Development of a Tropical Cyclone Rain Climatology and Persistance Model

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INTRODUCTION:

- Tropical cyclones (TC) pose significant quantitative precipitation forecast (QPF) problem as evidenced by tragic loss of life and property from rain in Hurricanes Mitch (1998), Floyd (1999), Keith (2000), and unnamed storm that hit South Florida this year.
- Over last 30 years majority of TC-related deaths are caused by flooding (Rappaport 2000).
- Threat of flooding is a function of rain rate (R) and duration, making storm size (D) and motion (V_s) critical parameters.
- Enhanced rainfall over a given location due to orographic forcing and/or interactions with mid-latitude frontal boundaries or troughs increase threat of flooding.

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- The complexities of precipitation processes and lack of microphysical data to support parameterizations in numerical models has limited QPF.
- Improved QPF, particularly in TCs, is one of primary objectives of U. S. Weather Research Program (USWRP).

- Nature of TC rain makes QPF complex.
  - Convection forced by many sources.
  - w drafts are small (3 km), relatively weak (10%>±6.5 ms^{-1}; 1%>±10.5 ms^{-1}), with 3 times more updrafts than down.
  - R cores are small (50% diameters >3.7 km) and short-lived (10% durations >8 min) covering only 10% of storm rain area. 90% of rain area is stratiform.
  - Yet, stratiform rain makes up ~50% of total rain from TC.

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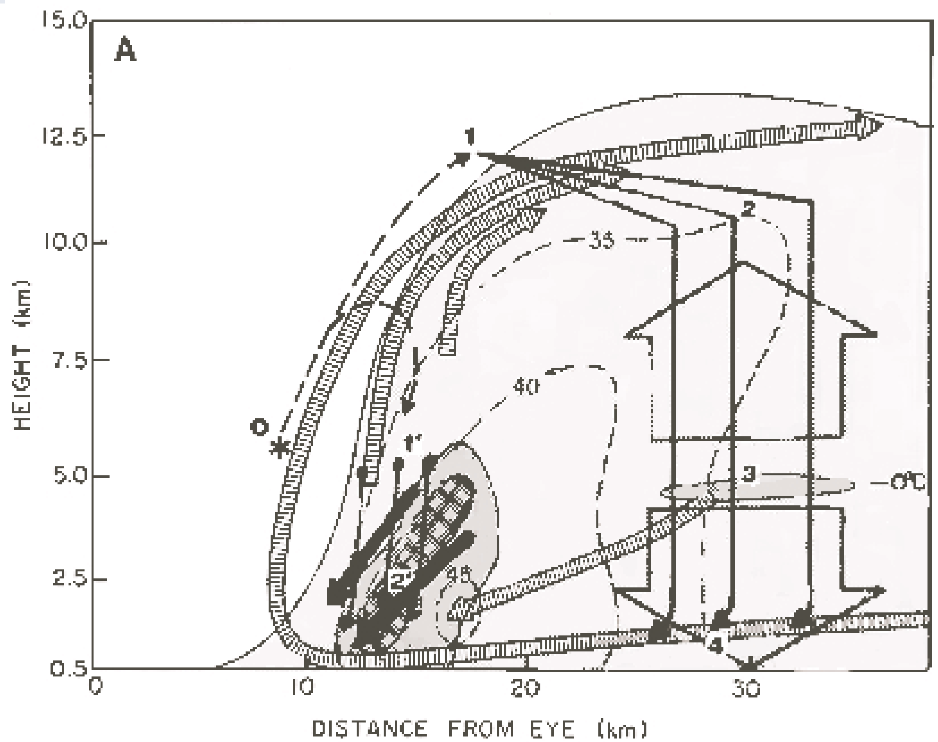
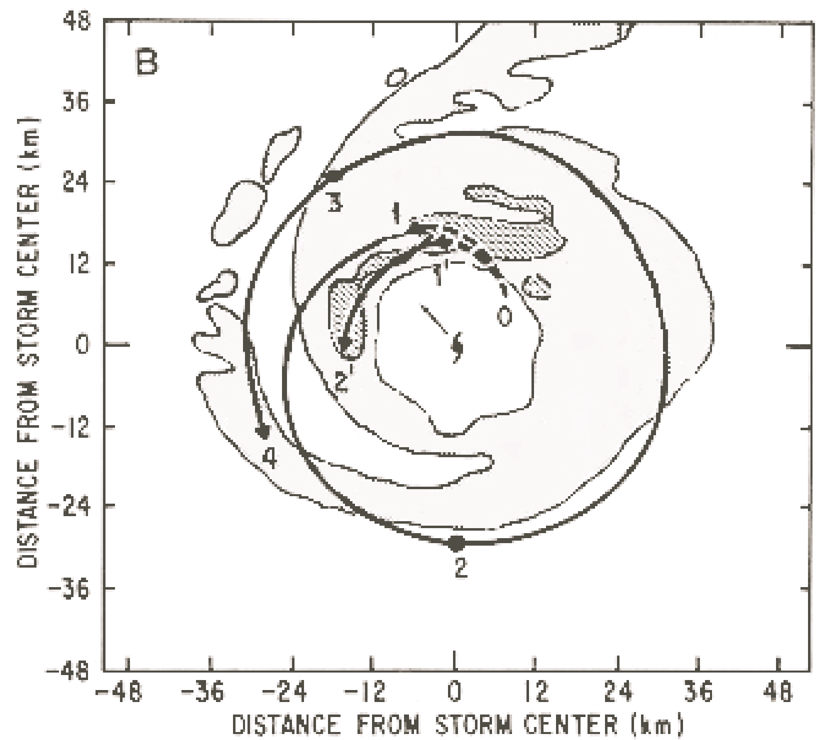
- However, TC vortex structure dynamically constrains smaller scale circulations (characteristic time scale is V_θ/r not N) that confound better QPF.
- TC provides a perfect laboratory for testing QPF techniques.
- If we can't improve QPF in TCs, then QPF in other situations may be hopeless.





- Over open water simplest TC QPF is a climatology and persistance (CLIPER) model that predicts peak storm total rain (R_{max}) as:

$$R_{max}=\overline{R}DV_s^{-1}$$

integral of $\overline{R}$ along line (D) with V_s.

