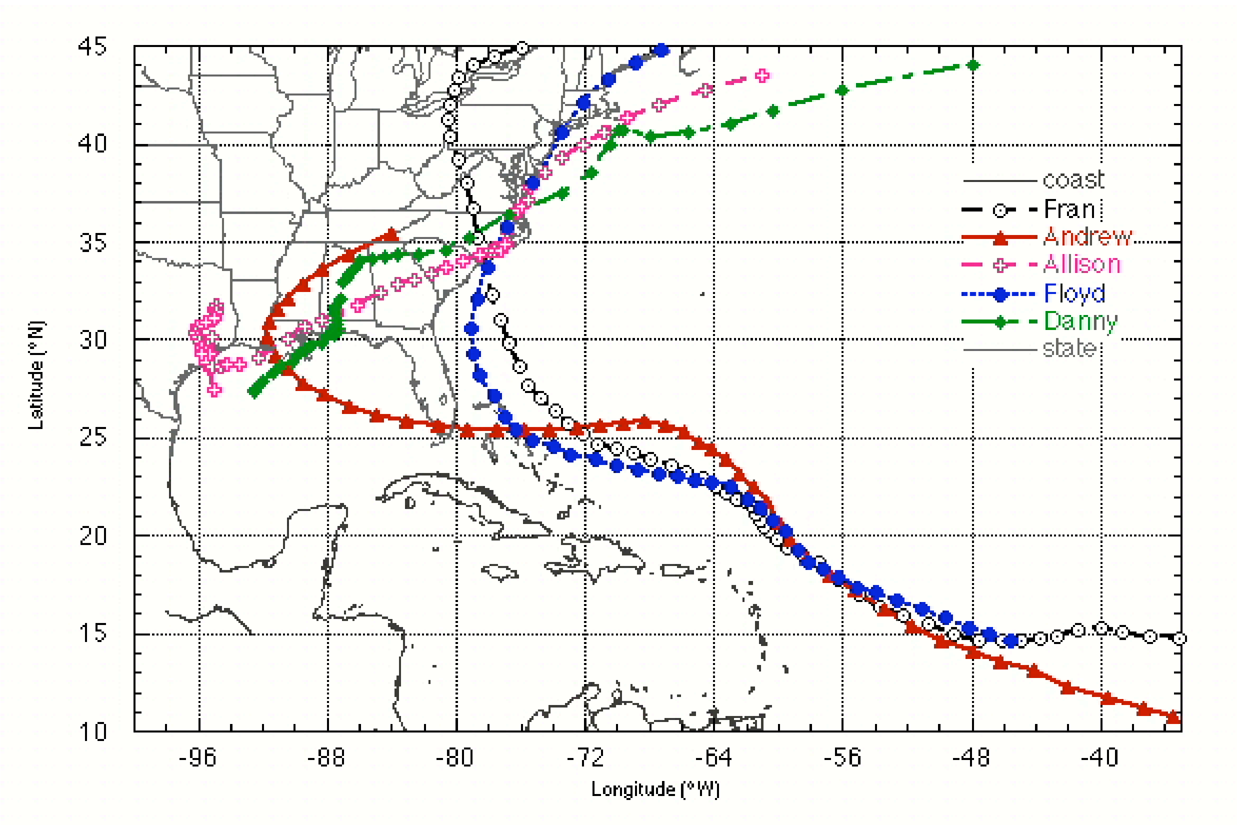


Fig. 5. Best track for the five cases used for the R-CLIPER validation.

