Tropical Cyclone Rainfall

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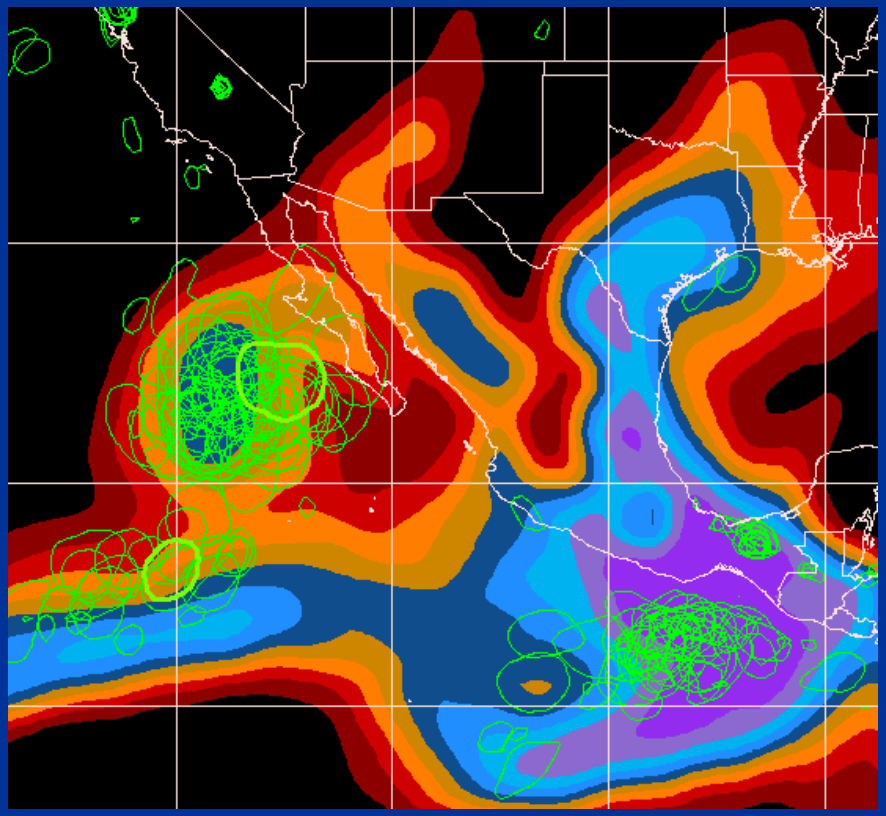
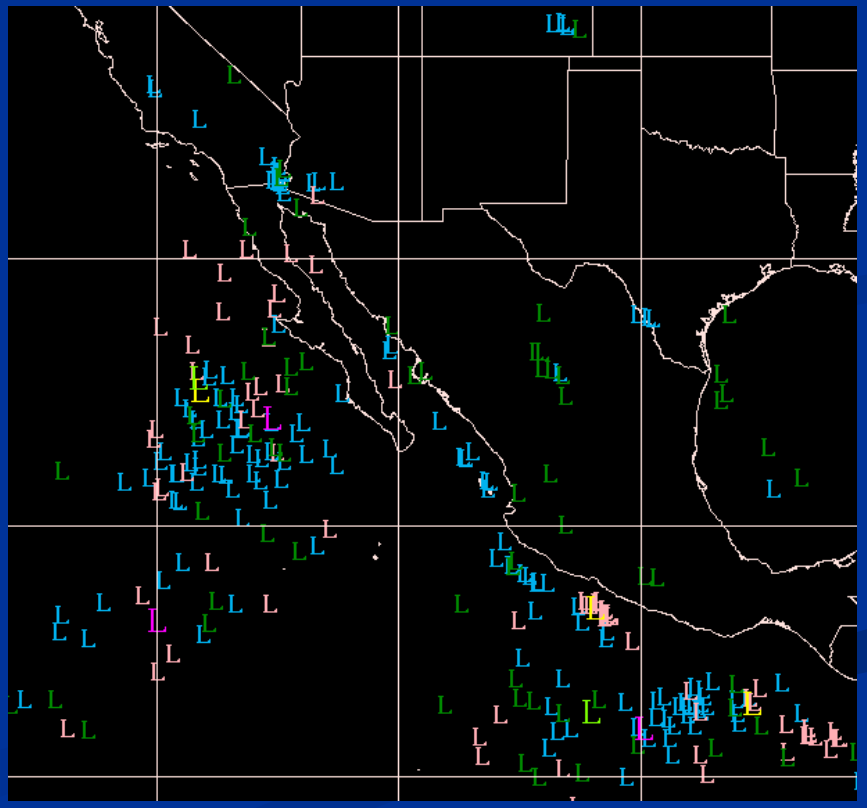
Role in the Tropical Cyclone Program

- Collaborative track forecast – medium range
- Rainfall Statements composed by WPC
- WPC assumes responsibility for inland depressions outside of Florida
- Service Backup for NHC if needed

Medium Range

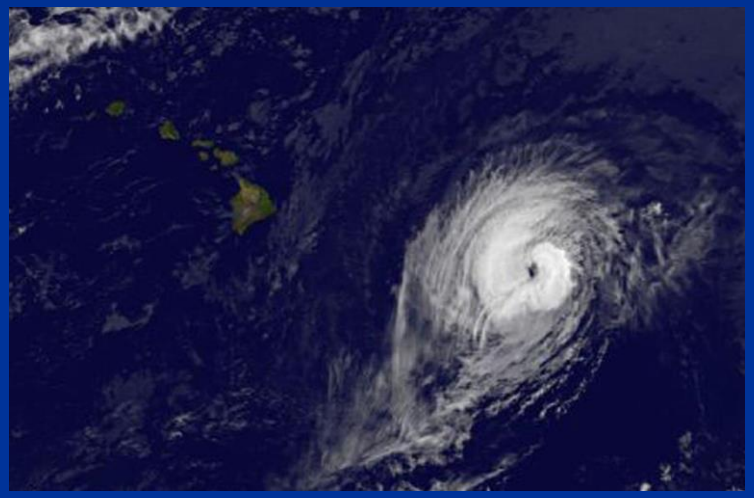
- Collaboration on days 3-7 forecast for systems not yet formed, or days 6-7 for active tropical cyclones.

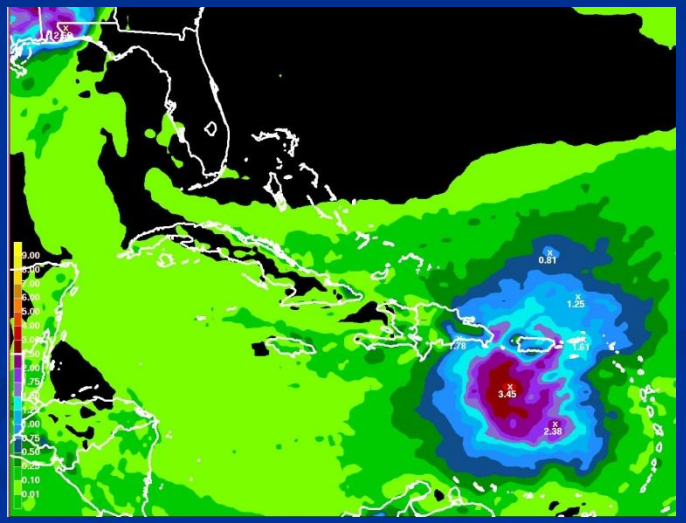




Rainfall Statement

- Expected areal average rainfall and isolated maximum amounts
- Atlantic and eastern Pacific basins

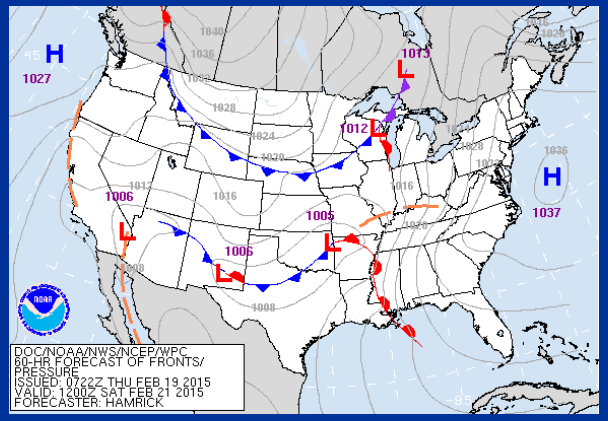




…total rain accumulations between 4 and 6 inches expected, and isolated totals of 12 inches possible. Heavy rain could potentially affect the other islands Saturday and Sunday. This rainfall could cause life-threatening flash floods and mud slides.

Public Advisories – Inland

- Inland advisories for cyclones that have been downgraded to tropical depression – outside Florida
- Forecast positions to Day 5 or loss of definable center
- Discontinued if system is no longer a flash flood threat

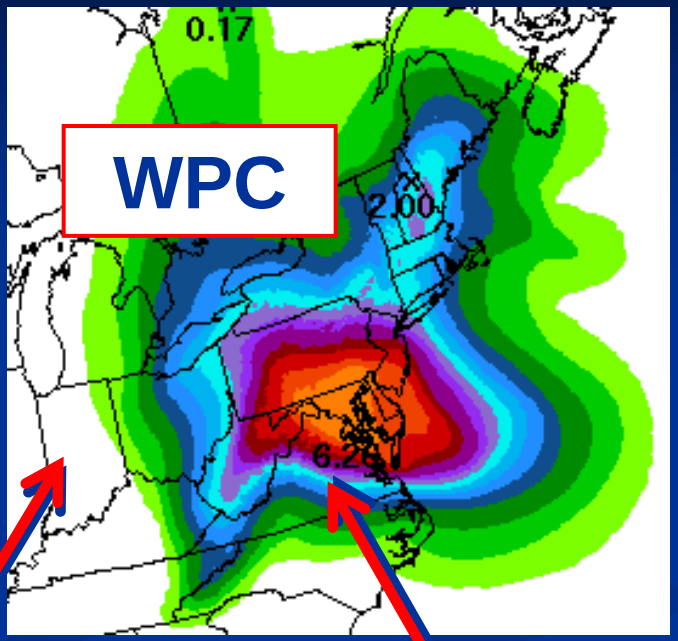


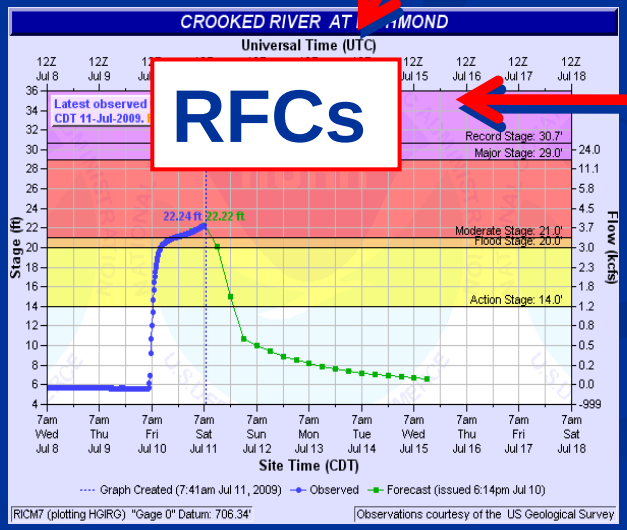
Content:

Current Watches/Warnings/Advisories
Storm description / intensity
Observed rainfall summary
Forecast evolution and track
Composed in ATCF starting in 2018

Deterministic QPF

- 6-hourly to 84 hours
- 48-hour summation days 4/5, 6/7
- Graphical, gridded, kml
- Associated discussions
- Manual product drawn at 20-km
- Downscaled to 5km

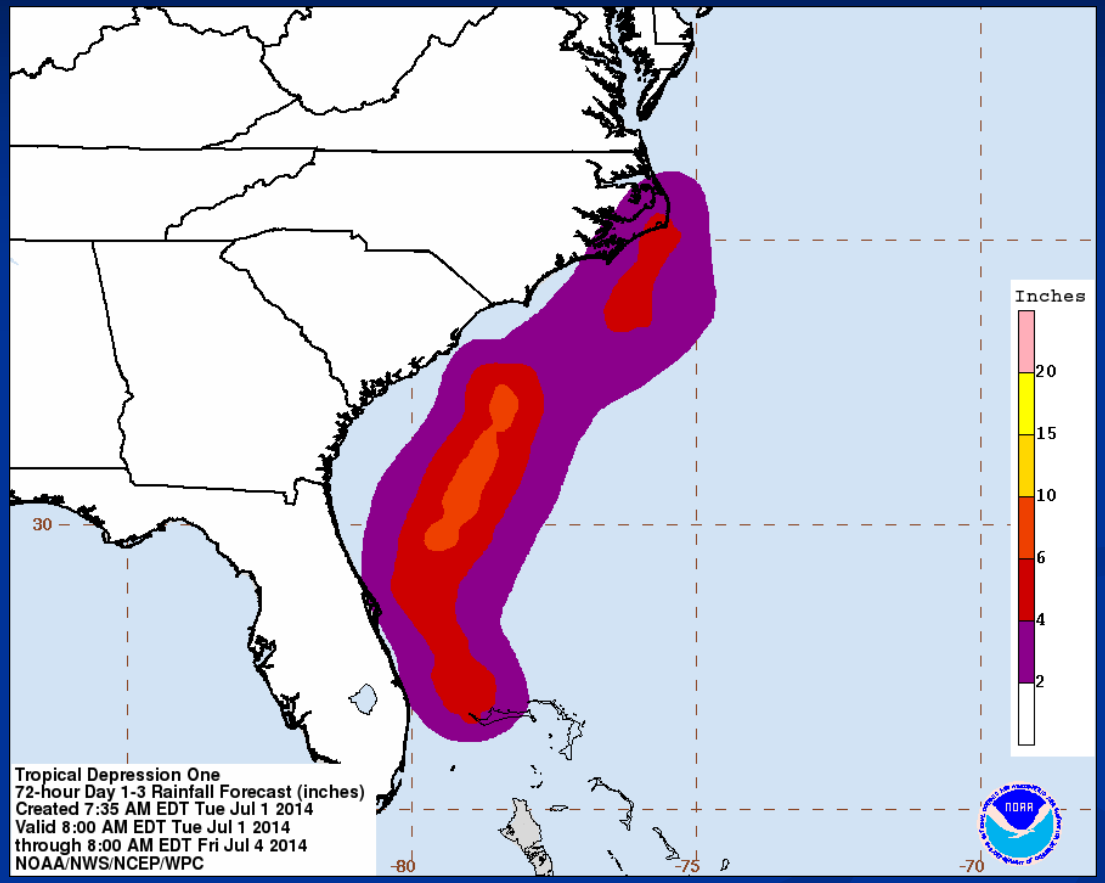




Tropical Cyclone Rainfall Graphic

WPC, NHC home page during tropical cyclones…

Variable duration summation – storm dependent

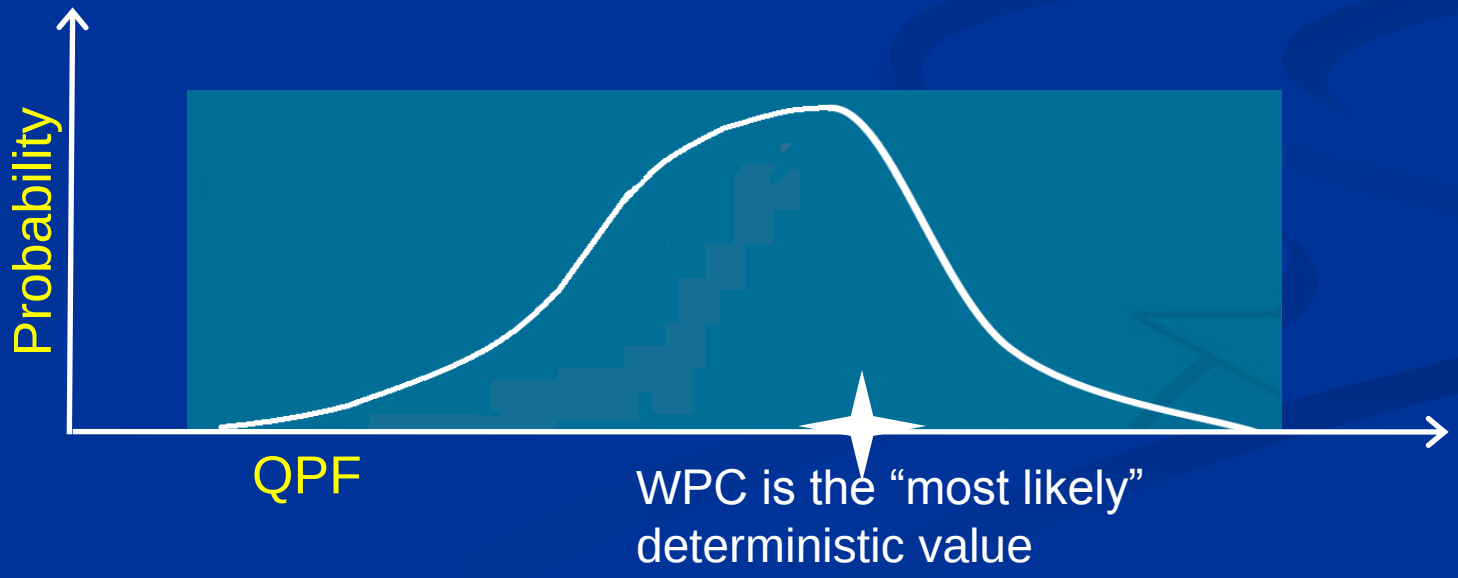


Note: Color scale and minimum contour of 2" was specified by FEMA. Alternate versions are now being considered.