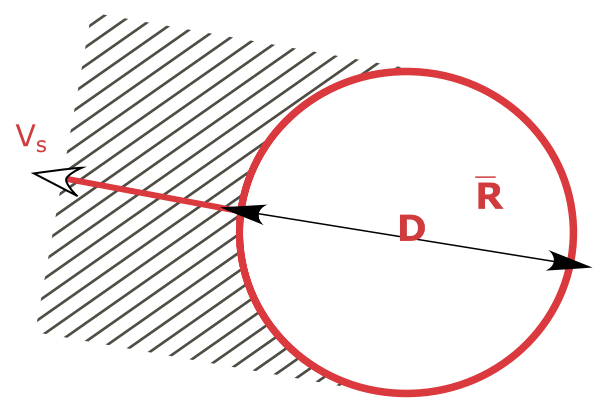
- Originated in late 1950s as Kraft's "rule of thumb" where:

$$R_{max}=130.8\ V_s^{-1}$$

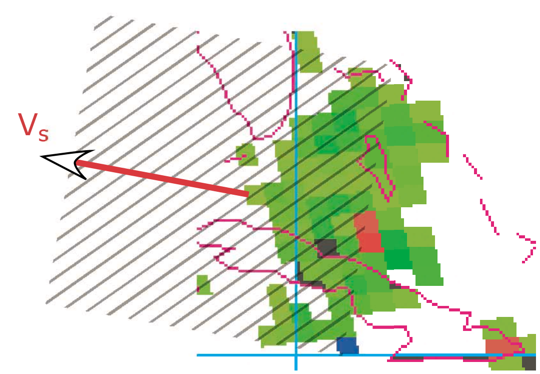
where R_{max} in cm, V_s in m s^{-1}, and climatological $\overline{R}$=0.49 cm h^{-1} and D=1000 km.

- Tropical Rainfall Potential (TRaP) (Ferraro et al 1998) uses similar approach, but with satellite R-estimates projected along track
- Note these techniques have no adjustments for storm intensity, topography, or other parameters.

Rule of Thumb



TRaP



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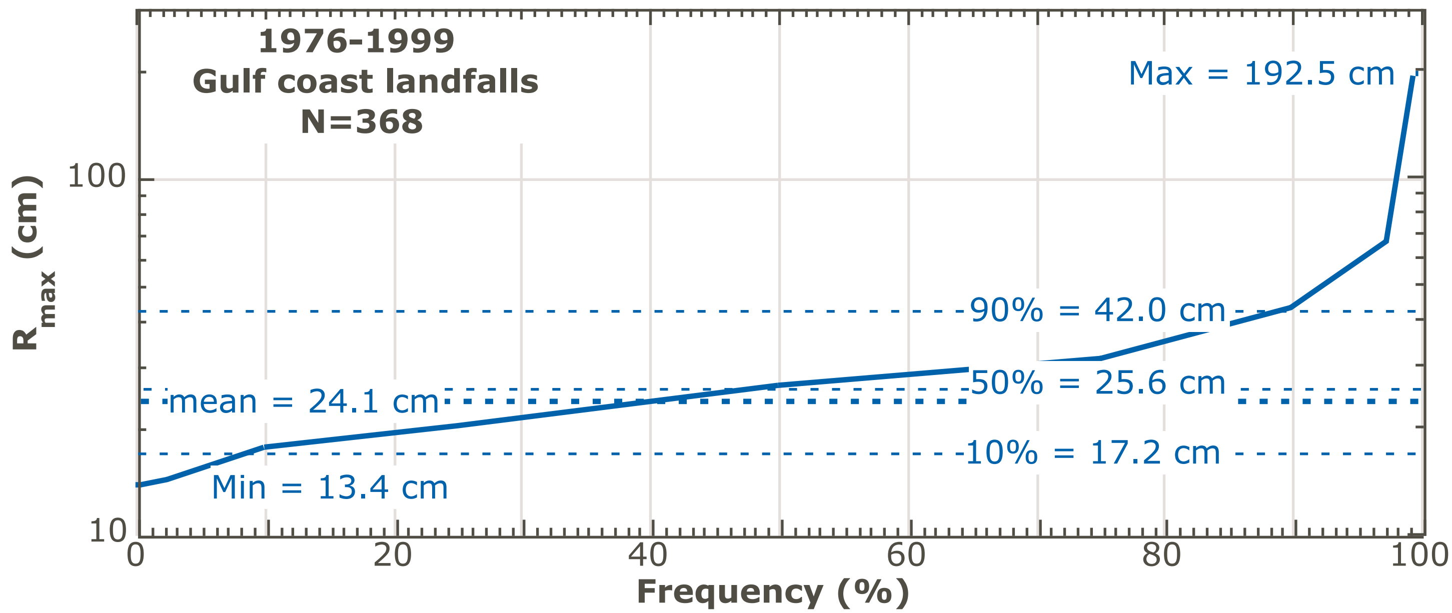
- Problem is sensitivity to assumptions of $\overline{R}$, D, and V_s which come from TC climatology. Relatively good estimates of D and V_s climatology are available globally.

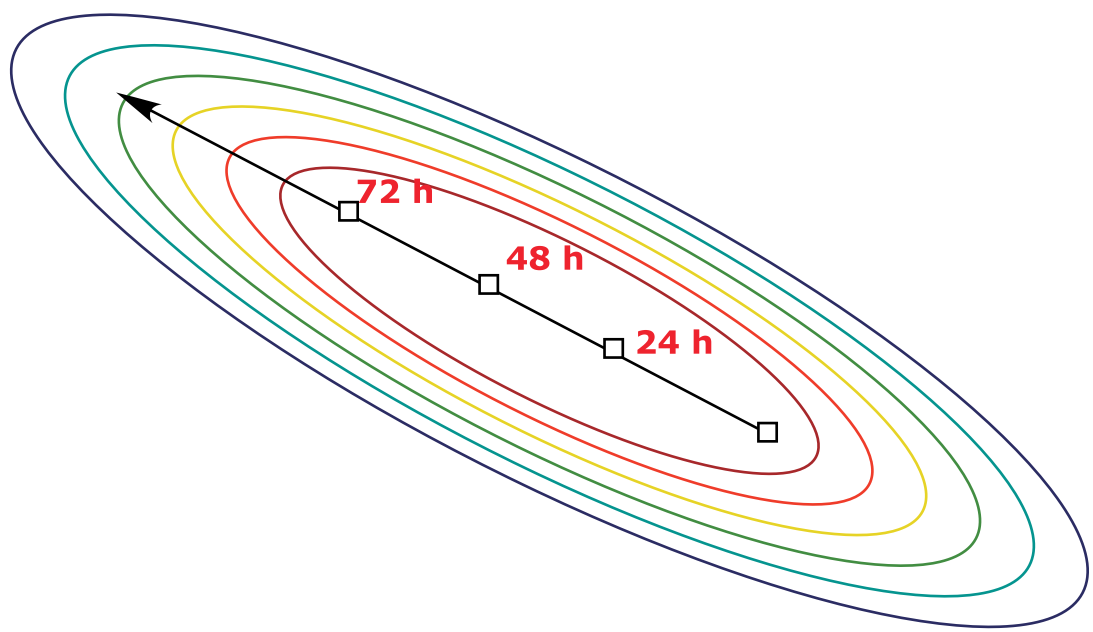
Sensitivity of R_{max} to V_s, holding $\overline{R}$ and D fixed for all Gulf landfalls 1976-1999



- Major stumbling blocks are: (1) use of $\overline{R}$ to represent R distribution (poor measure of non-normal distribution); and (2) lack of a comprehensive TC R climatology to define the probabilty distribution of R and $\overline{R}$.
- Estimates of R distribution based on radar (WSR-88D) and satellite microwave remote sensors offer promising ave-nues to develop R climatology.