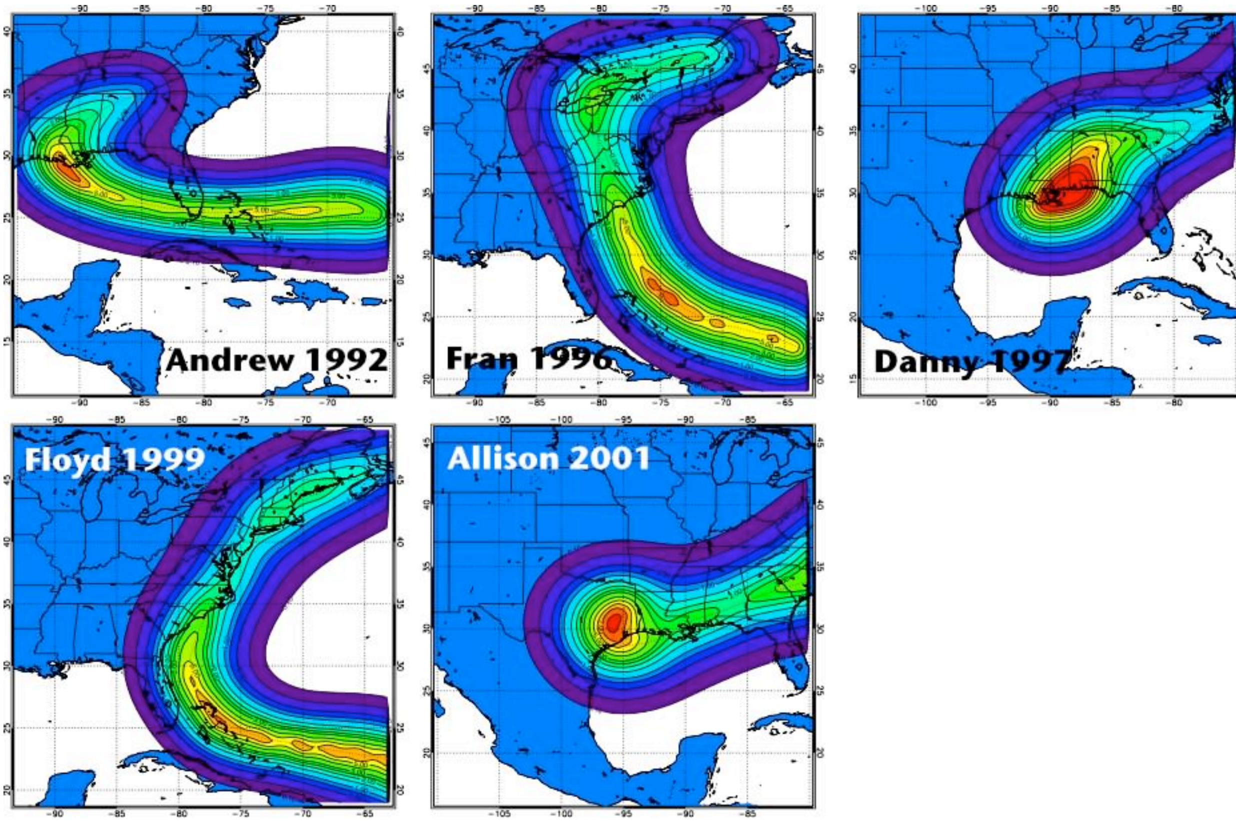


Fig. 6. Storm-total rainfall (inches) for the five cases in Fig. 5. Rainfall totals are denoted by color shading and contours, whereas the storm best-track (6 h) is denoted by a red dotted line.