Probabilistic QPF

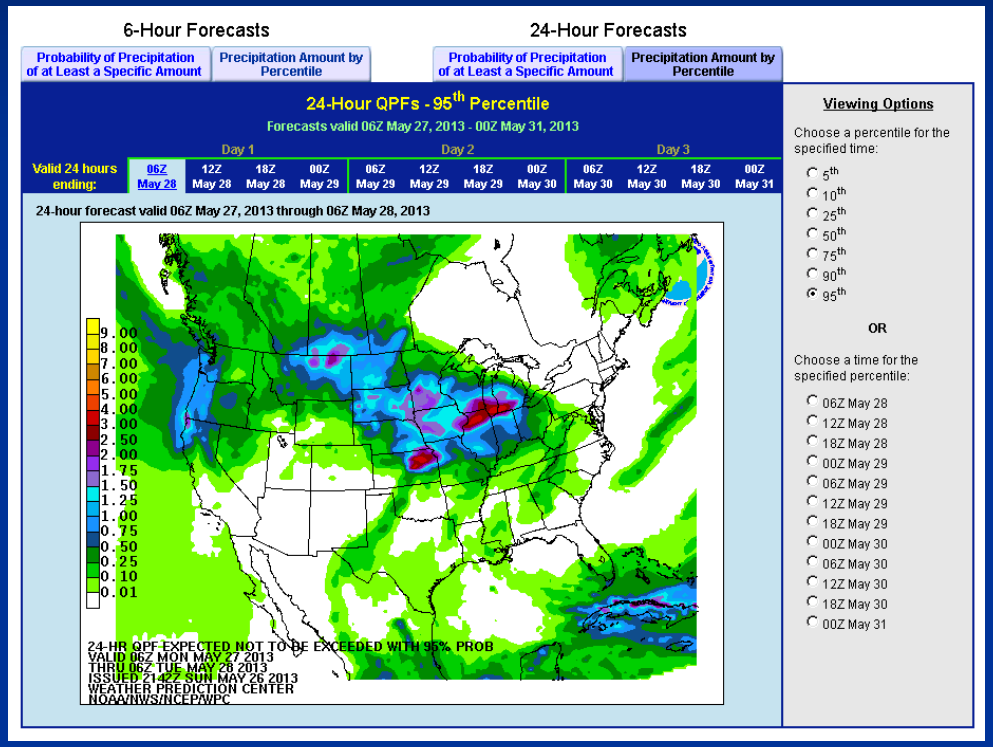
- When the manual WPC forecast is ready, it is lumped with the NAM, GFS, ECMWF and its ensemble members, GEFS, and SREF to form a 46 member ensemble.

- The probabilistic distribution is then forced into this format: WPC deterministic QPF is the mode (most likely value), variance is that of the ensemble, and skew is based on the position of the WPC manual forecast

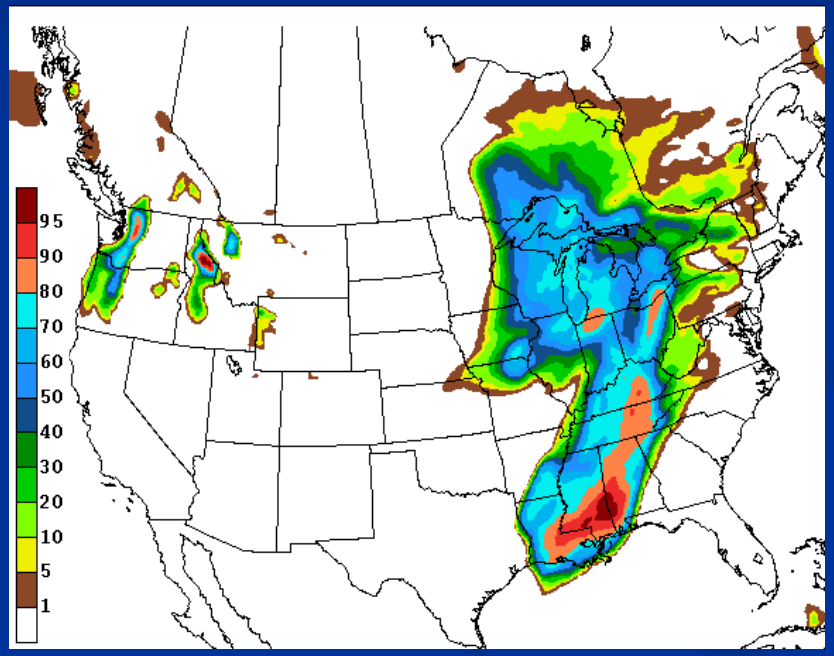


Probabilistic QPF

QPF by Percentile



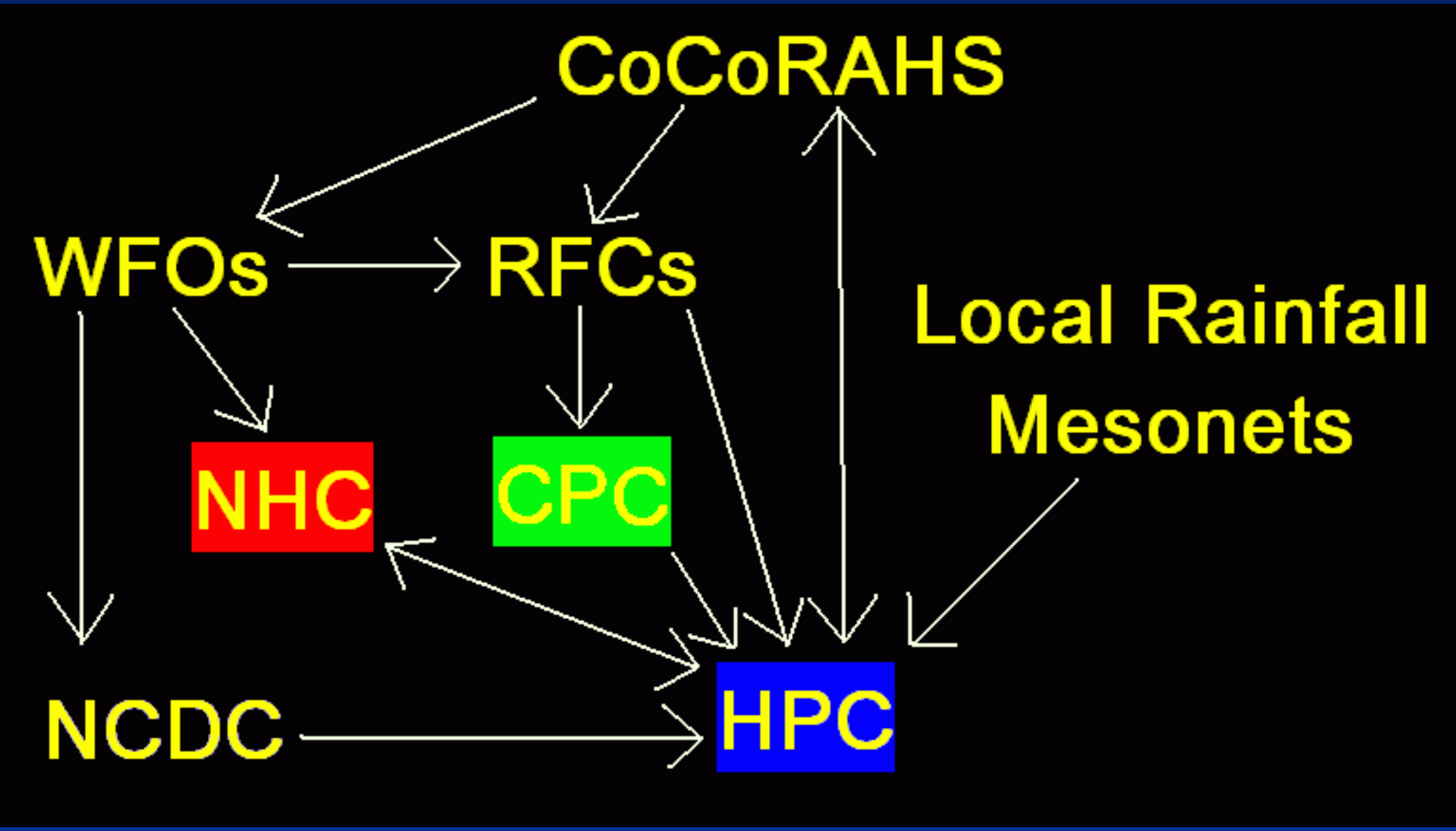
Probability of QPF Exceeding a Threshold



- *View 6- or 24-hourly*
- *PQPF and PWPF updates lag deterministic products by*

Flow of rainfall-related data to and from the Weather Prediction Center (WPC)

Flow of rainfall data to WPC

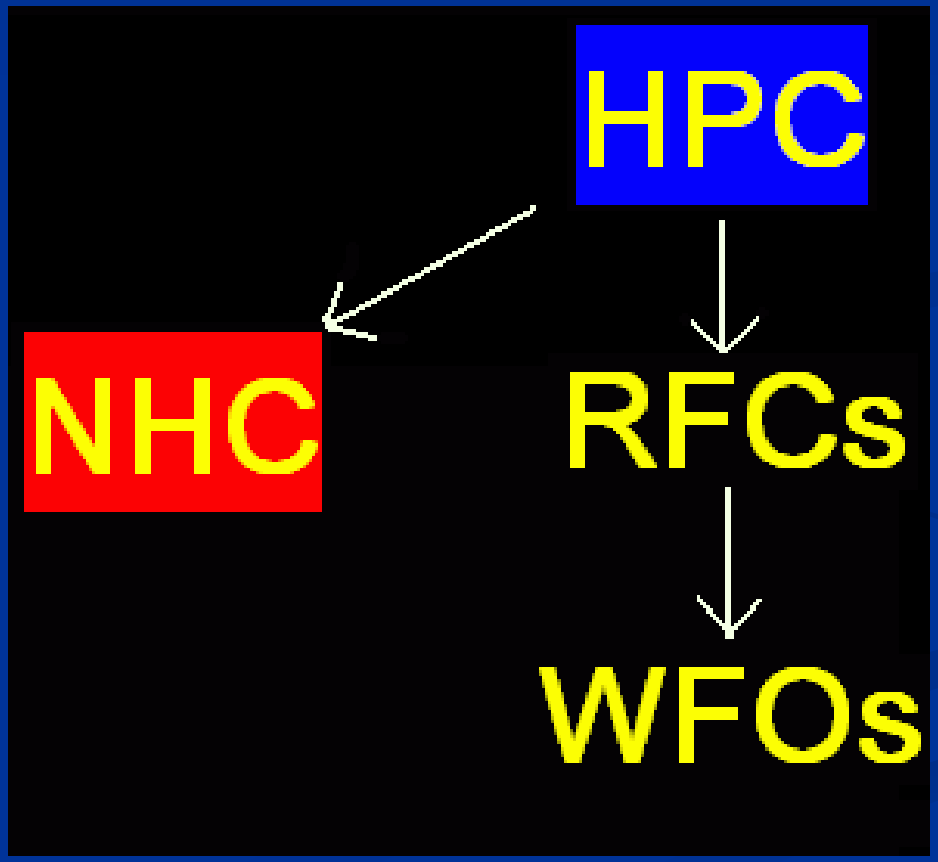


Flow of tropical cyclone rainfall forecasts within the United States National Weather Service (NWS)