R-CLIPER:

- Produce swath of peak storm total rain (R_{max}) along storm forecast path using gauge and TRMM R climatology project ed a on the 72 h forecast track and intensity forecast.
- R-CLIPER forecast would be used as a baseline for com- parison with other TC rain forecasts to determine skill.
- R-CLIPER could be extended to use PDF of R to provide probabilistic R forecasts, using data from different basins, or adding asymmetries.



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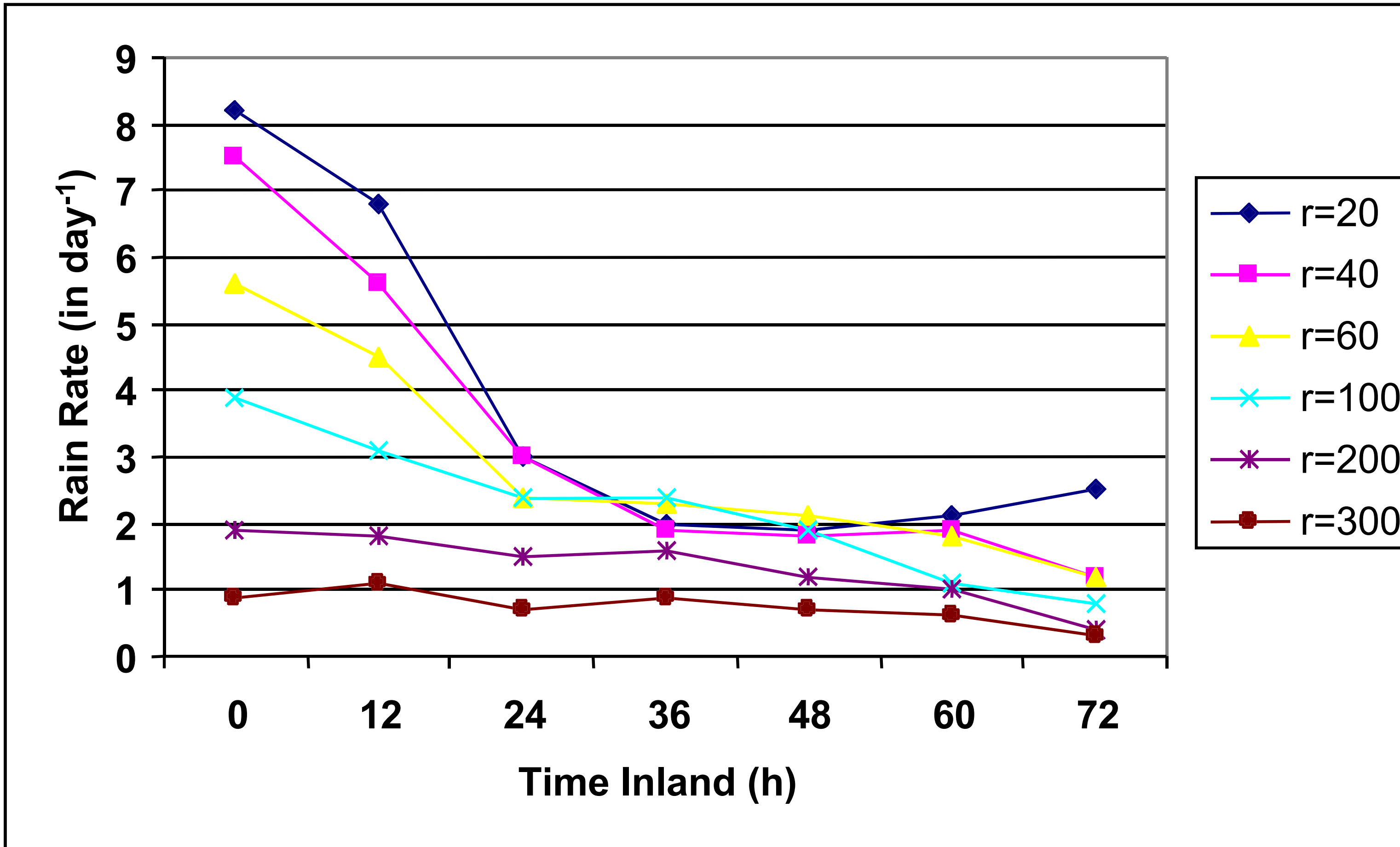
R-CLIPER Model

(Rain Gauge Version)



Climatological Rainfall Rate for U.S. Landfalling Hurricanes 1948-2000

Functional Form: $R(r,t) = (ae^{-\alpha t}+b)e^{-(r-r_m)/r_e}$

Parameters: a, b, α, r_m, r_e

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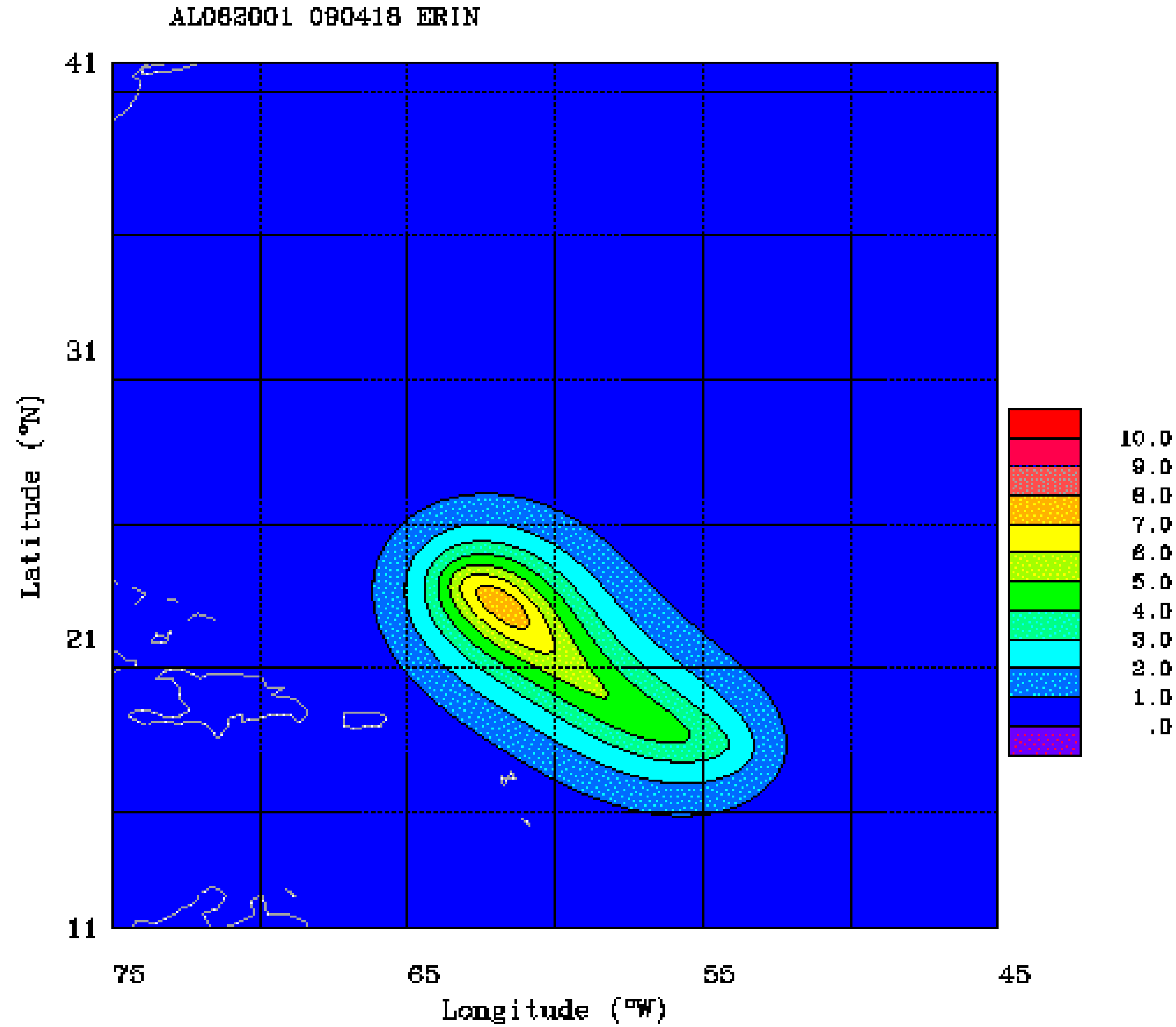
R-CLIPER Forecast for Erin 2001