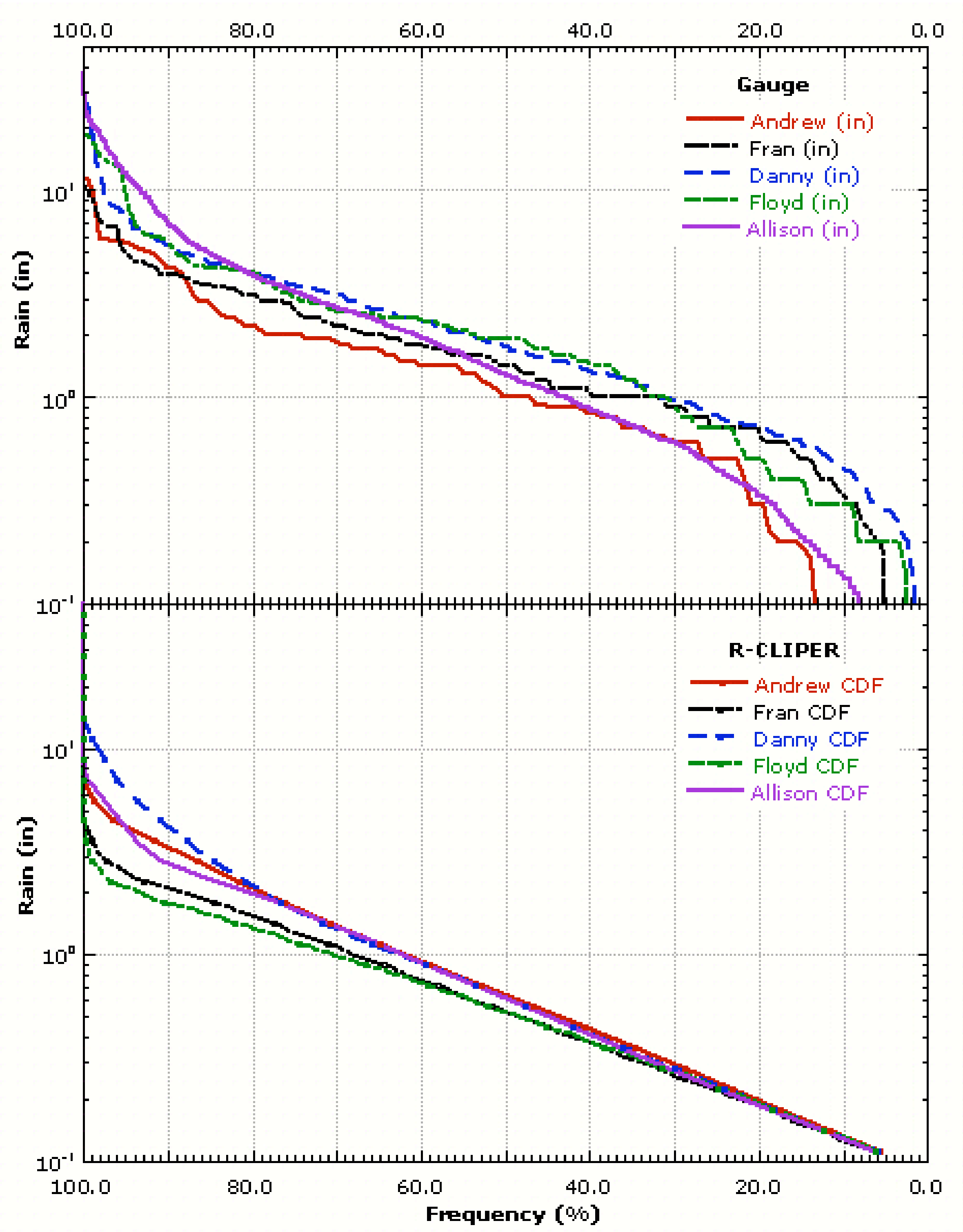


Fig. 7. Cumulative probability distributions of gage and R-CLIPER storm-total rainfall (inches) for the five cases.