Statement

Four times

a day



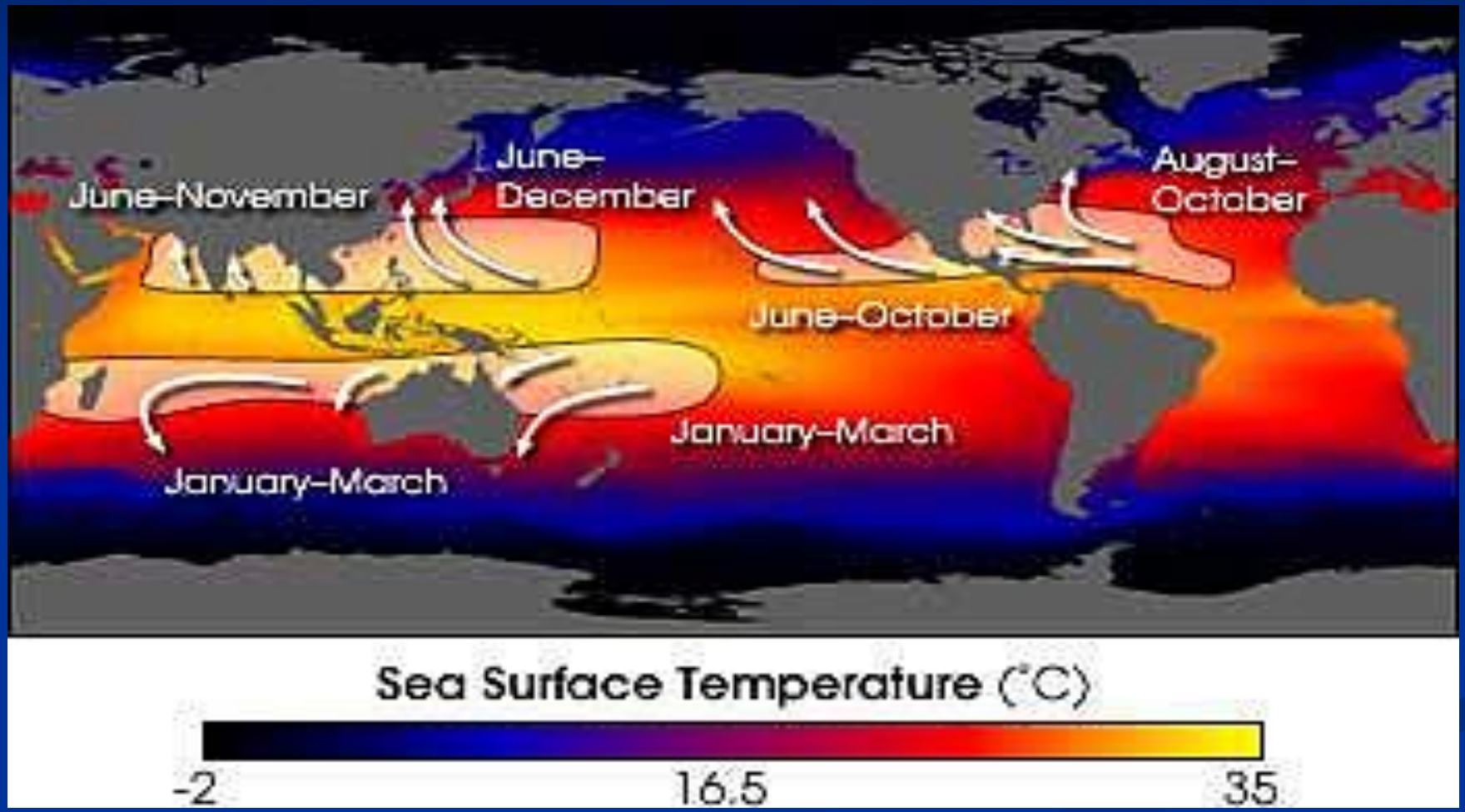
Graphics

Four times

A day

Tropical Cyclone Rainfall Climatology

Timing of Peak activity in Tropical Cyclone Basins



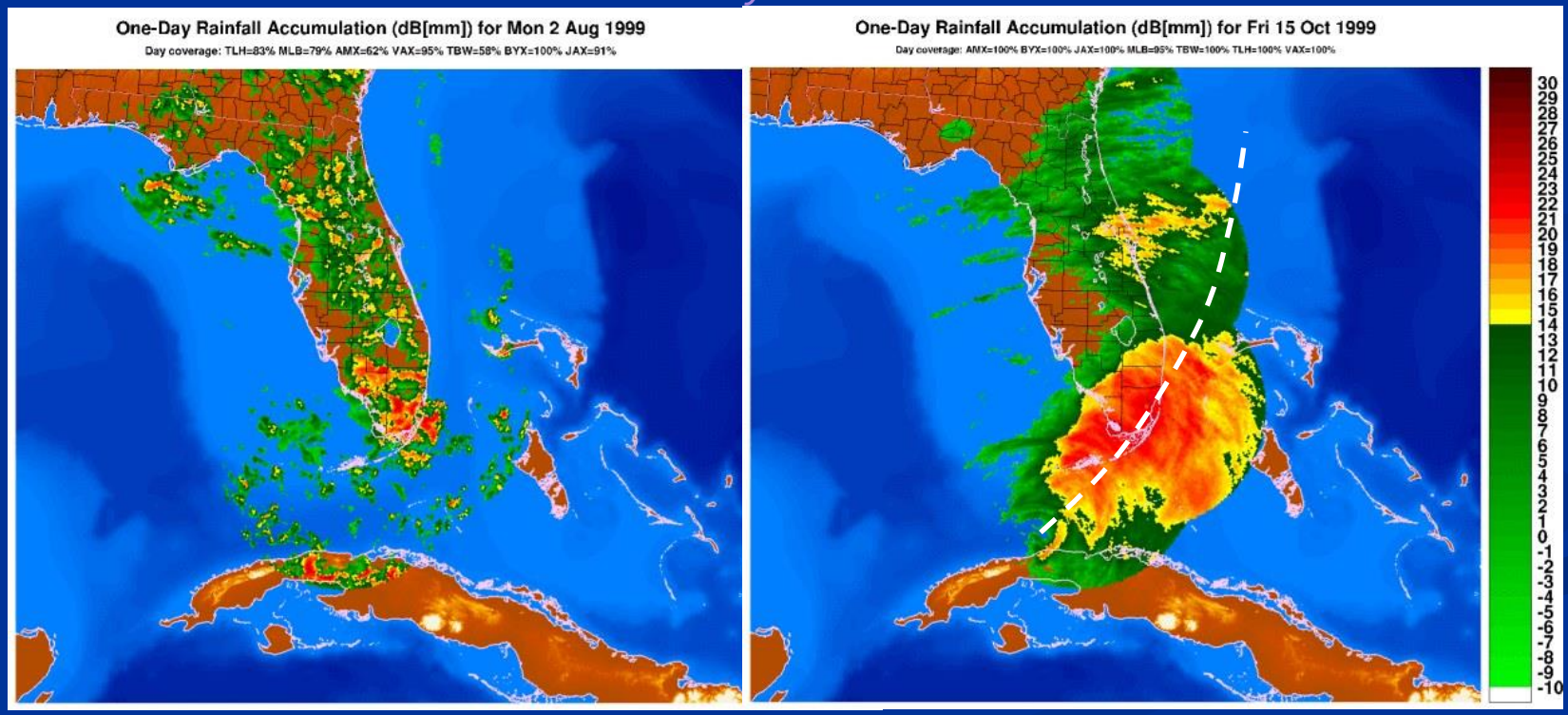
After Gray (1975) /Dr. J. Marshall Shepherd (University of Georgia/NASA)

Characteristics of TC precipitation

Stratiform and Convective mechanisms

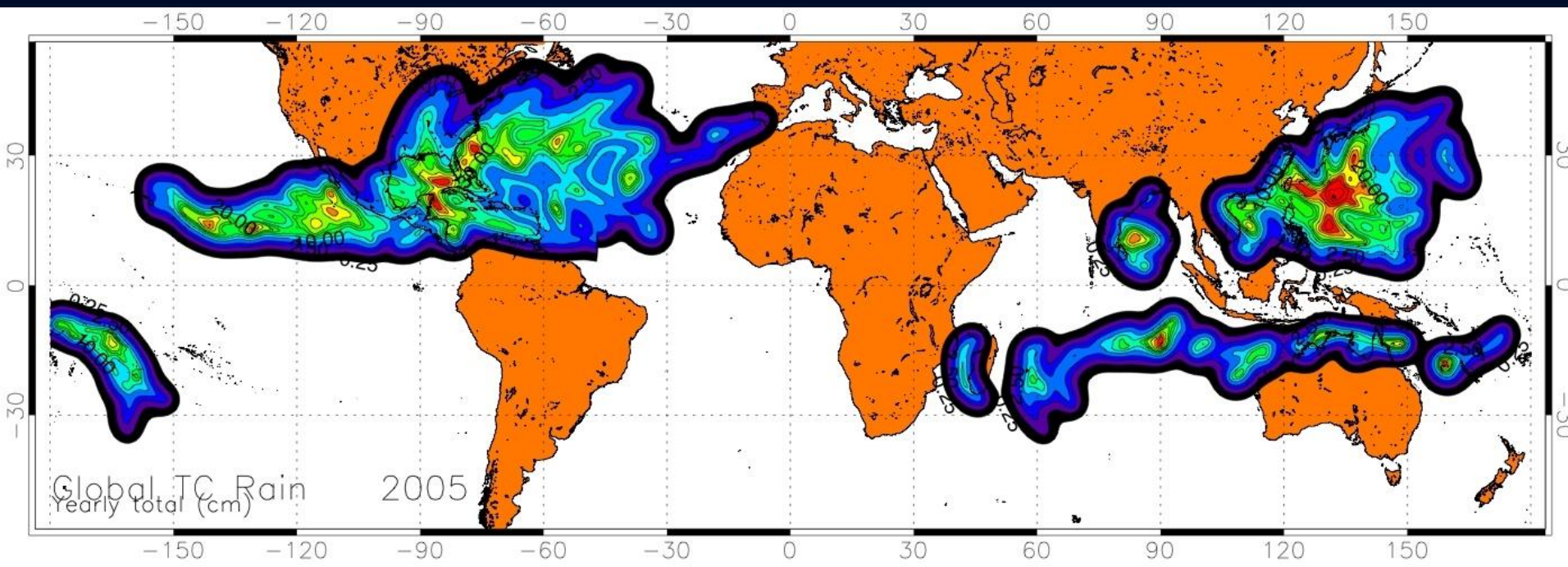
- Stratiform rain ~50% of total rain from TC.

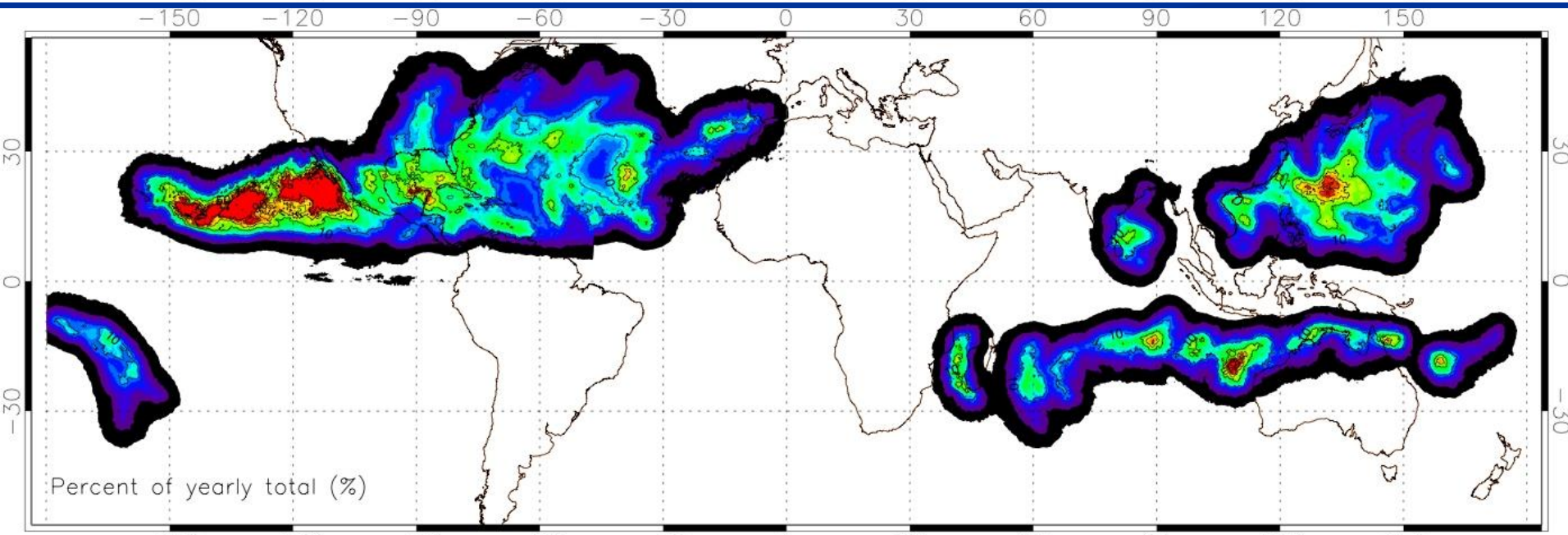
WSR-88D DPA daily accumulations

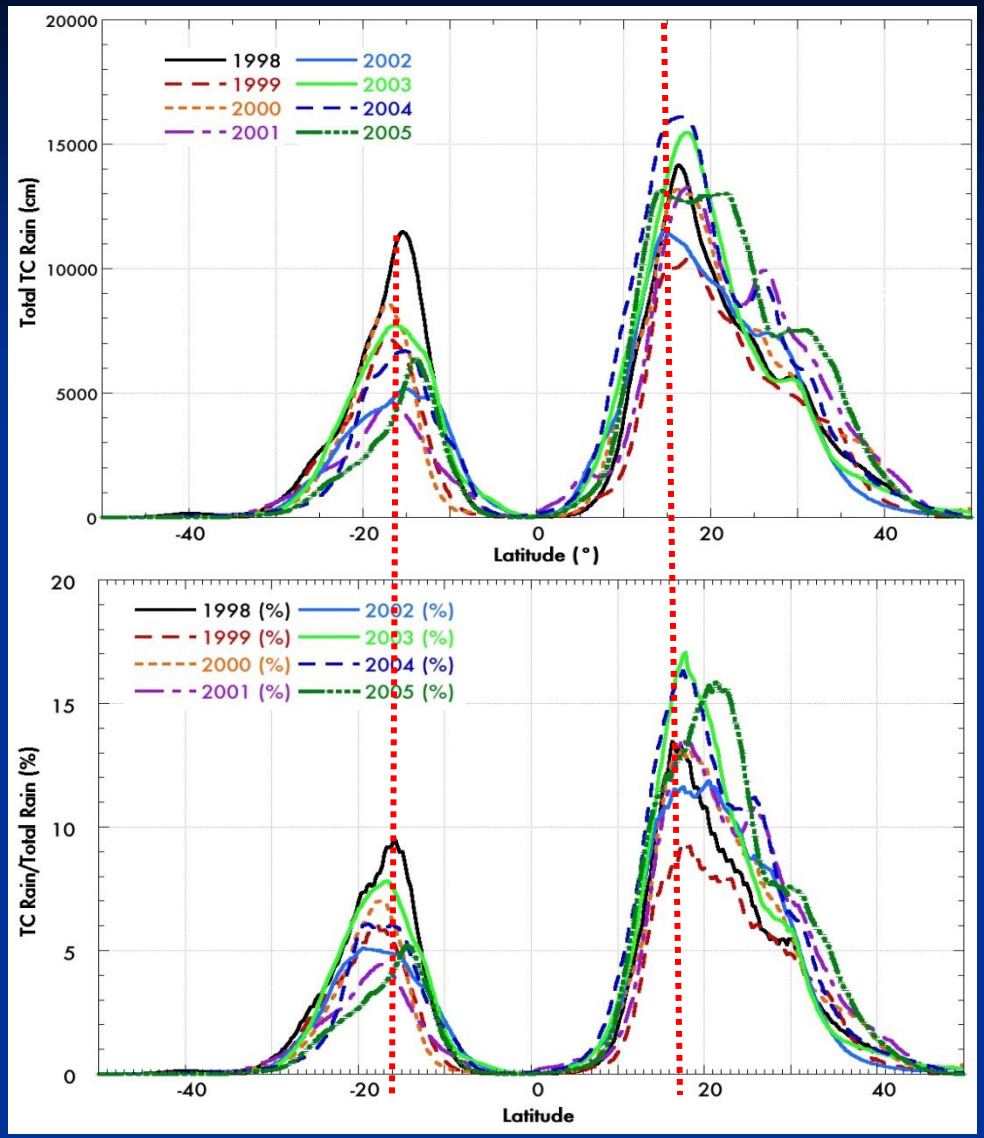


Hurricane Irene (15 October 1999)

Frank Marks (HRD)


Global TC Rain 2005
Yearly total (cm)


Percent of yearly total (%)



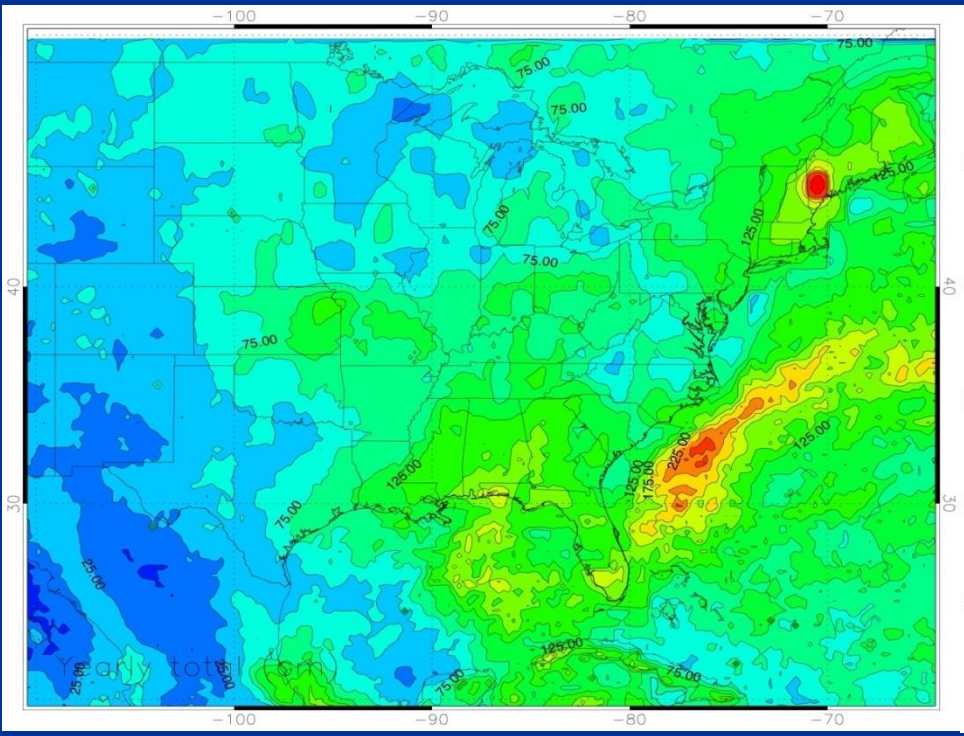
- TC rainfall peaks when global rainfall is low
- Asymmetric-generally more rain in the Northern Hemisphere
- Global rainfall is decreasing with increasing latitude while TC rainfall is increasing
- TC contributes 10-17% of global rain 15-30° poleward from Equator (subtropics)

Frank Marks (HRD)