Rainfall Rate from Gauge Climatology Accumulated
Along 72 h NHC Track Forecast for Erin
(4 Sept. 2001 18 UTC)

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GOAL FOR TRMM:

- Improve understanding of tropical cyclone (TC) rainfall (R) by developing rain climatology in TCs globally, and
- Develop methodology to validate model forecasts of TC rain.

DATA AND METHOD:

- R estimates from TRMM Microwave Imager (TMI).
- 245 storms from December 1997 to December 2000, yielding 2121 events, globally, from tropical storm to category 5 hurricane.

1998-2000 Events by intensity.

Storm Intensity	Events
Tropical Storm	1361
Category 1-2	548
Category 3-5	212
Total	**2121**

- 64% of events tropical storms, 26% category 1-2 hurricanes, and 10% >category 3.

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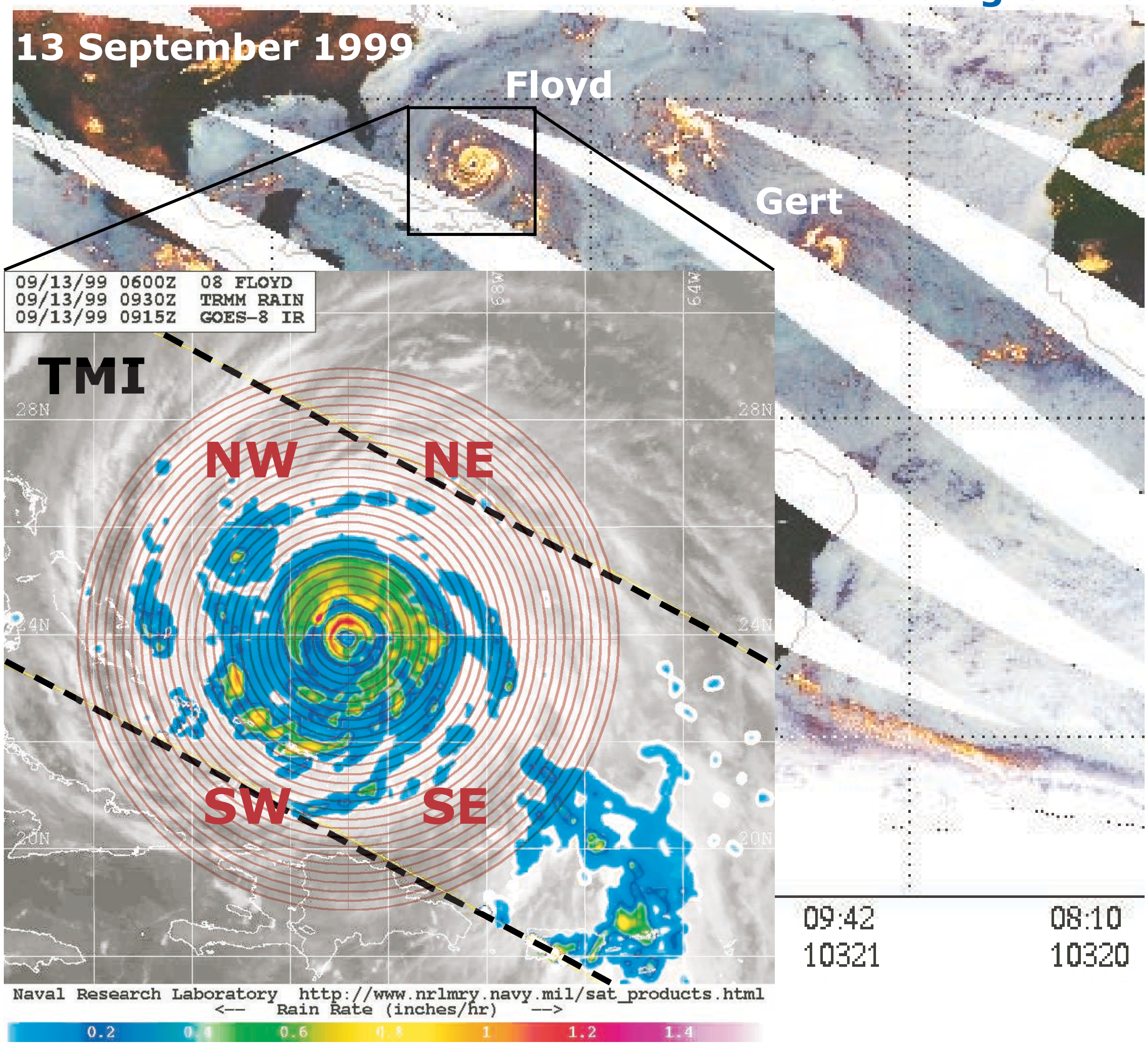
METHOD (continued):

- TMI passive microwave radiometer at 10.7, 19.4, 21.3, 37, and 85.5 GHz over a 758.5 km swath with ~5 km resolution. Surface rain (R, mm h^{-1}) estimates from T_B.