(a) (b)

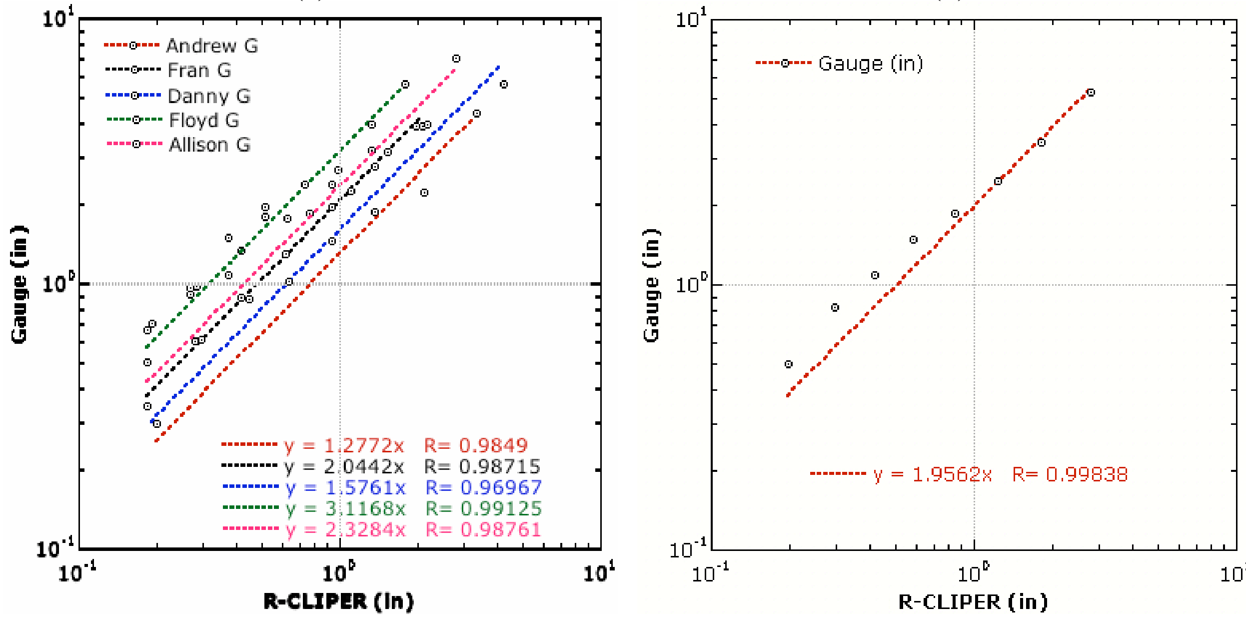
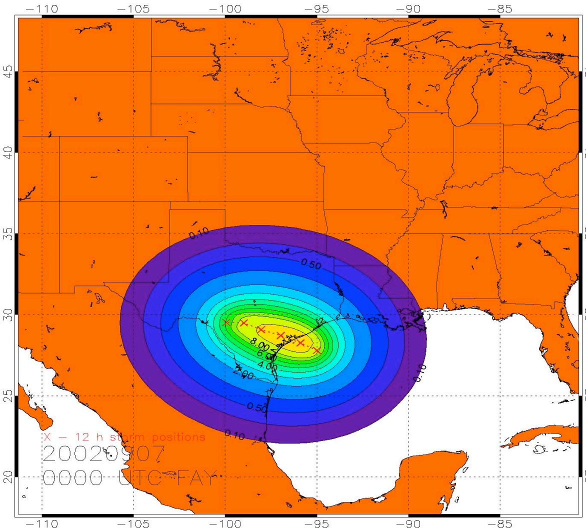
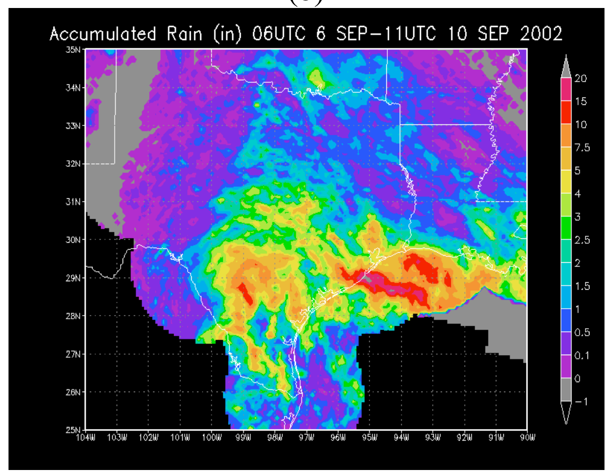


Fig. 8. (a) Probability-matched storm total rain estimates from gages and R-CLIPER for each of the five cases in Fig. 5, and (b) for all five storms combined. Each point represents the probability-matched value at 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90% from left to right, respectively. A least-square fit to the probability-matched values is denoted by the dashed line and the best-fit linear regression for each case is denoted at the bottom of the figure.