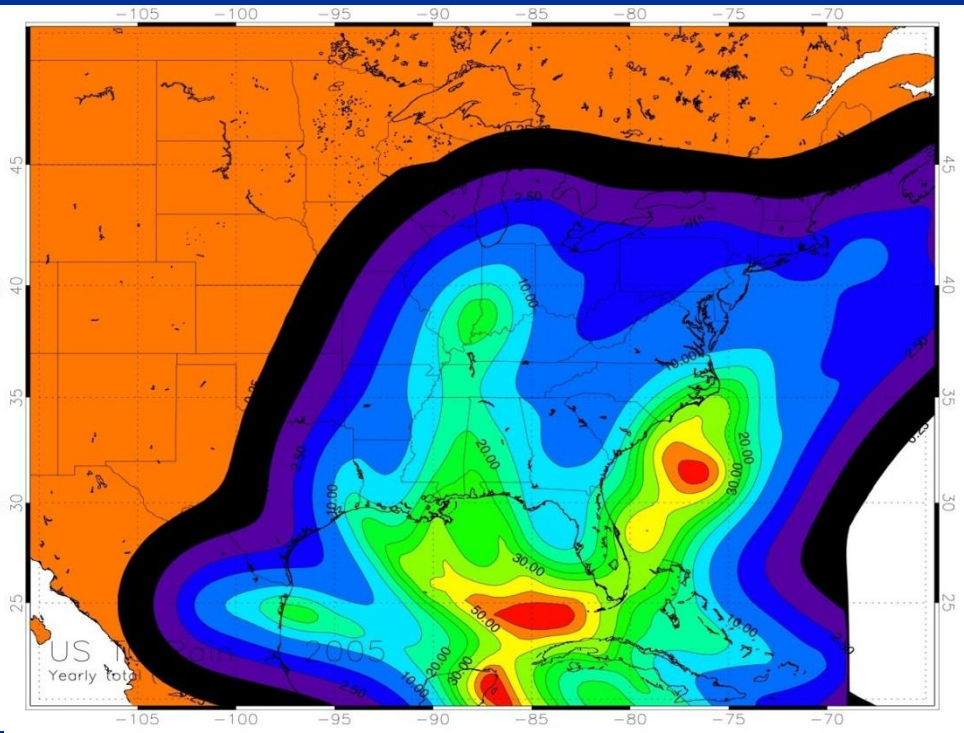
United States

Units in cm

2005 US Summer rain

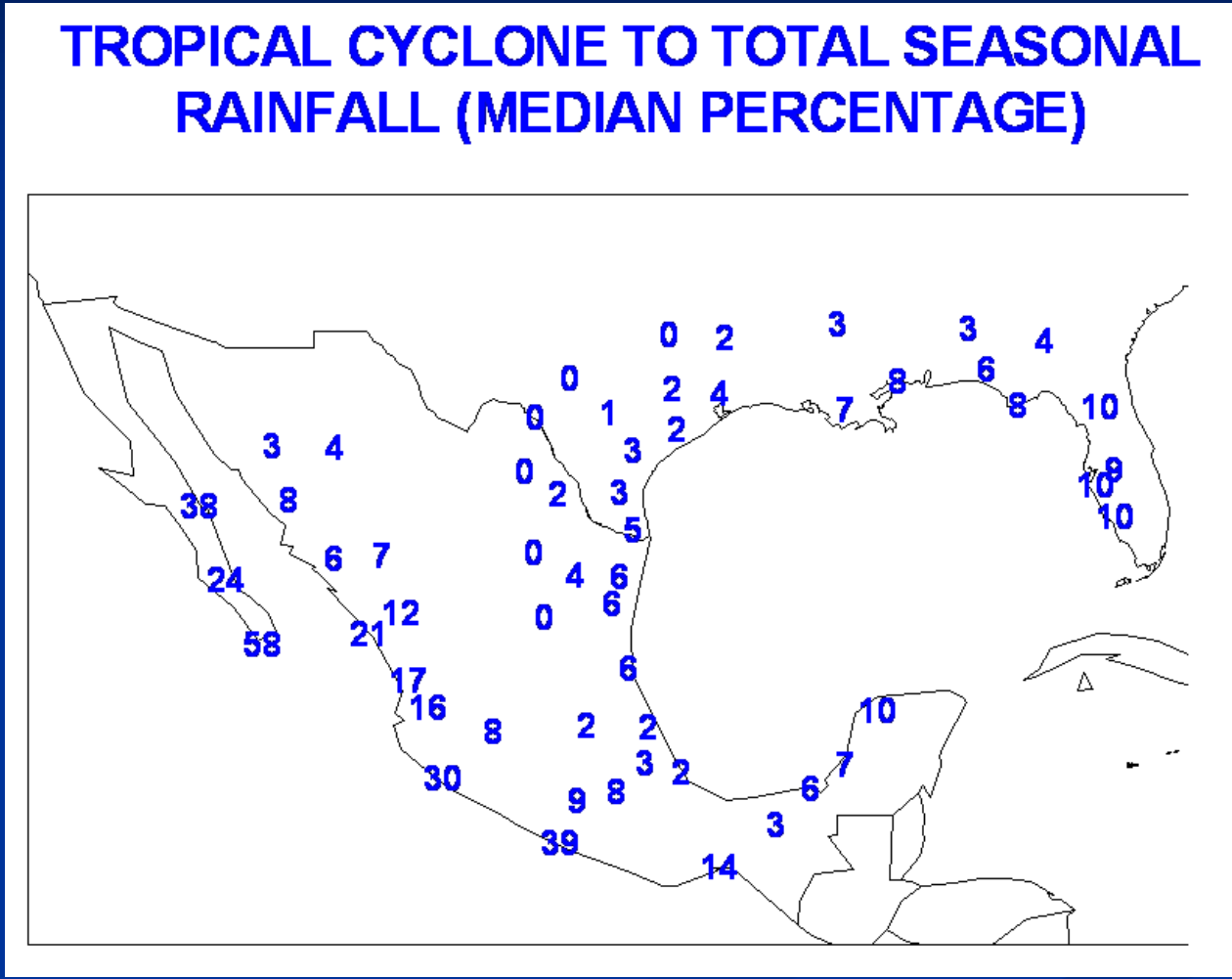


2005 US TC rain



Frank Marks (HRD)

Tropical Cyclone vs. Total Seasonal Rainfall in Mexico

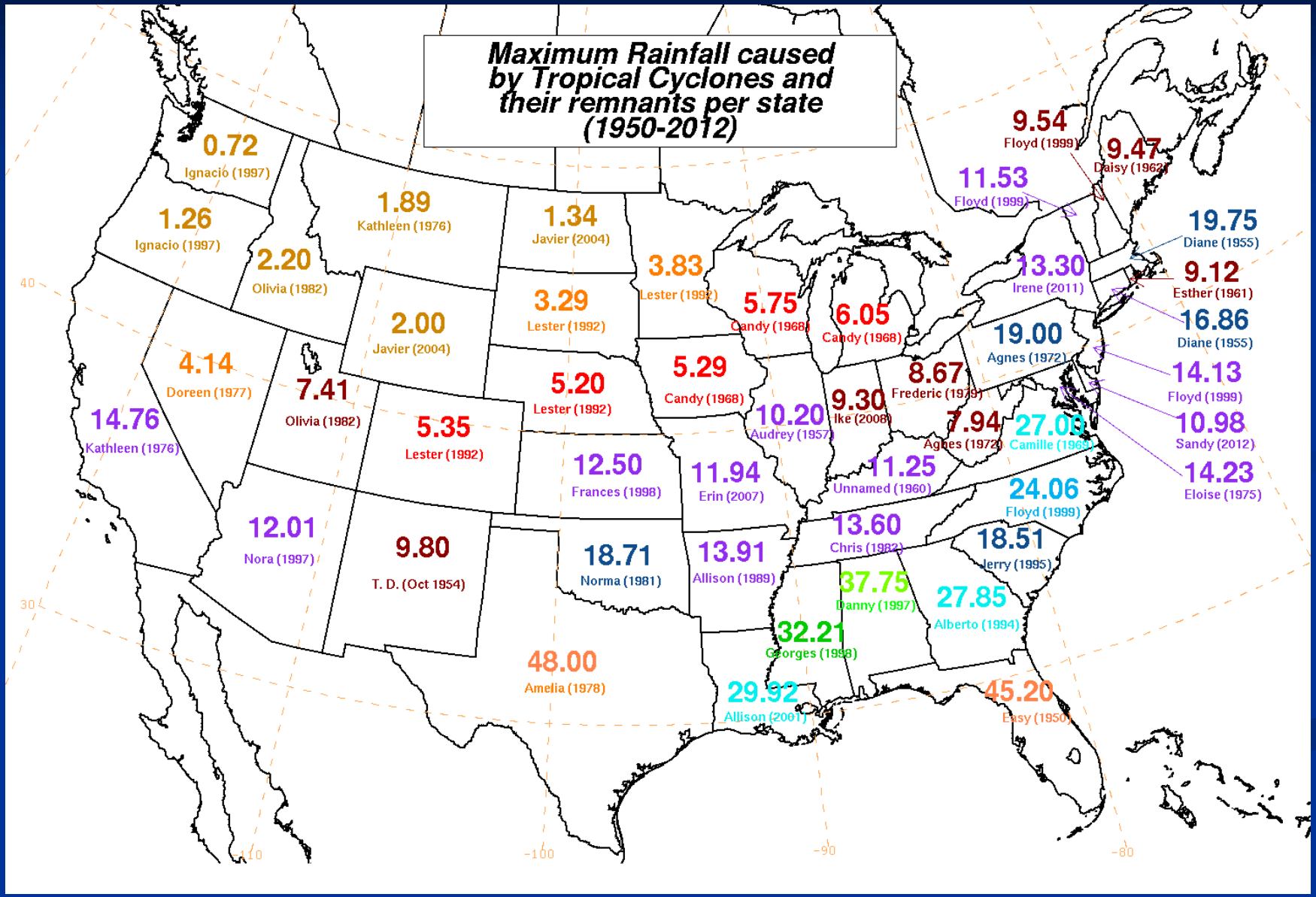


Art Douglas (Creighton University)

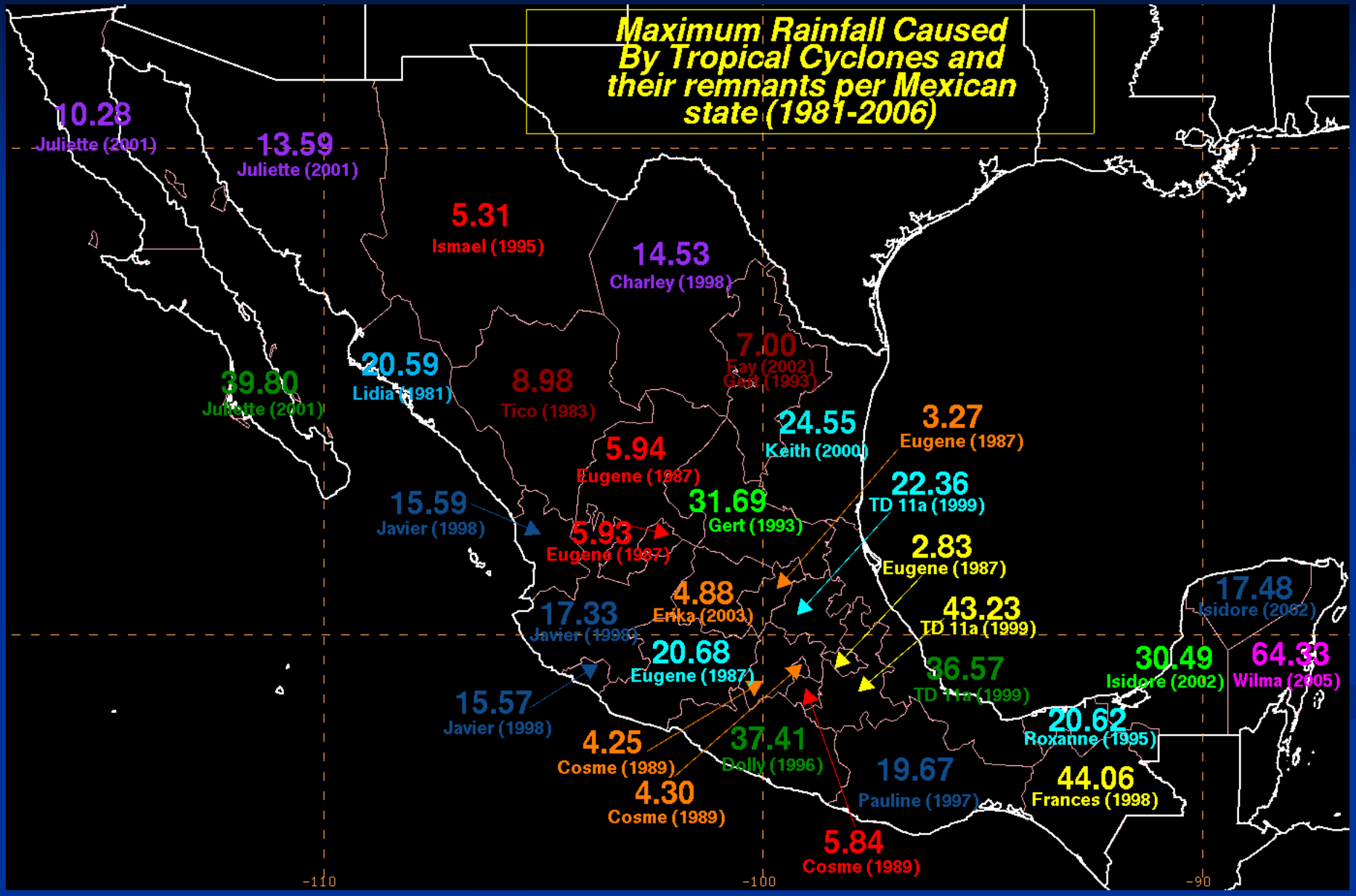
Biggest Rain Producers by Country/Island

Anguilla	490.0 mm	19.29”	Lenny (1999)
Belize	829.8 mm	32.67”	Keith (2000)
Bermuda	186.7 mm	7.35”	October 1939 Hurricane
Canada	302.0 mm	11.89”	Harvey (1999)
Cayman Islands	764.8 mm	31.29”	Sanibel Island Hurricane (1944)
Cuba	**2550 mm**	**100.39”**	**Flora (1963)**
Dominica	422.3 mm	16.63”	Jeanne (2004)
Dominican Rep.	1001.5 mm	39.43”	Flora (1963)
Guadeloupe	508 mm	20.00”	Marilyn (1995)
Haiti	1447.8 mm	57.00”	Flora (1963)
Honduras	912 mm	35.89”	Mitch (1998)
Jamaica	2451 mm	96.50”	November 1909 Hurricane
Martinique	680.7 mm	26.80”	Dorothy (1970)
Mexico	1576 mm	62.05”	Wilma (2005)
Nicaragua	1597 mm	62.87”	Mitch (1998)
Panama	695 mm	27.36”	Mitch (1998)
Puerto Rico	1058.7 mm	41.68”	T.D. #19 (1970)
St. Martin/Maarten	866.6 mm	34.12”	Lenny (1999)
Swan Islands	362.7 mm	14.28”	Alma (1966)
United States	1219 mm	48.00”	Amelia (1978)
Venezuela	339 mm	13.35”	Bret (1993)