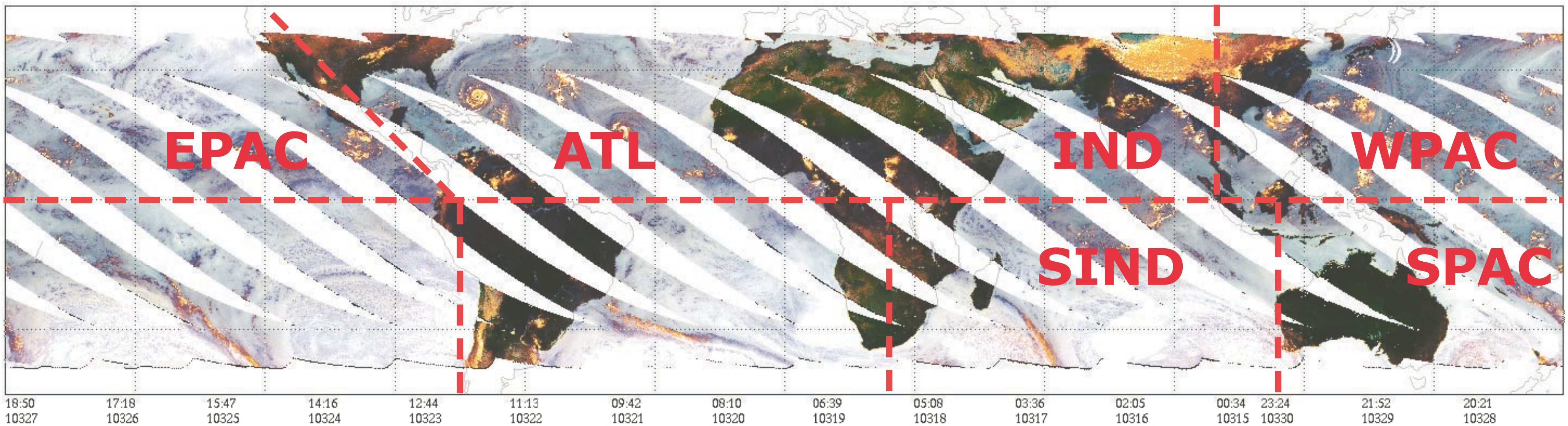
TRMM Descending Orbits



Analysis domain:
- storm-centered
- 100 10-km wide annuli
- 4 quadrants

METHOD (continued):

- Distribution of R examined as a function of intensity and geographical location.



TMI data for Monday, 13 September 1999

1998-2000 Events by basin.

Basin	Events
Atlantic (ATL)	472
E Pacific (EPAC)	343
W Pacific (WPAC)	675
N Indian (IND)	72
S Indian (SIND)	226
S Pacific (SPAC)	320
Total	**2108**

- Probability distribution of R computed for 10 km radial bands in 1 dBR (10 $\log_{10}$R) steps from 0.3-300 mm h^{-1} (-5 to 25 dBR).
- Stratified by intensity and motion, to compare to WSR-88D radar, and gage estimates.

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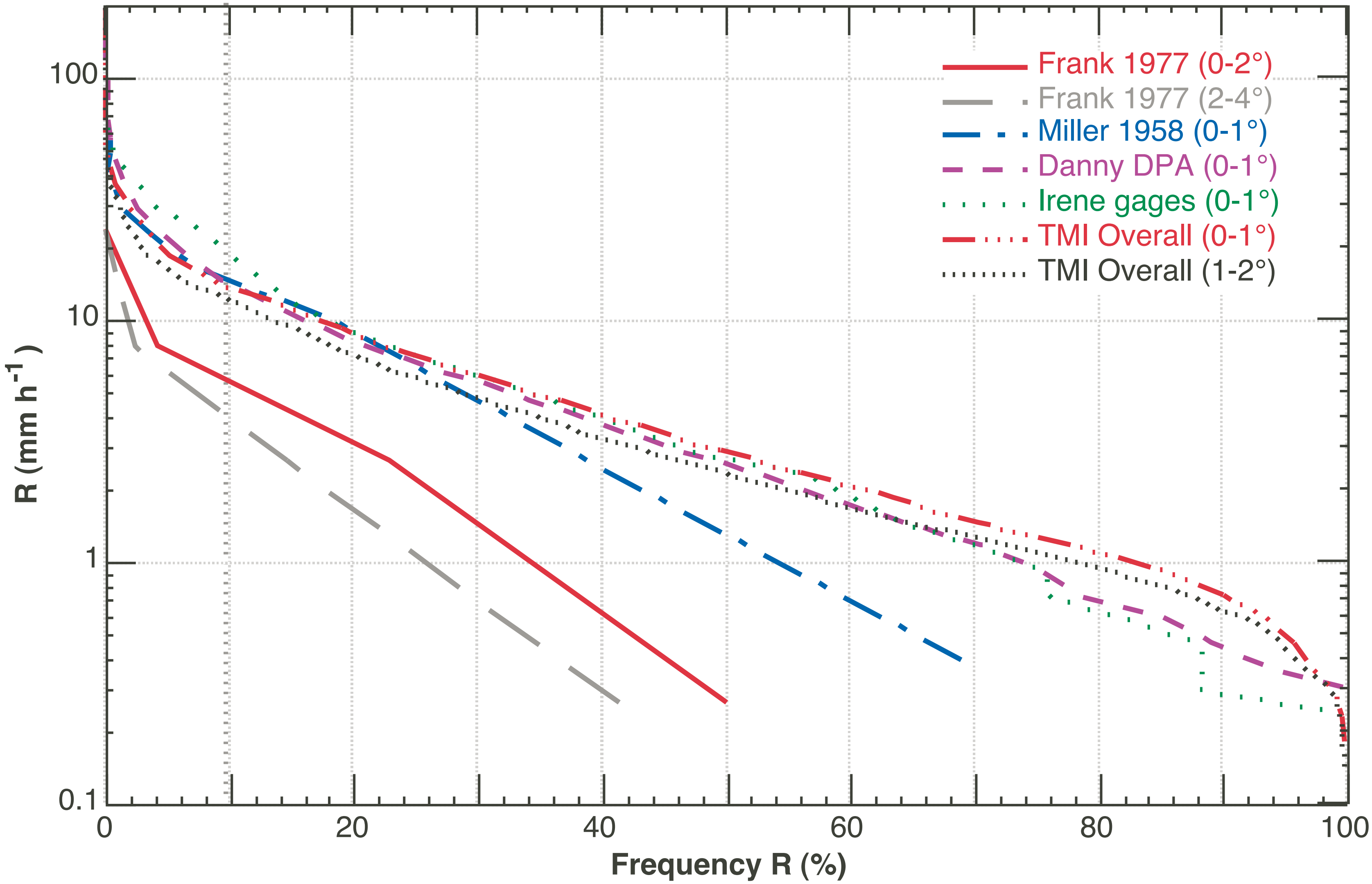
- Comparison of TMI to published TC R distributions by Miller (1958) and Frank (1977) shows fairly good agreement with Miller, but higher frequency of large R. Not much difference between 0-1° and 1-2° TMI distributions.
- Comparison of TMI with recent WSR-88D and gage estimates shows very good agreement.