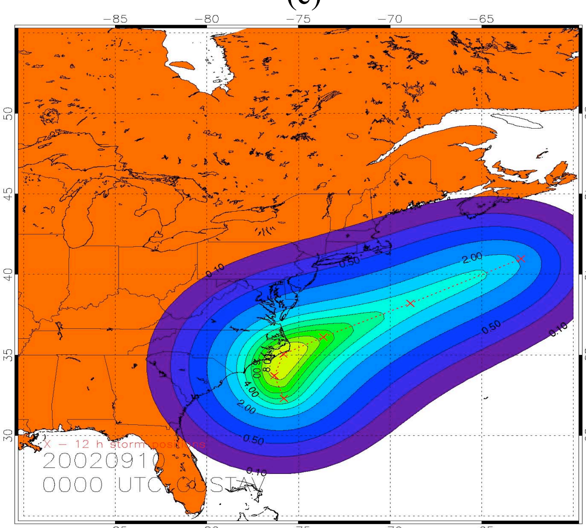
(a)


X – 12 h storm positions

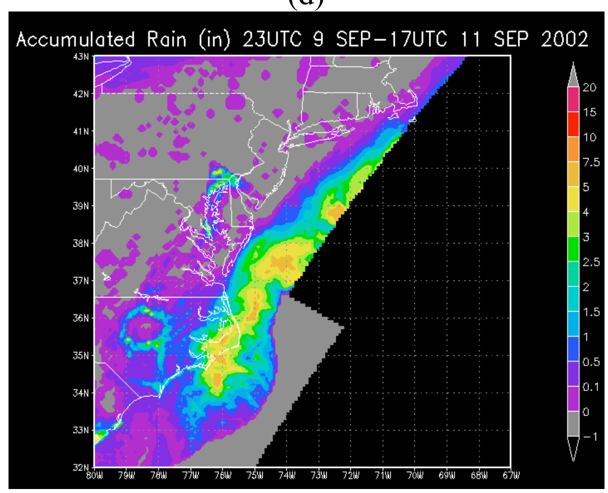
(b)


Accumulated Rain (in) 06UTC 6 SEP–11UTC 10 SEP 2002
20
15
10
7.5
5
4
3
2.5
2
1.5
1
0.5
0.1
0
–1

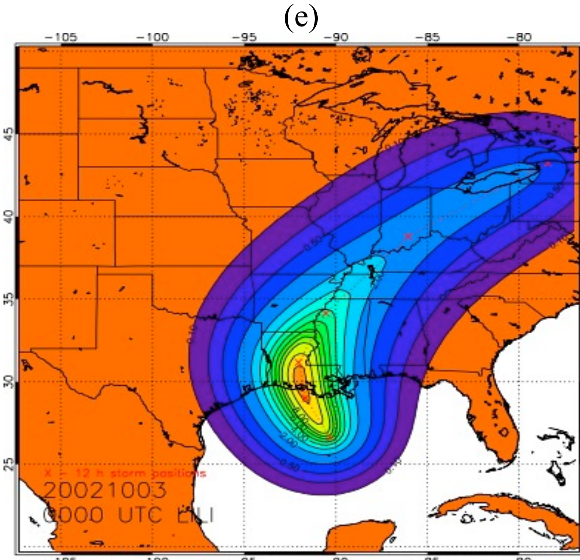
(c)



(d)