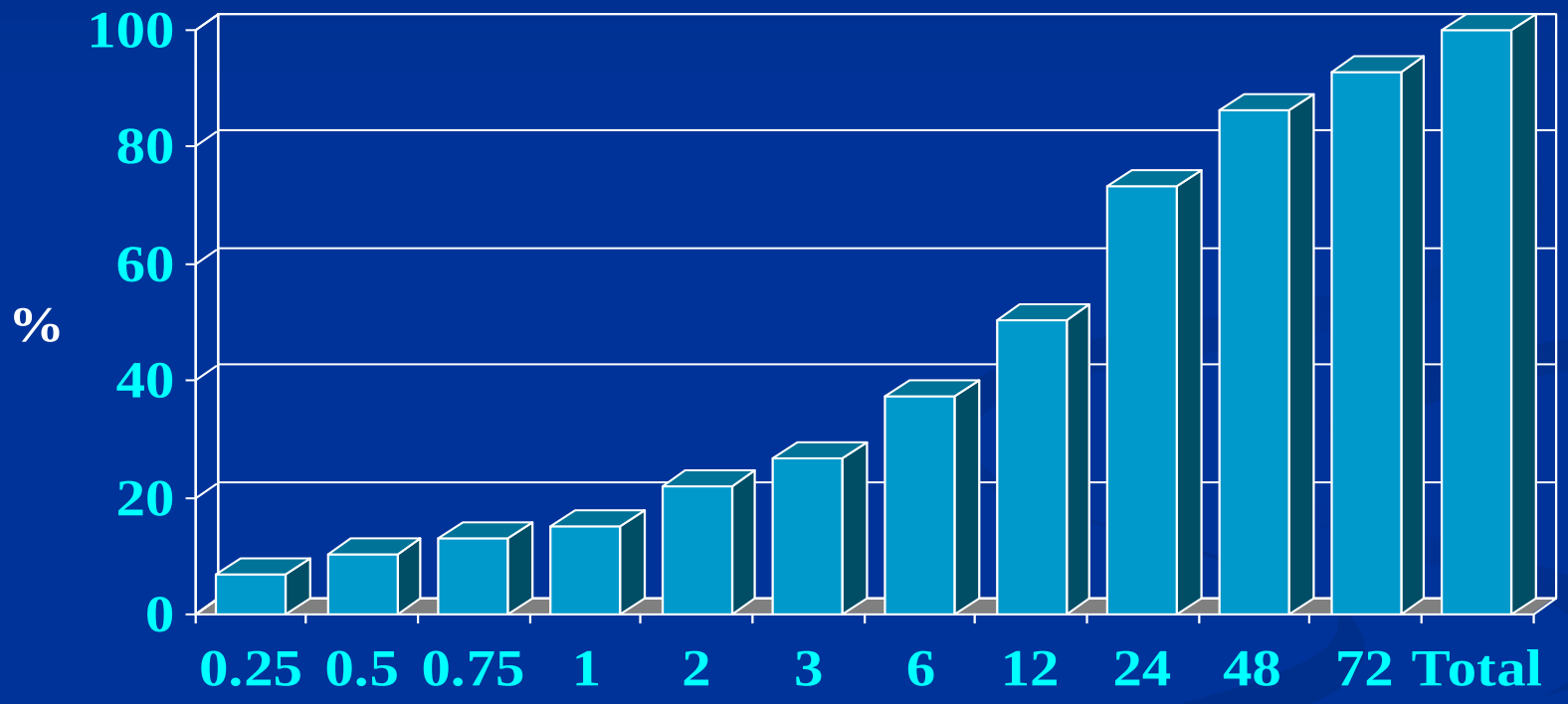
United States



Mexico


Maximum Rainfall Caused By Tropical Cyclones and their remnants per Mexican state (1981-2006)
10.28
Juliette (2001)
13.59
Juliette (2001)
5.31
Ismael (1995)
14.53
Charley (1998)
7.00
Fay (2002)
Gert (1993)
20.59
Lidia (1981)
8.98
Tico (1983)
39.80
Juliette (2001)
24.55
Keith (2000)
3.27
Eugene (1987)
5.94
Eugene (1987)
22.36
TD 11a (1999)
15.59
Javier (1998)
31.69
Gert (1993)
5.93
Eugene (1987)
2.83
Eugene (1987)
4.88
Erika (2003)
17.33
Javier (1998)
43.23
TD 11a (1999)
17.48
Isidore (2002)
20.68
Eugene (1987)
30.49
Isidore (2002)
64.33
Wilma (2005)
36.57
TD 11a (1999)
15.57
Javier (1998)
20.62
Roxanne (1995)
4.25
Cosme (1989)
37.41
Dolly (1996)
19.67
Pauline (1997)
44.06
Frances (1998)
4.30
Cosme (1989)
5.84
Cosme (1989)
-110
-100
-90

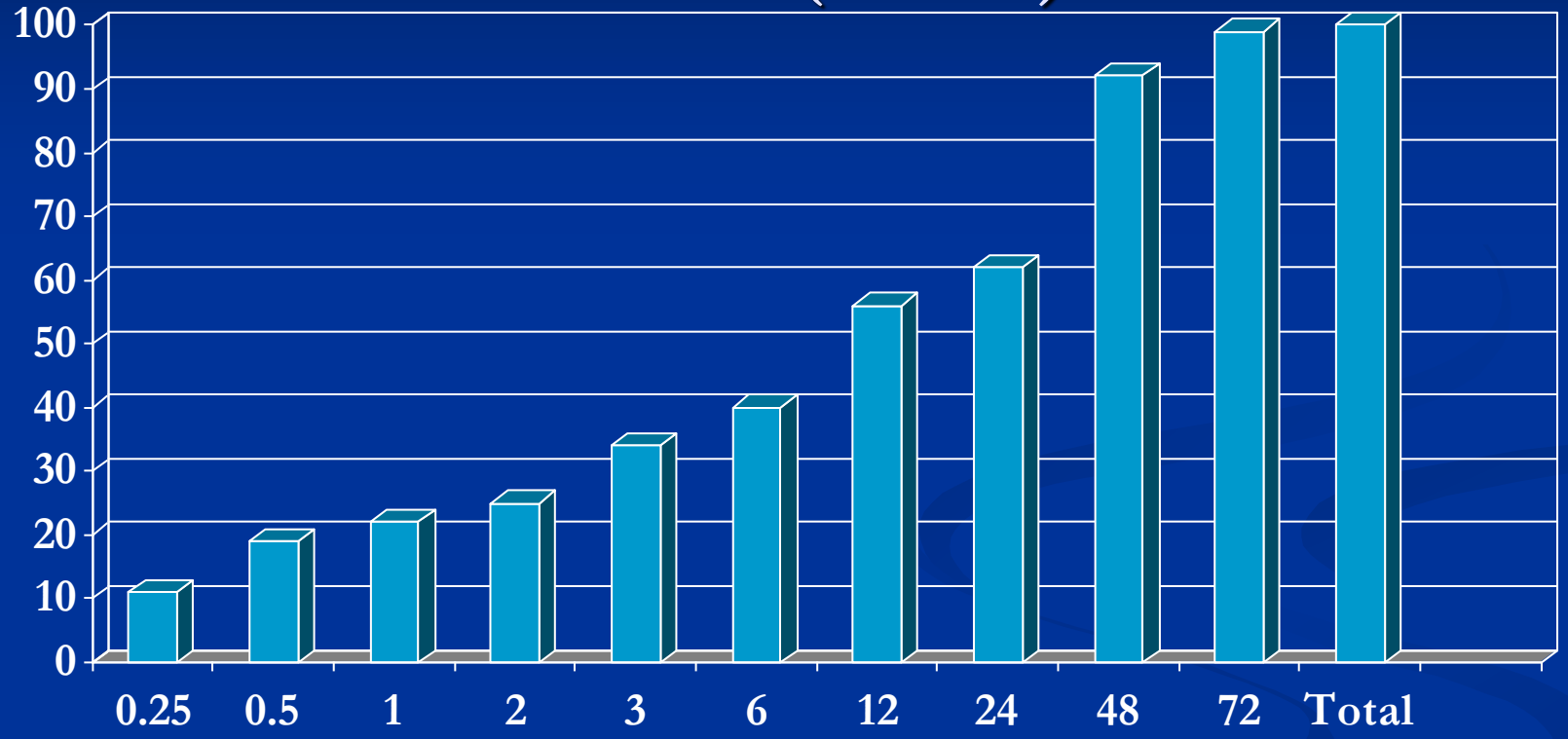
Percent of Maximum storm total rainfall (Hrs)
81 cases – 1991-2005



Average	0.92	1.40	1.76	2.04	2.98	3.61	5.01	6.71	9.77	11.48	12.34	13.34
Maximum	1.90	3.04	4.56	6.08	10.04	13.47	22.27	28.33	32.52	35.29	36.31	40.68

Percent of Wettest Southwestern TC Rainfall Per Time Frame (hours)

1992-2006 (8 cases)



	0.25	0.5	1	2	3	6	12	24	48	72	Total
Average	.56	.94	1.10	1.26	1.70	2.00	2.83	3.15	4.64	5.02	5.05
Max.	.90	1.60	2.20	2.60	3.10	3.20	4.00	6.60	10.24	12.01	12.01

Tropical Cyclone QPF

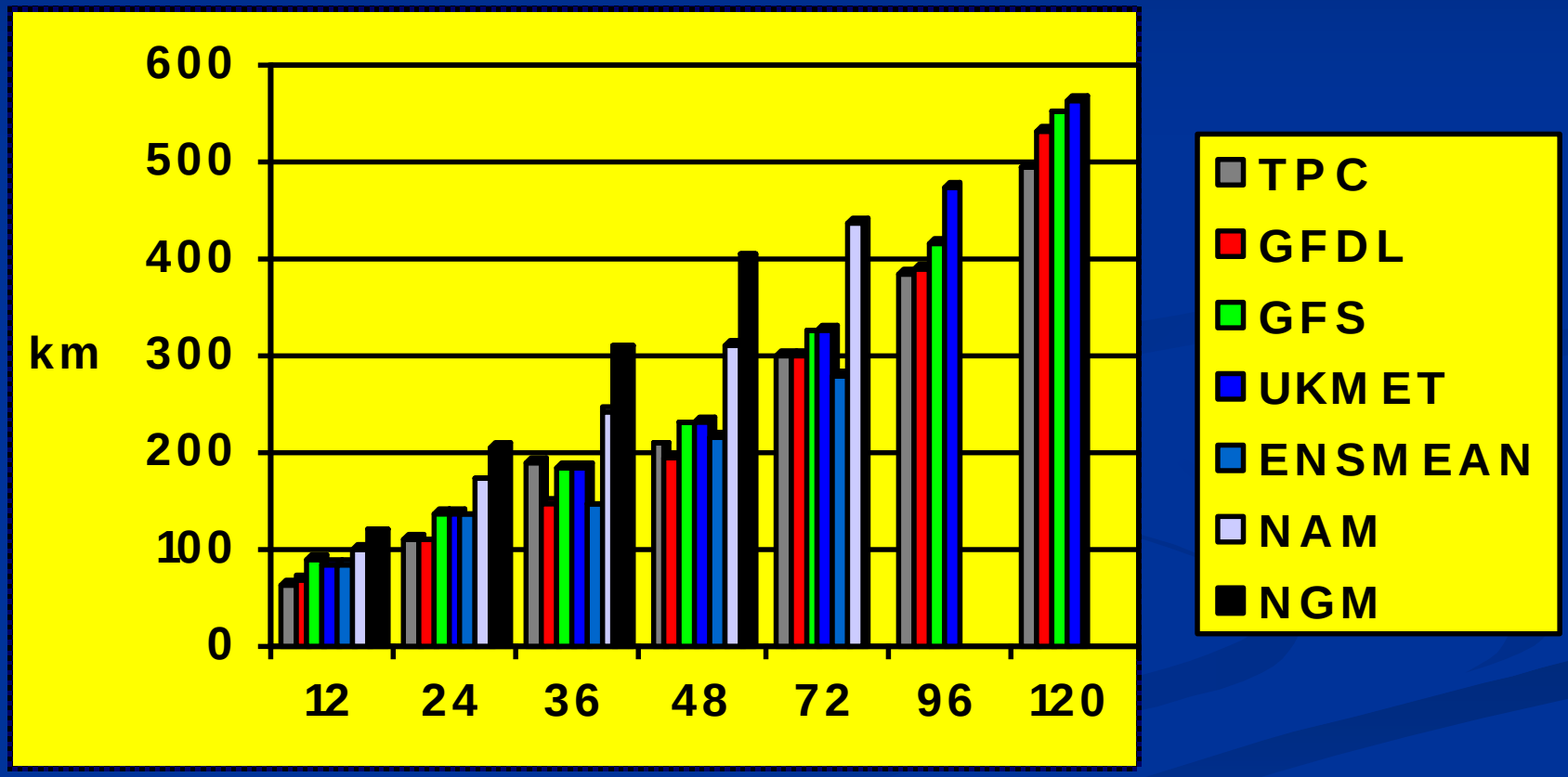
Factors impacting rainfall distributions in landfalling TC's

- Storm track (location)
- Time of day – core rainfall overnight/ outer band rainfall during day
- Storm size (positive) – the bigger the storm, the more it rains at any given spot
- Topography – Positive in the upslope areas, but negative past the spine of the mountains
- Wind shear (negative) – leads to a quicker dropoff in rainfall for inland TCs
- Nearby synoptic-scale features/Extratropical Transition

Rules of thumb for Tropical Cyclone QPF

- Like other systems, moisture, lift, and instability lead to rainfall
- Lift can be caused by rain bands, nearby fronts, or within the CDO/eyewall of tropical cyclones
- Rain rates are dependent on precipitable water values and available instability
- Within moist environments, 500+ J/kg of MUCAPE (where CIN exists) or MLCAPE (surface based convection) achieves rain rates that can slightly exceed the precipitable water amount per hour
- The lower the instability, the broader any overrunning convection becomes around nearby boundaries (up to 150 nm from instability gradients)

TC Model Track Error (km) (2002-2006)



Time of Day – Alberto, July 4-5, 1994

04/18z

00z

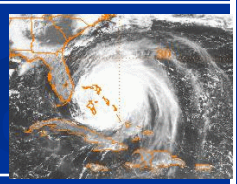
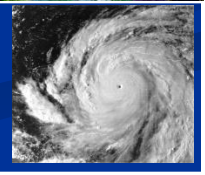
05/06z

12z

18z

Storm Size

Determined by distance from center to outermost closed isobar

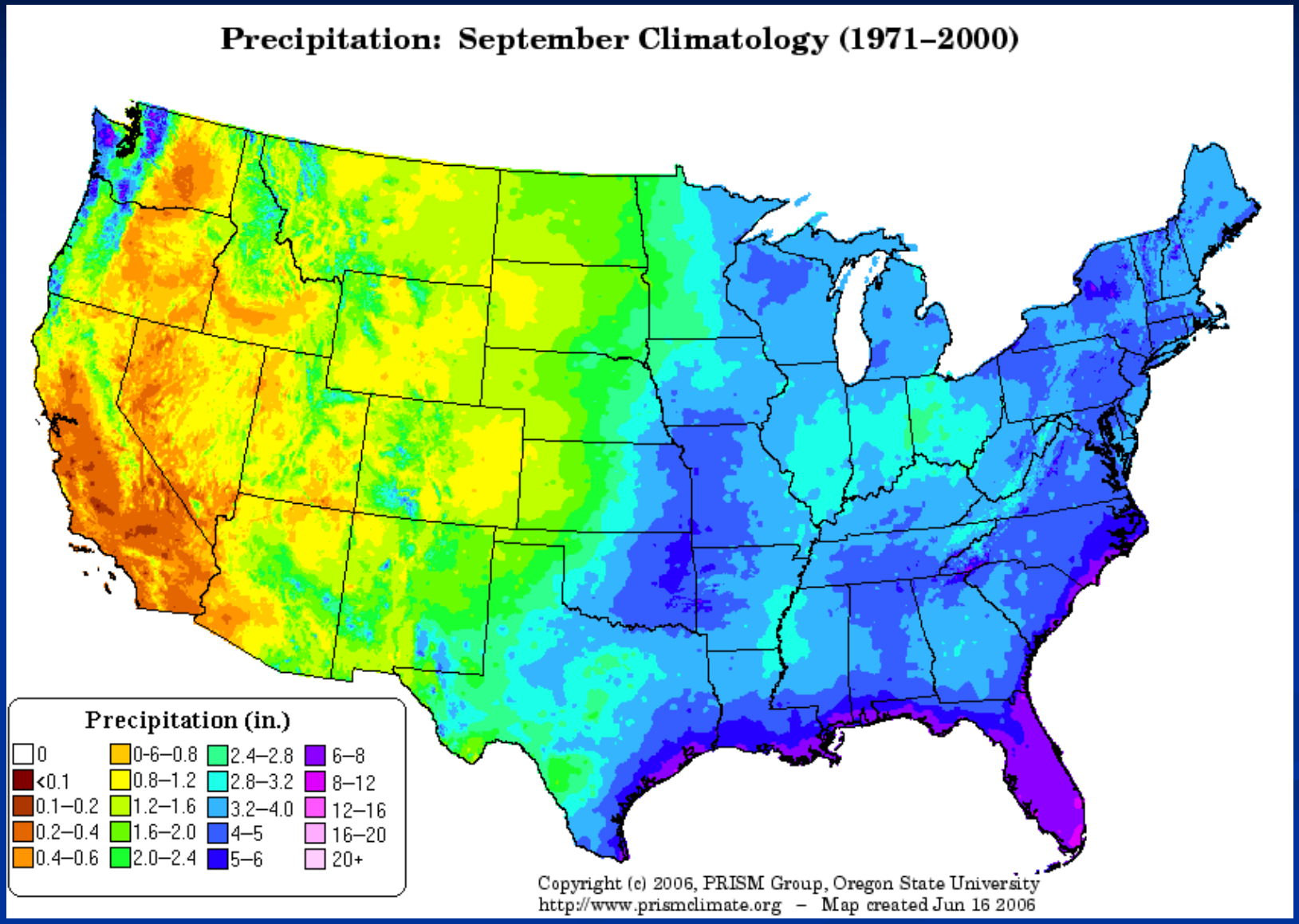
<2 degrees	"Very small/ midget"	Charley 
2-3 degrees	"Small"	Allison 
3-6 degrees	"Average"	Frances 
6-8 degrees	"Large"	Wilma 
>8 degrees	"Very large"	Gilbert 