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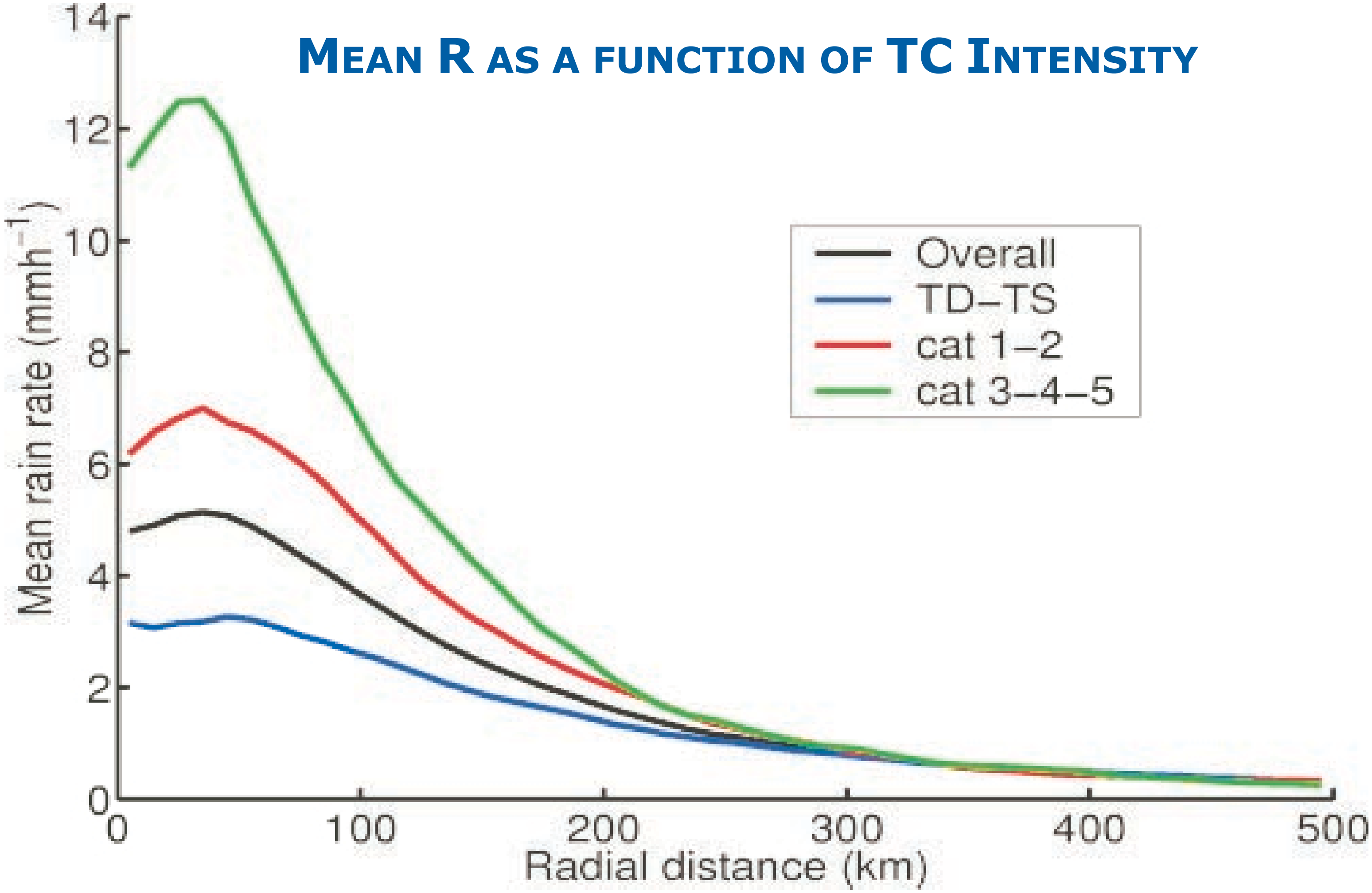
- Radial distributions of R total as well as a function of intensity shows R increase near center with increasing intensity.
- R near center increases with increasing intensity from 3 mm h^{-1} for storms, to 7.0 mm h^{-1} for hurricanes, to 12.5 mm h^{-1} for major hurricanes.
- Radius of maximum R decreases with increasing storm intensity from 55 km for storms, to 45 km for hurricanes, to 28 km for major hurricanes.

MEAN R AS A FUNCTION OF TC INTENSITY



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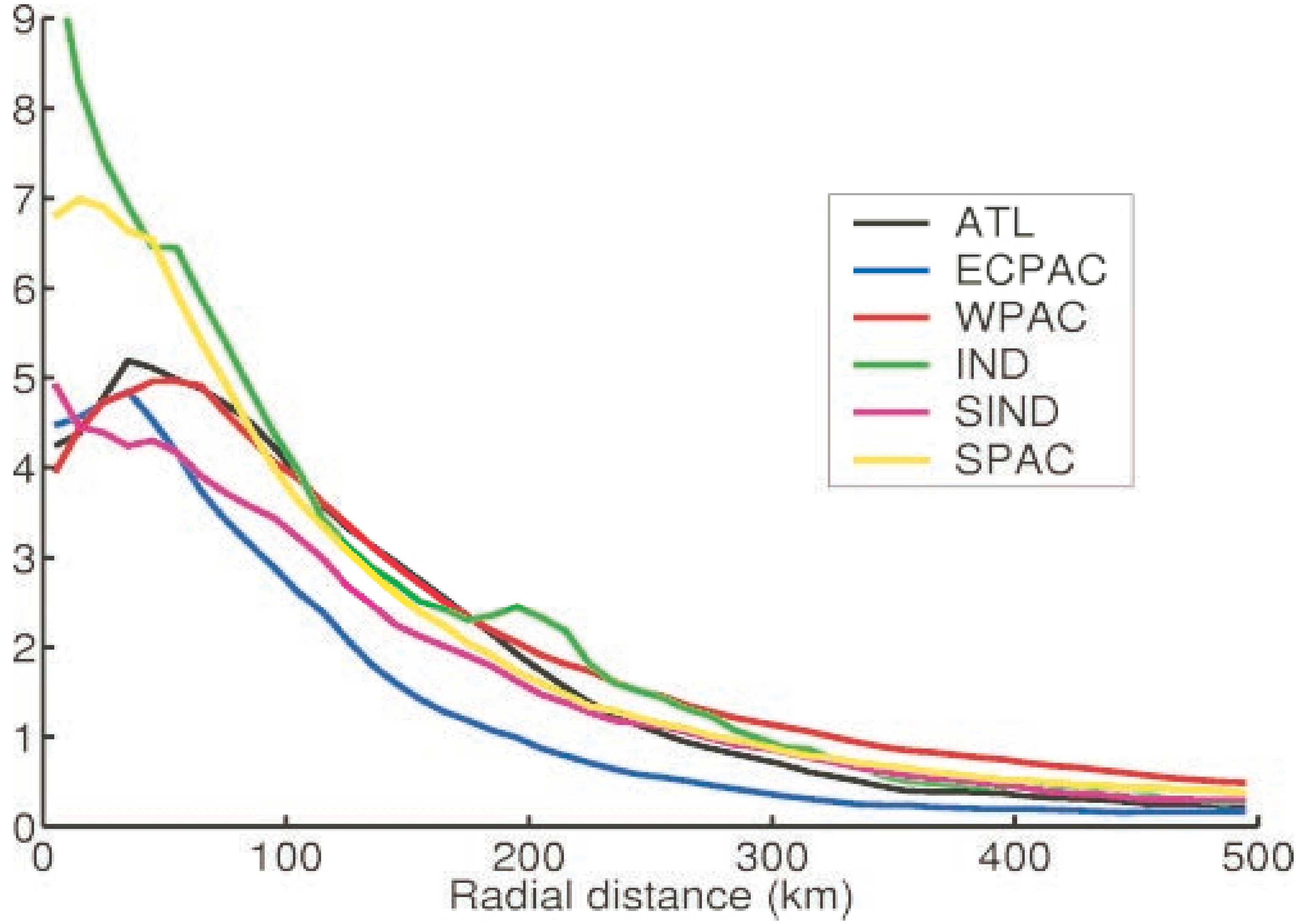
- Radial distribution of R realistic, with peak between 4.8 mm h^{-1} for the EPAC basin to 7.0 mm h^{-1} in SPAC basin (IND basin has too few events). R in all basins drops below 1 mm h^{-1} by 375 km.
- Radial distributions of R as function of basin indicate EPAC has smallest storms with R<1 mm h^{-1} by 230 km. WPAC has broadest storms with R<1 mm h^{-1} near 375 km.