Accumulated Rain (in) 23UTC 9 SEP–17UTC 11 SEP 2002

(e)


X – 12 h storm positions
20021003
0000 UTC LILI

(f)

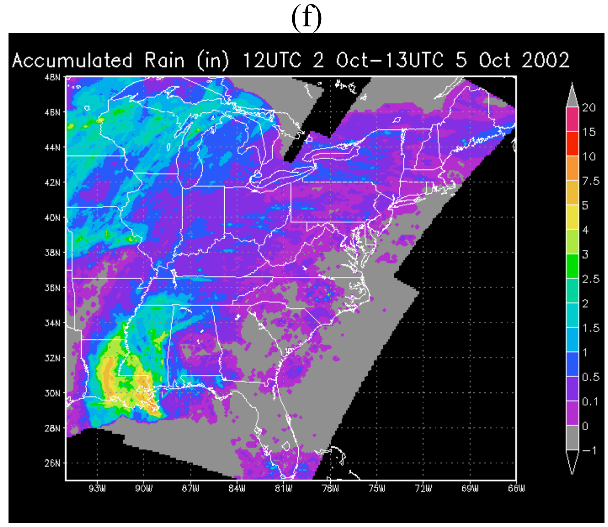

Accumulated Rain (in) 12UTC 2 Oct–13UTC 5 Oct 2002

Fig. 9. (a) TMI R-CLIPER operational forecasts for Tropical Storm Fay 0000 UTC 7 September 2002, and (b) storm-total rainfall (inches) from the Stage IV gage-corrected radar product from 0000 UTC 6 September to 1100 UTC 10 September 2002. (c) TMI R-CLIPER operational forecasts for Tropical Storm Gustav 0000 UTC, 10 September 2002, and (d) storm-total rainfall (inches) from the Stage IV gage-corrected radar product from 2300 UTC 9 September to 1700 UTC 11 September 2002. (e) TMI R-CLIPER operational forecasts for Hurricane Lili 0000 UTC, 3 October 2002, and (f) storm-total rainfall (inches) from the Stage IV gage-corrected radar product from 1200 UTC 2 October to 1500 UTC 3 October 2003. In (a), (c), and (e) storm-total rainfall (inches) is denoted by color shading and contours, whereas the official forecast storm track is denoted by a red line.