Joint Typhoon Warning Center

Sizes of country/island vs. tropical cyclone

- United States 9,800,000 square km
- Mexico 2,000,000 square km
- **Tropical Cyclone 350,000 square km**
- Cuba 111,000 square km
- Hispaniola 76,500 square km
- Puerto Rico 9,100 square km
- Martinique 1,130 square km
- Dominica 750 square km
- St. Lucia 620 square km
- Barbados 430 square km
- Grenada 340 square km
- St. Maarten/Martin 87 square km

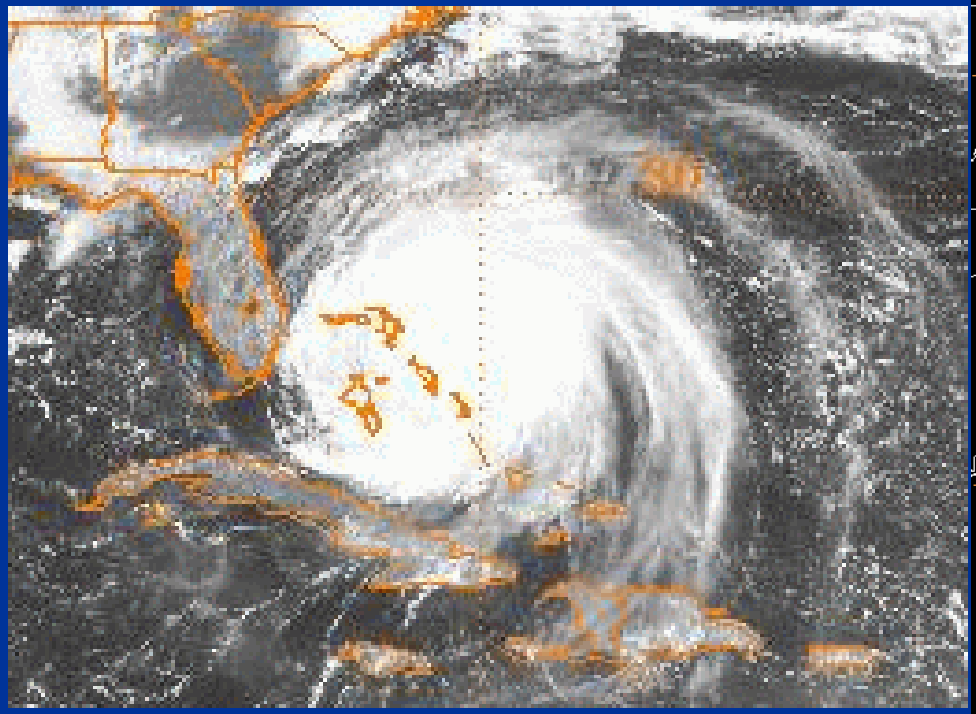
How Mountains Affect the Precipitation Distribution

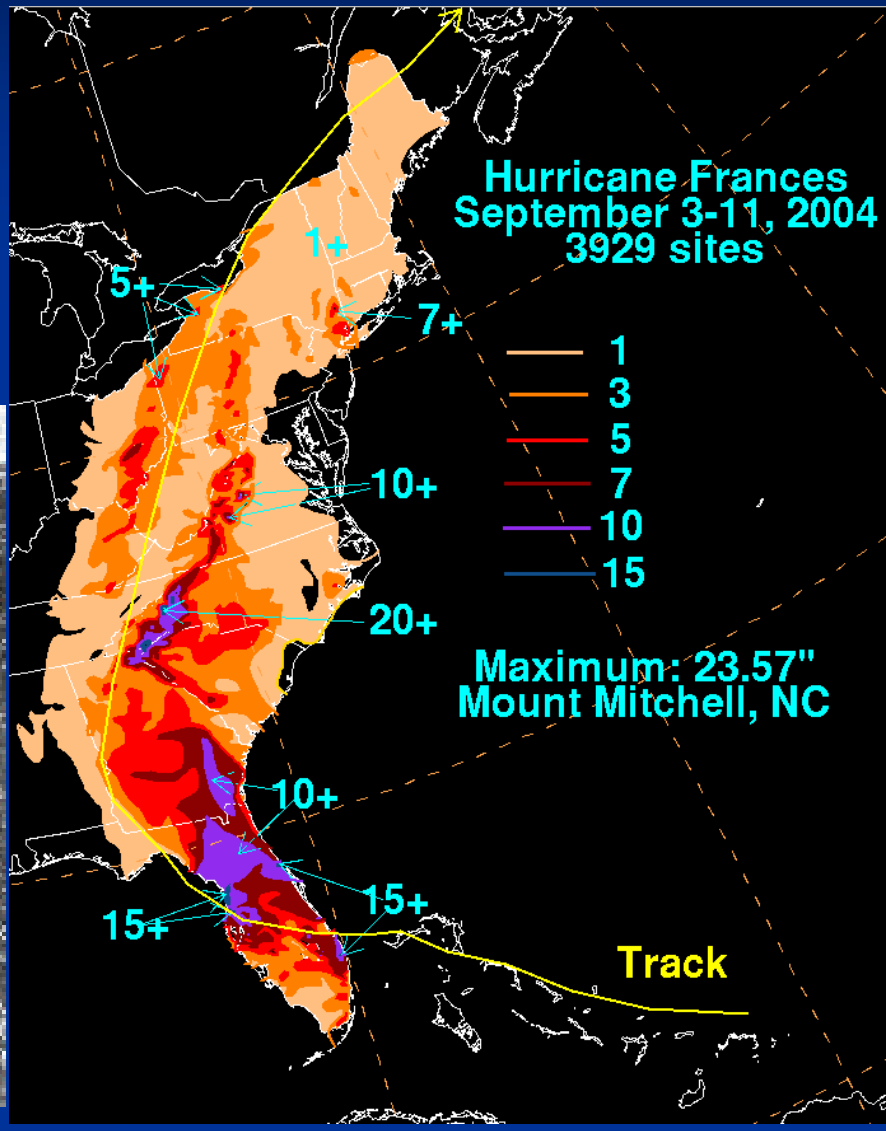


http://www.prism.oregonstate.edu/index.phtml

Size and Topography

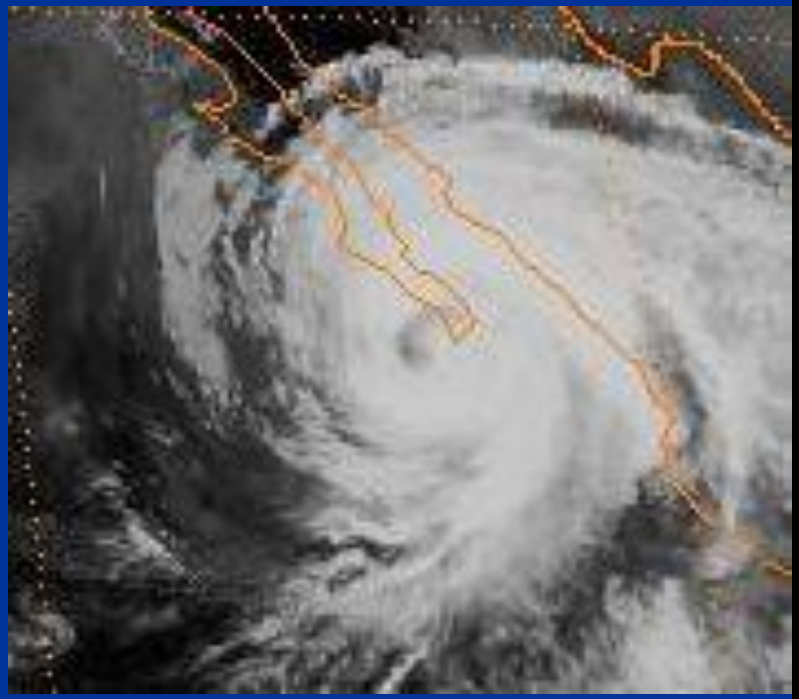
Hurricane Frances (2004)

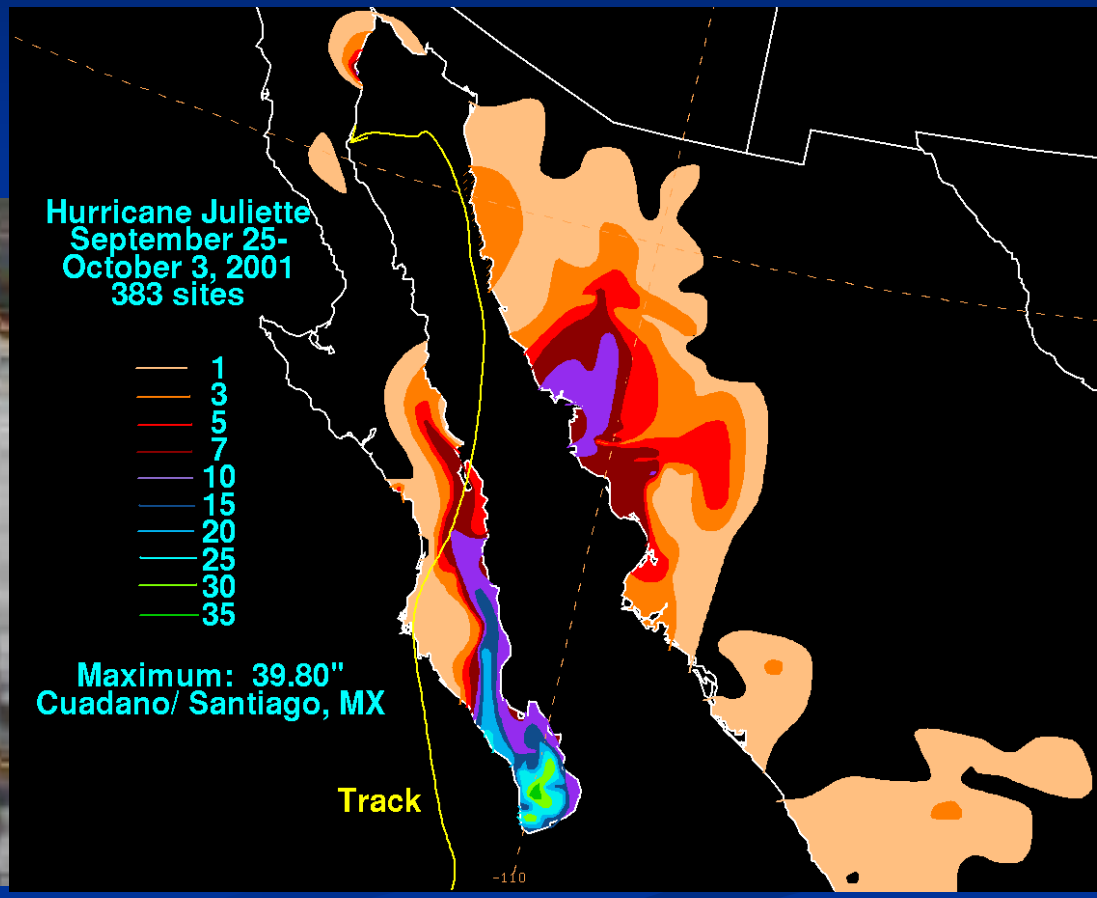




Size and Topography

Hurricane Juliette (2001)

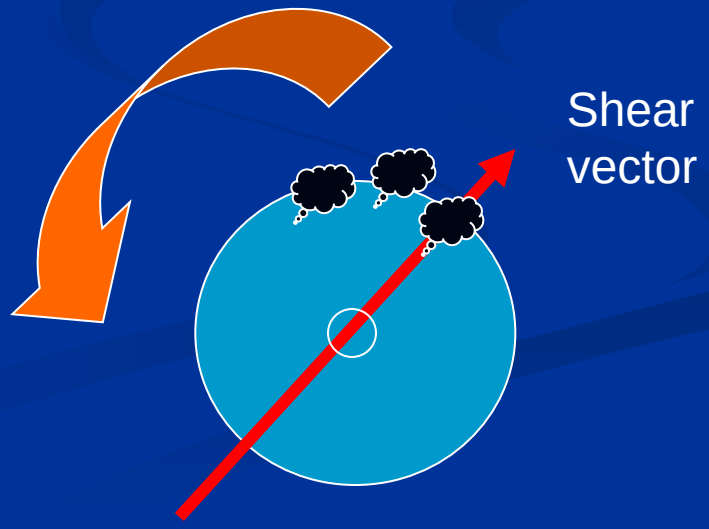




Vertical Wind Shear

- **Heaviest rain tends to fall left and downwind of the shear vector.**

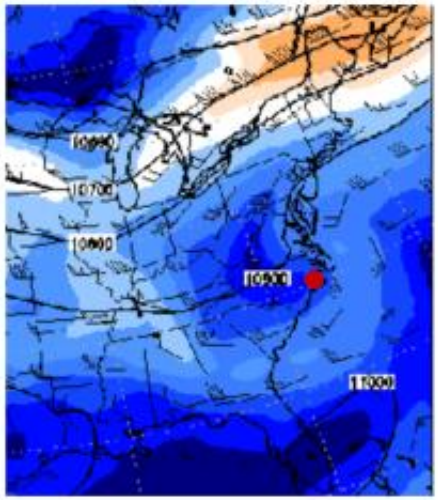
- **If the shear is strong enough, all rainfall may move away from the center (exposed center)**



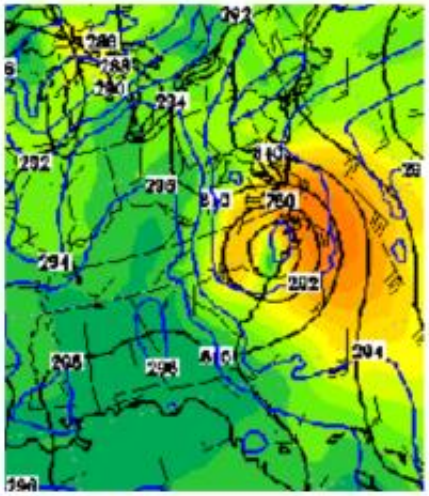
Depth of Upper Trough Causing Recurvature Key

- Storms which drop most of the rain right of track are steered predominantly by shear lines or through a break in the subtropical ridge. Rainfall tends to be concentrated near and right of track.
- Storms which drop most of their rain left of track recurve due to significant upper troughs in the Westerlies. Rainfall streaks out well to the north of the system due to jet streaks moving around the upper trough and frontogenesis at the trough's leading edge.