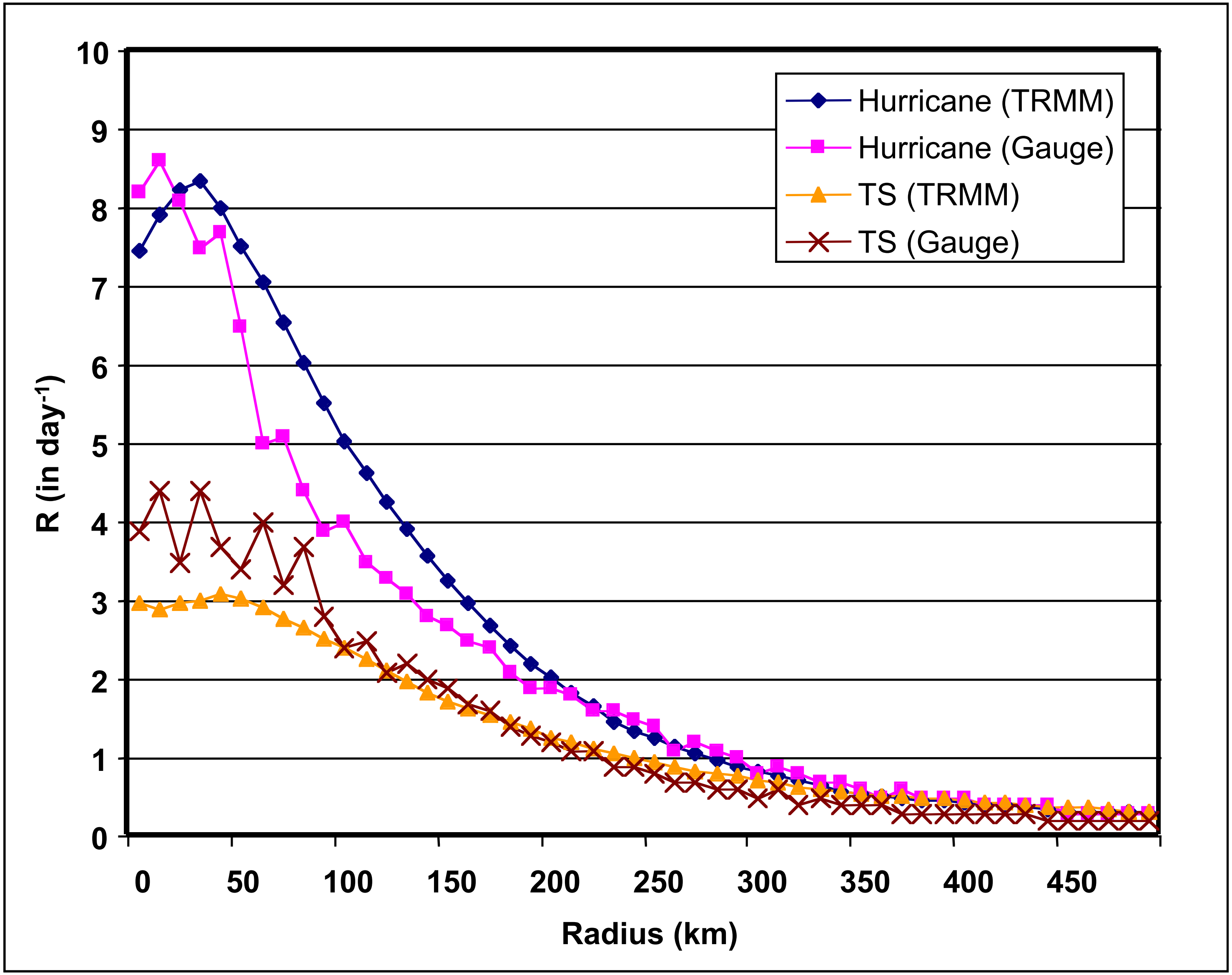


R-CLIPER Generalization using TRMM Data

- Gauge data insufficient to stratify by intensity
  - Gauge R-CLIPER forecasts depend only on track
- Use TRMM data to determine R versus intensity
  - Replace gauge R with TRMM R
  - TRMM R-CLIPER depend on track and intensity

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

(Rain gauge data for storms within 6 h of landfall)



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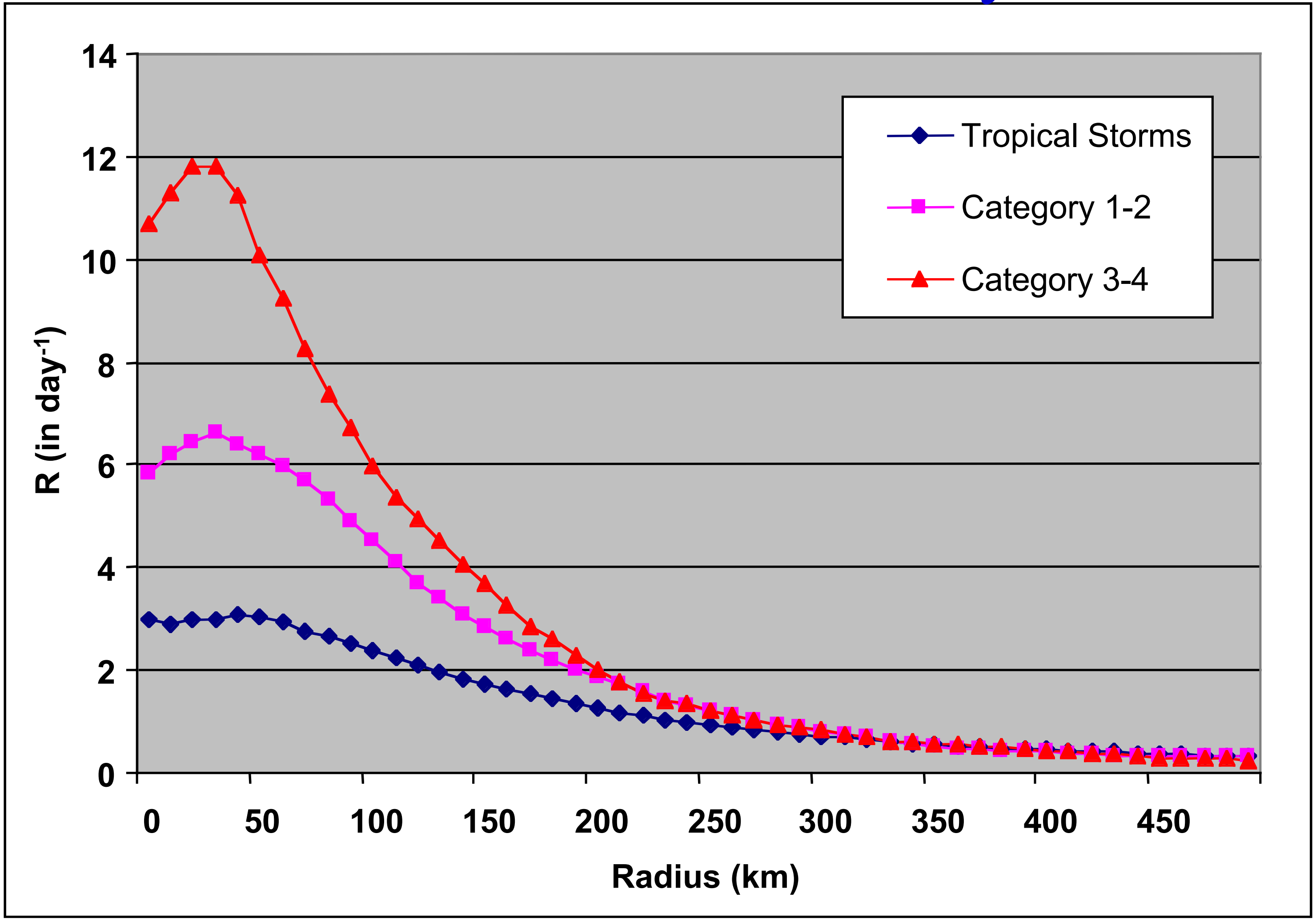
TRMM Rainfall Rate Stratified by Max Winds