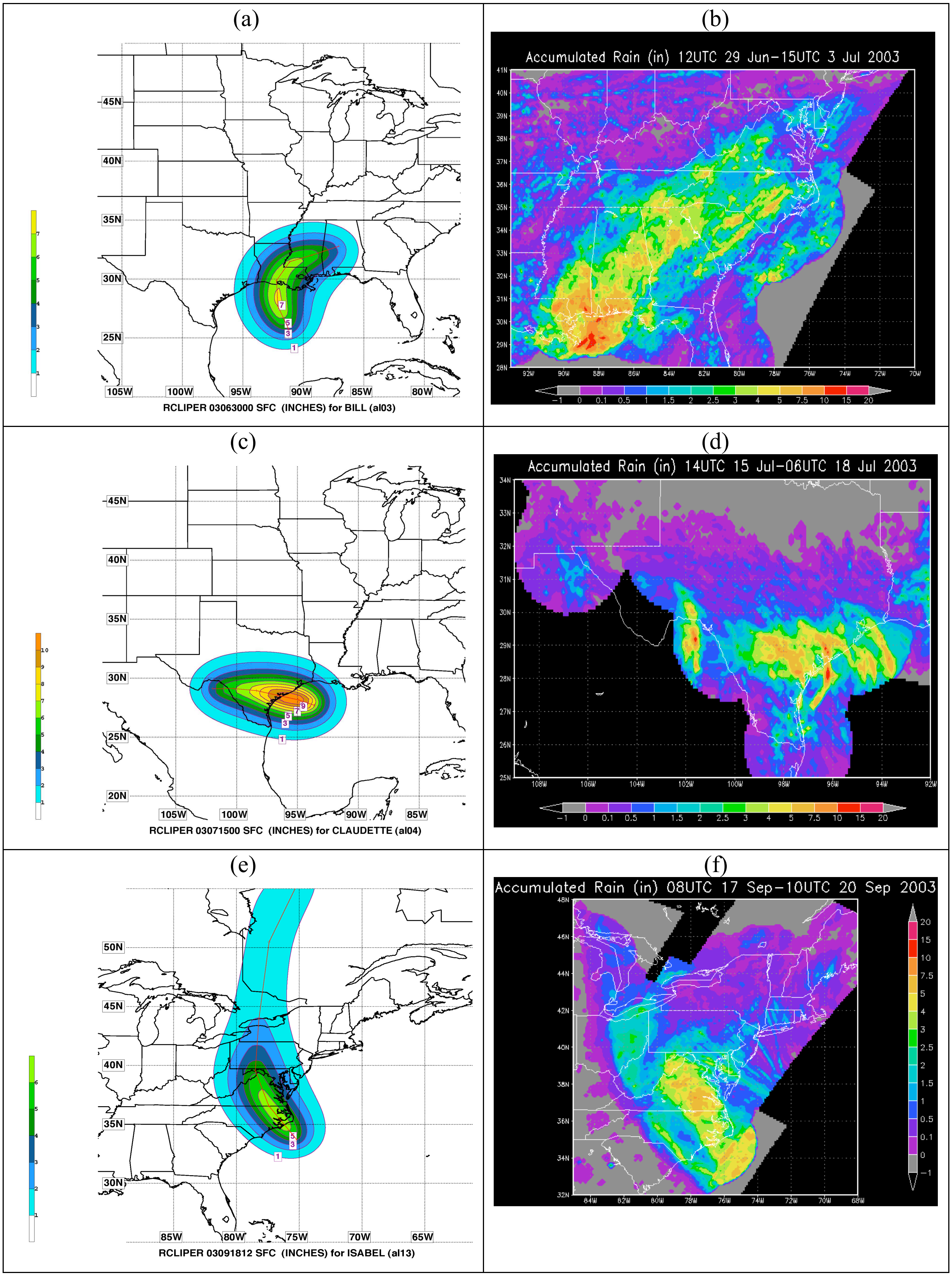

(a)
(b)
Accumulated Rain (in) 12UTC 29 Jun-15UTC 3 Jul 2003
RCLIPER 03063000 SFC (INCHES) for BILL (al03)
(c)
(d)
Accumulated Rain (in) 14UTC 15 Jul-06UTC 18 Jul 2003
RCLIPER 03071500 SFC (INCHES) for CLAUDETTE (al04)
(e)
(f)
Accumulated Rain (in) 08UTC 17 Sep-10UTC 20 Sep 2003
RCLIPER 03091812 SFC (INCHES) for ISABEL (al13)

Fig. 10. (a) TMI R-CLIPER operational forecasts for Tropical Storm Bill 0000 UTC, 30 June 2003, and (b) storm-total rainfall (inches) from the Stage IV gage-corrected radar product from 1200 UTC 29 June to 1500 UTC 3 July 2003. (c) TMI R-CLIPER operational forecasts for Hurricane Claudette 0000 UTC, 15 July 2003, and (d) storm-total rainfall (inches) from the Stage IV gage-corrected radar product from 1400 UTC 15 July to 0600 UTC 18 July 2003. (e) TMI R-CLIPER operational forecasts for Hurricane Isidore 1200 UTC, 18 September 2003, and (f) storm-total rainfall (inches) from the Stage IV gage-corrected radar product from 0800 UTC 17 September to 1000 UTC 20 September 2003. In (a), (c), and (e) storm-total rainfall (inches) is denoted by color shading and contours, whereas the official forecast storm track is denoted by a red line.