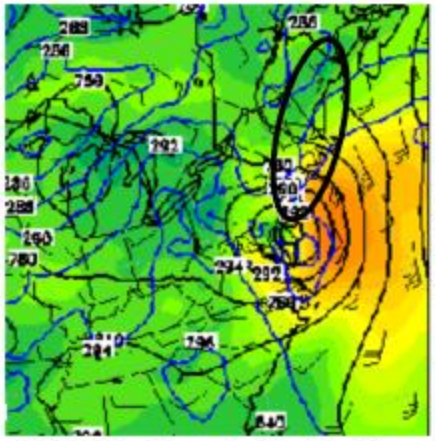
Bertha



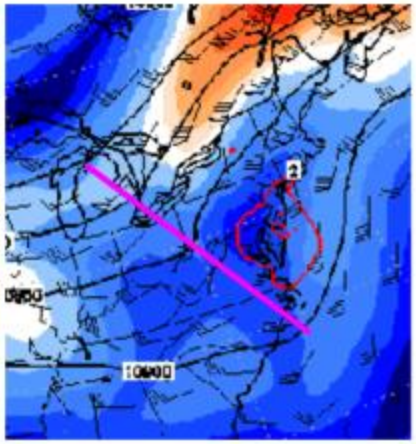
250-hPa winds and heights valid 0000 UTC 13 July 1996, the red dot indicates the positions of Bertha



925-hPa height and winds (black), temperature (blue lines, °K), valid 0000 UTC 13 July 1999

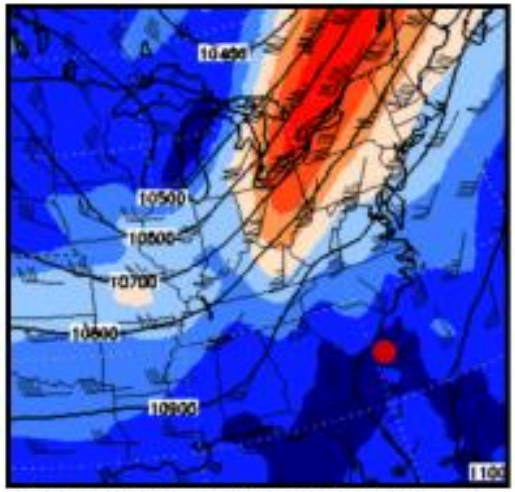


925-hPa height and winds (black), temperature (blue lines, °K), valid 1500 UTC 13 July 1999

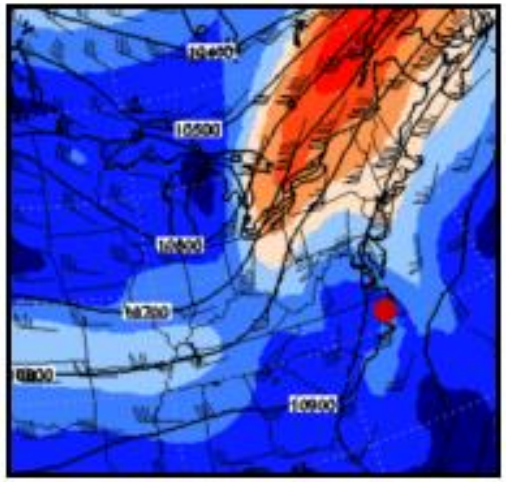


250-hPa winds and heights valid 1500 UTC 13 July 1999

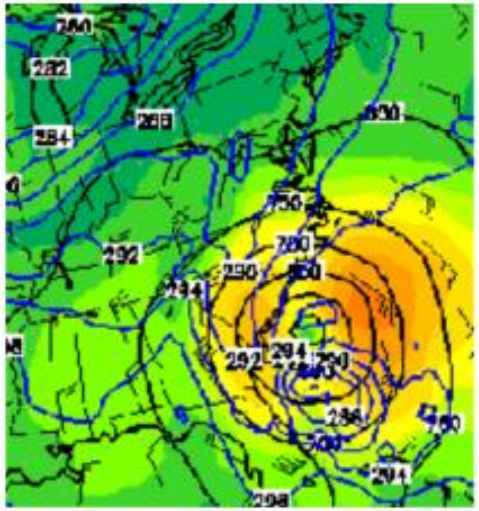
Floyd



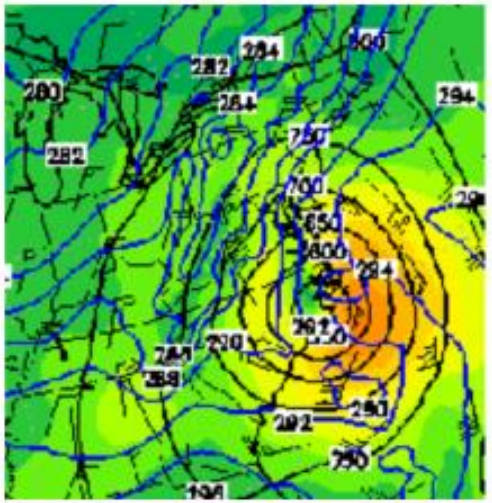
250-hPa winds and heights valid 0000 UTC 16 Sept 1999, the red dot indicates the positions of Floyd



250-hPa winds and heights valid 1200 UTC 16 Sept 1999, the red dot indicates the positions of Floyd

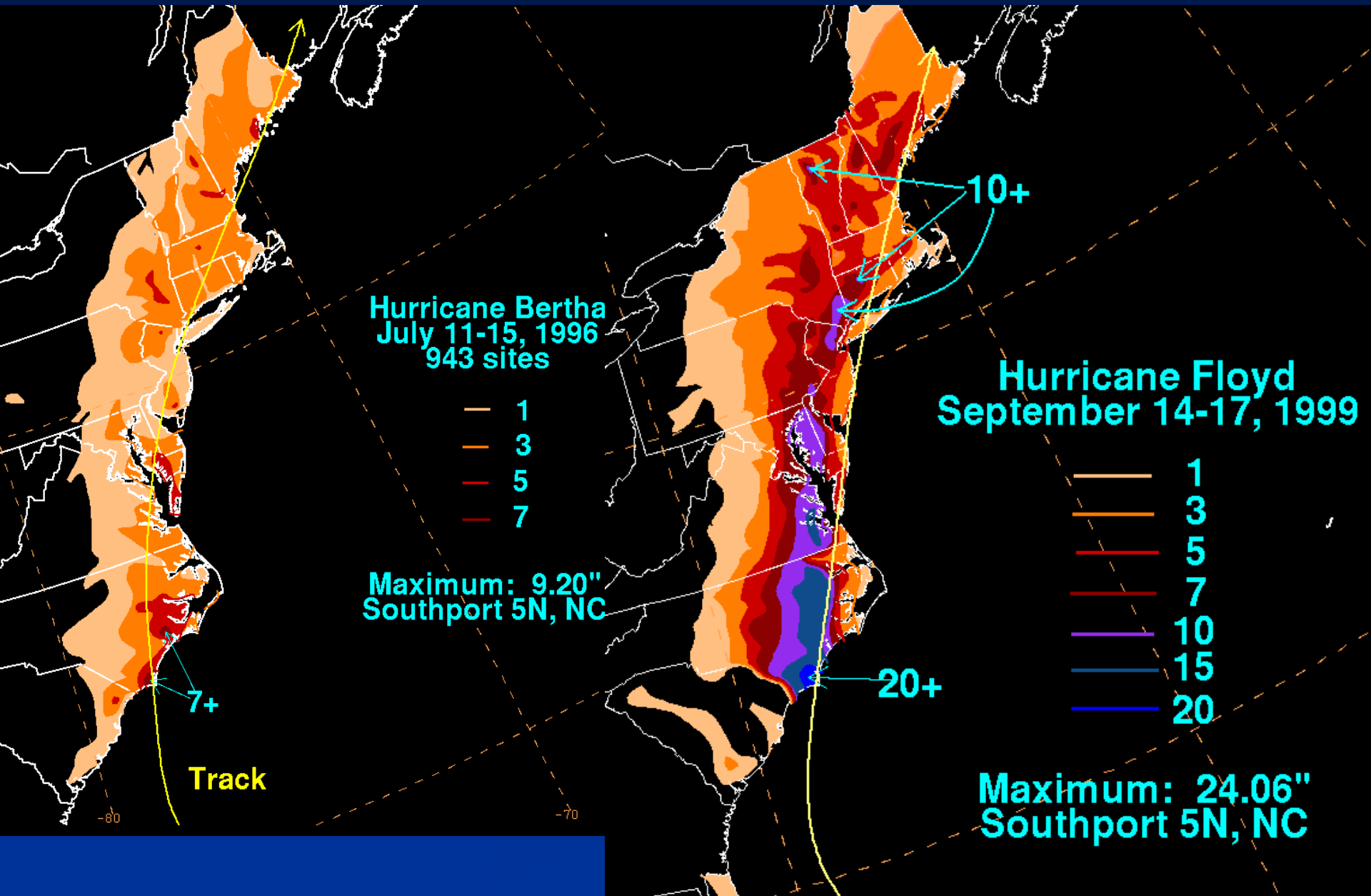


925-hPa height and winds (black), temperature (blue lines, °K), valid 0000 UTC 16 Sept 1999

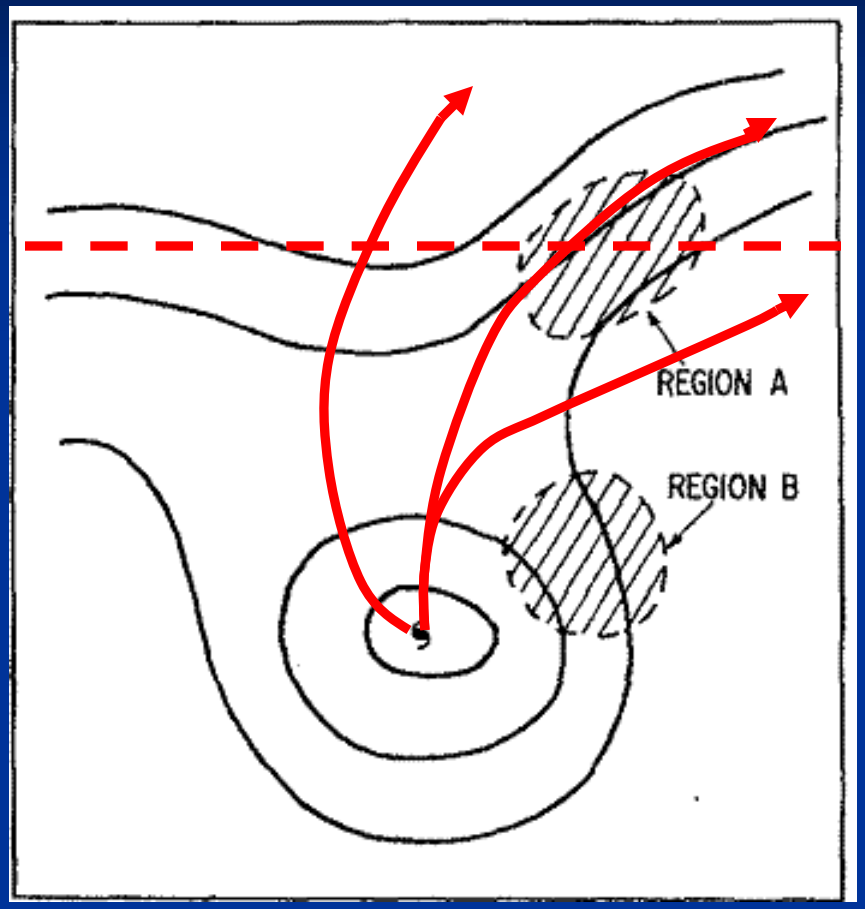


925-hPa height and winds (black), temperature (blue lines, °K), valid 1200 UTC 16 Sept 1999

Bertha (1996) vs. Floyd (1999)