Functional Form: $R(r) = (R_0) + (R_m - R_0)(r/r_m) \quad r<r_m$

$= R_m \exp(-(r-r_m)/r_e) \quad r>r_m$

Free parameters R_0, R_m, r_m, r_e are functions of max winds

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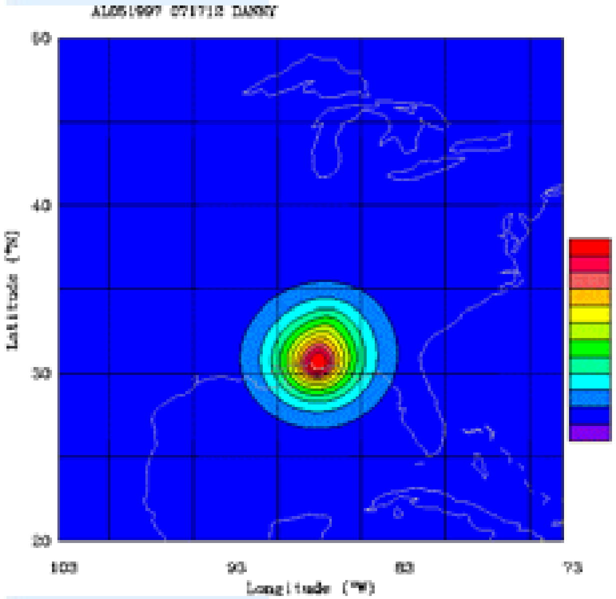
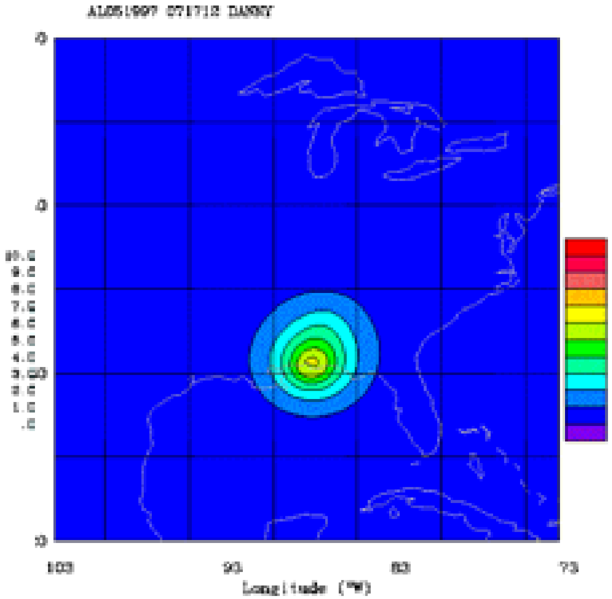
72 hr R-CLIPER Forecasts for Danny 1997

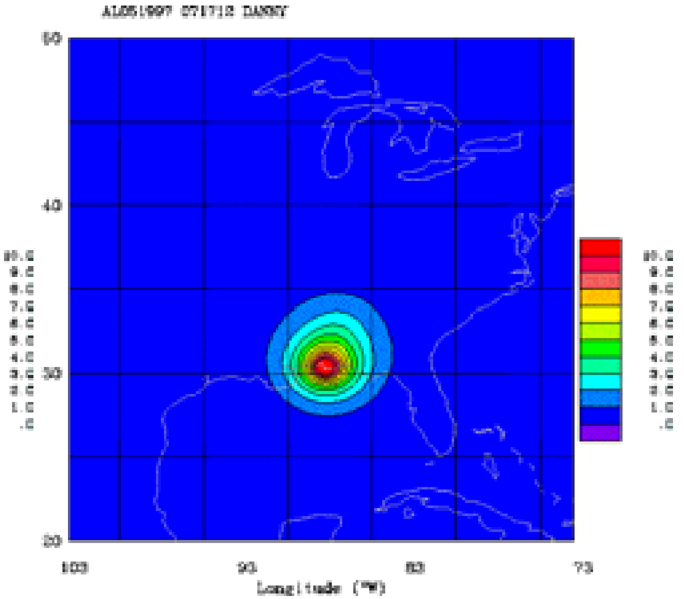
(Position and Intensity from Best Track)



Gauge Version



TRMM Version



TRMM Version with Doubled Landfall Intensity

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SUMMARY:

- TMI produces realistic TC R climatology which can be used for comparison to numerical models and for studies of TC QPF.
- TMI views more than 25% of 10 km annuli area out to 500 km, giving confidence in R and distributions.
- The radial distributions of rain rates are realistic, with peak 5.1 mm h^{-1} in first 50 km, and drop to <1 mm h^{-1} by 250 km.
- R>10 mm h^{-1} makes up 15% or rain area at radii<500 km with majority at radii<50 km (similar to Anita study - Marks et al 1993).
- R-estimates over 28 km^2 area reach >60 mm h^{-1}, the high R values are extremely rare (<<1%) and the vast majority of R values are modest (<0.5 mm h^{-1}).
- Radial distribution of R provides climatoligical R distribution for TC globally which can be used to formulate a rainfall climatology and persistence (R-CLIPER) for quantitative precipitation forecasts.
- R-CLIPER developed as a technology transfer of research to operations under the USWRP Joint Hurricane Testbed (JHT).