PRE STATISTICS



Bosart and Carr (1978) conceptual model of antecedent rainfall

Separation Distance

1086 ± 482 km
Median: 935 km

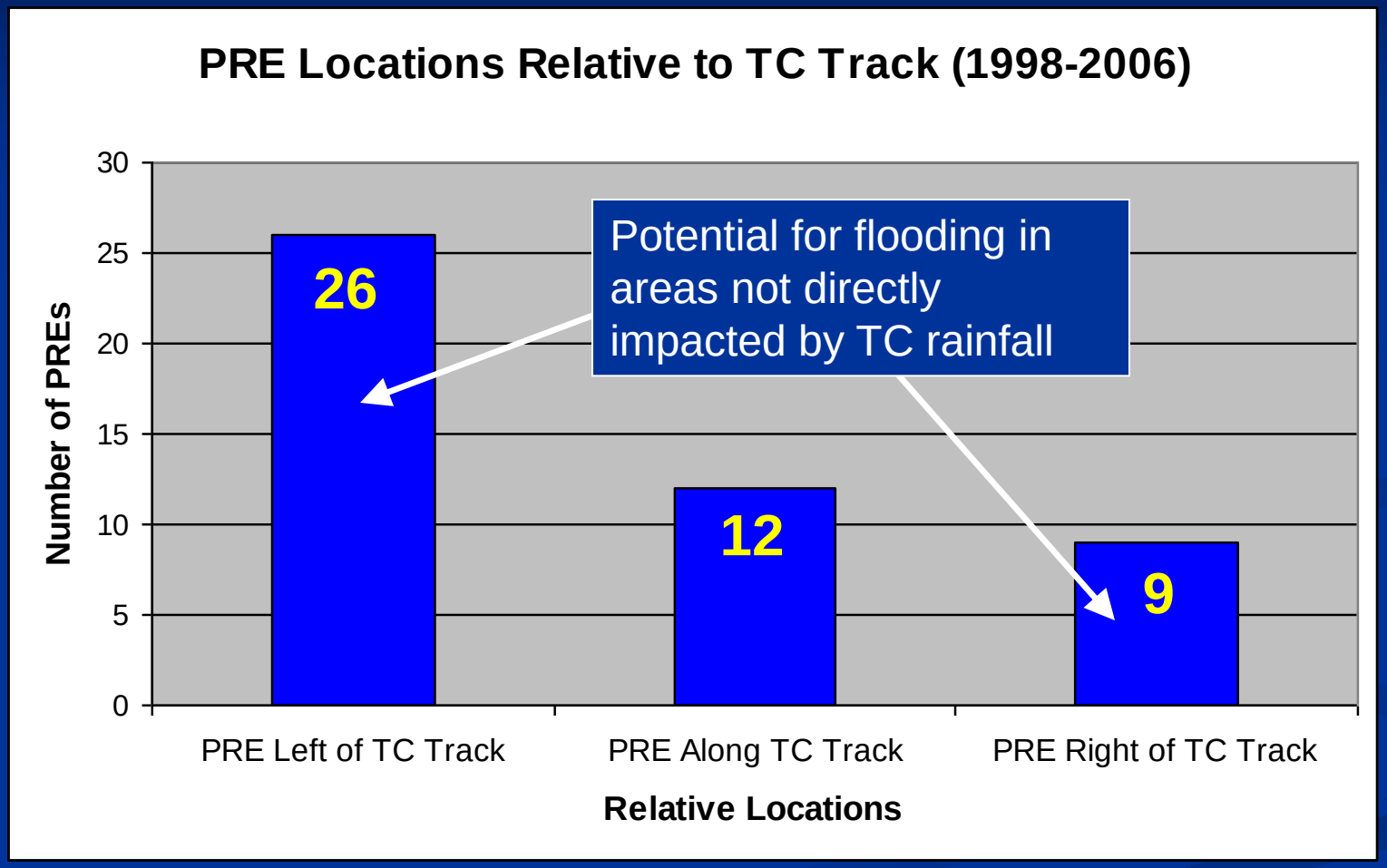
Event Duration

14 ± 7 h
Median: 12 h

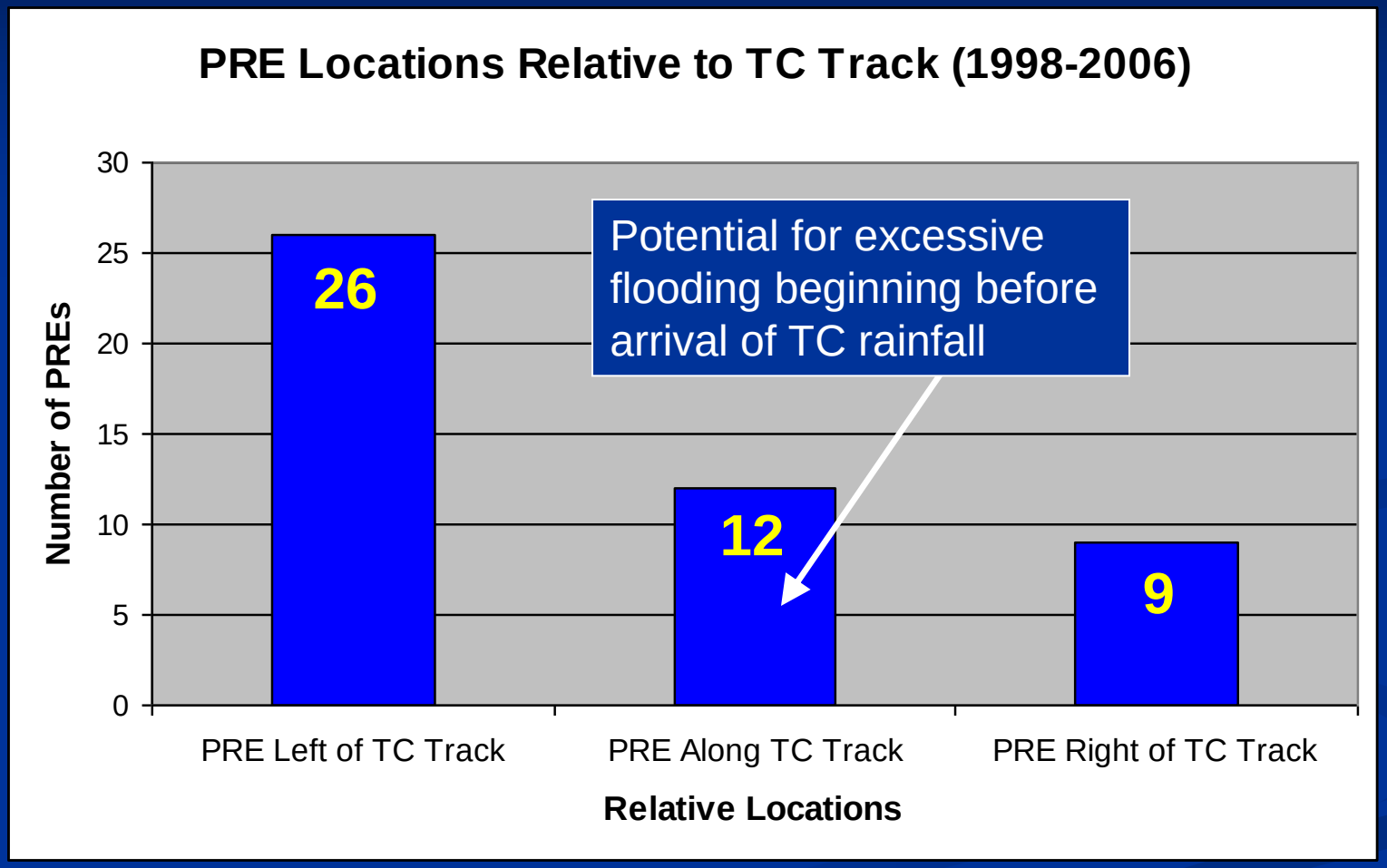
Time Lag

45 ± 29 h
Median: 36 h

PRE TRACK-RELATIVE POSITIONS



PRE TRACK-RELATIVE POSITIONS



PRE TRACK-RELATIVE POSITIONS

Type of PRE (Number in category)	24-h rainfall rate statistics (mm)			Mean PRE speed ($m\ s^{-1}$)
	Mean	Std. deviation	Maximum	
Left of Track (22)	185	70	340	10.7
Along Track (8)	245	100	410	12.9
Right of Track (7)	260	80	410	5.7

GREATEST RAINFALL

SLOWEST MOVEMENT

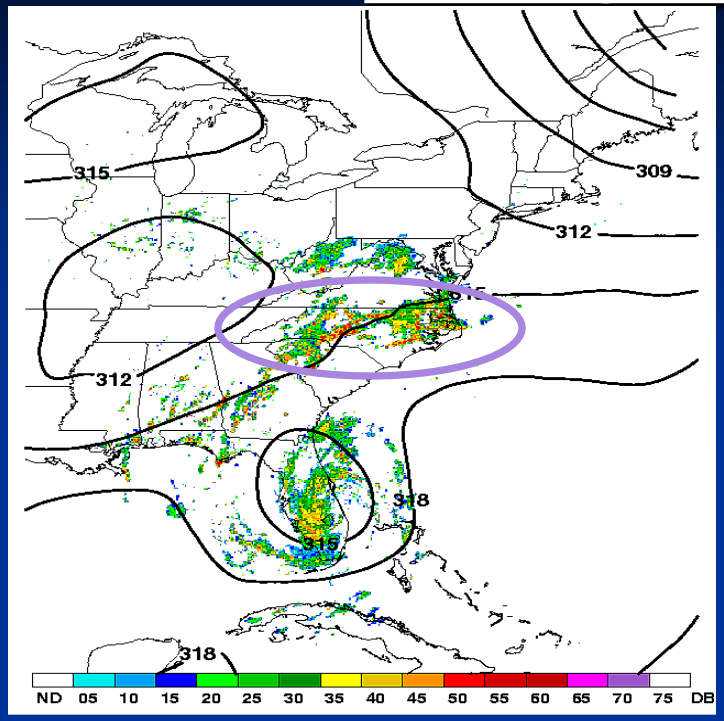
PRE TRACK-RELATIVE POSITIONS

Type of PRE (Number in category)	24-h rainfall rate statistics (mm)			Mean PRE speed ($m\ s^{-1}$)
	Mean	Std. deviation	Maximum	
Left of Track (22)	185	70	340	10.7
Along Track (8)	245	100	410	12.9
Right of Track (7)	260	80	410	5.7

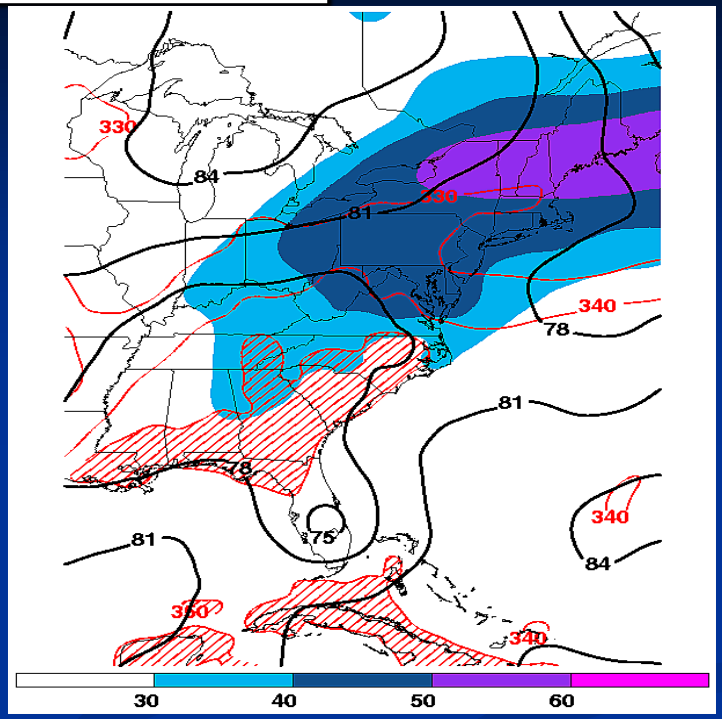
HIGH RAINFALL

PREs MOVE TWICE AS FAST

Along Track PREs



2100 UTC 060830 700 hPa Ht (dam) and WSI NOWRAD image

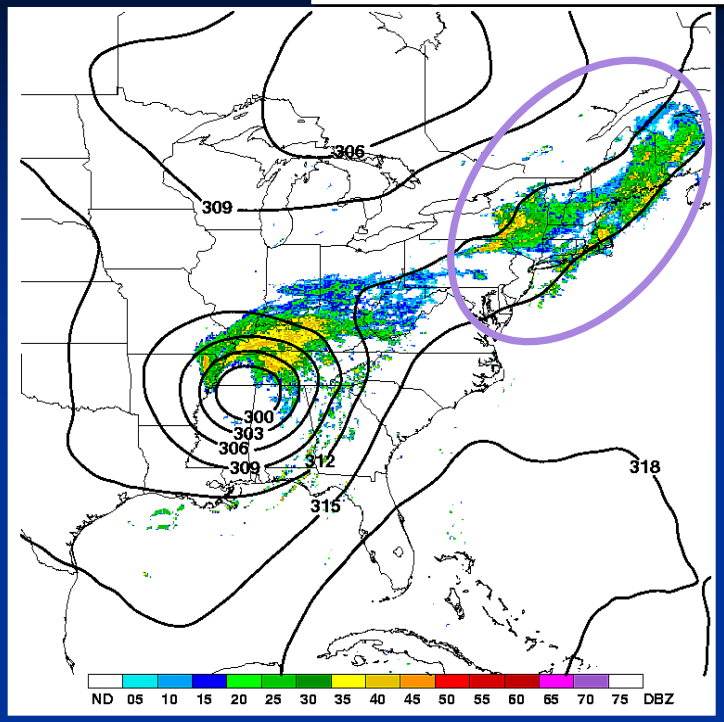


2100 UTC 060830 925 hPa Ht (dam), θ_e (K), and 200 hPa wind speed (m s^{-1})

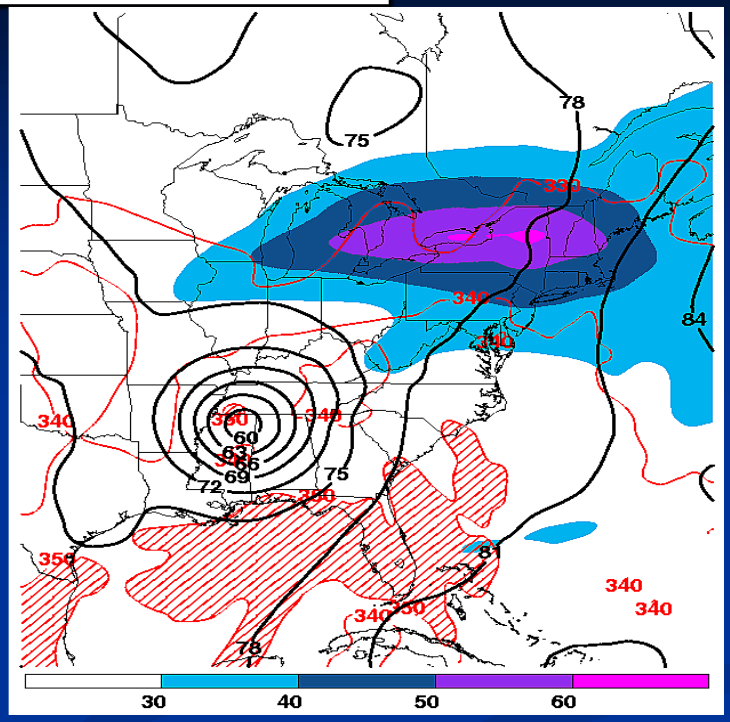
Ernesto (2006)

- NW/SE oriented trough well to the northeast
- Closed midlevel low NW and flat ridge east of TC
- Broad upper-level jet to the north
- On western edge of θ_e ridge

Right Of Track PREs



0900 UTC 050830 700 hPa Ht (dam) and WSI NOWRAD image

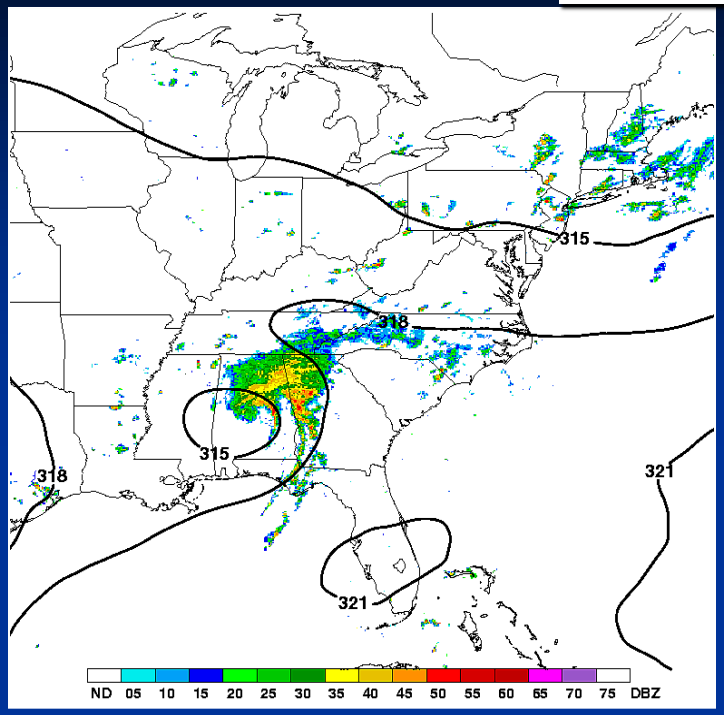


0900 UTC 050830 925 hPa Ht (dam), θ_e (K), and 200 hPa wind speed (m s^{-1})

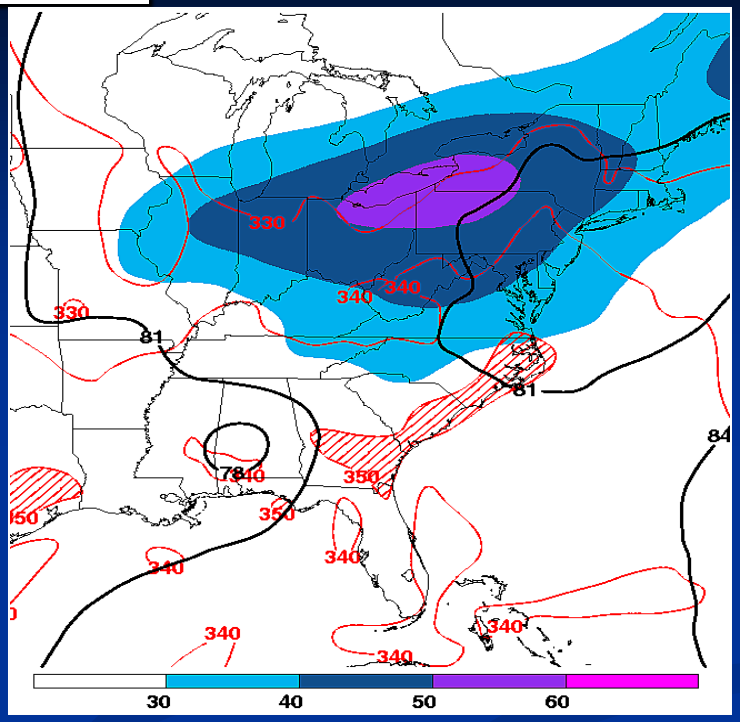
Katrina (2005)

- Large midlevel low NNE and ridge SE of TC
- PREs a bit downstream of where model predicts
- Jet dynamics only partially explain the PREs
- No prominent low-level θ_e ridge or gradient near PRE

Null Case



0000 UTC 050707 700 hPa Ht (dam) and WSI NOWRAD image



0000 UTC 050707 925 hPa Ht (dam), θ_e (K), and 200 hPa wind speed (m s^{-1})

Cindy (2005)

- WNW flow at midlevels
- Scattered rainfall over New England not related to Cindy
- Massive low-level ridge poleward of TC
- No rainfall near low-level θ_e ridge

Rainfall forecasts from landfalling TC's

standard forecasting tools

- Empirical Methods
- In-house Tropical Cyclone Rainfall Climatology
http://www.wpc.ncep.noaa.gov/tropical/rain/tcrainfall.html
- GFS/NAM/GFDL/WRF precipitation forecasts
- r-CLIPER (Climatology based on 1st order stations)
- TRaP (persistence to capture structure/Day 1)

standard validation tools

- bias score
- equitable threat score

Rules of Thumb

- Kraft Rule – 1950's guideline based on a broad grid of first order sites. Will not indicate the maximum in most cases (R=100/forward motion in knots). Environment Canada/Canadian Hurricane Center use a modified version of Kraft which halves this amount since most systems entering the country are sheared or moving over cooler water prior to landfall.
- 16-inch rule – Long term average of tropical cyclone rainfall maxima which strike the United States. Vertical wind shear, small sized tropical cyclones, or movement over cooler water prior to landfall can individually lead to a reduction of about half of this figure. Slow moving and larger than average tropical cyclones lead to higher values than the average.

Derived Equation used to Determine TC Rainfall Maxima

Rainfall maximum=2*(radial velocity)*(specific humidity in subcloud layer)*(pressure difference within lower km of atmosphere)*(1/radius from center)*(1/g)

- **Riehl (1954)**
- **Within 30 nm of center – 863 mm/33.98” per day**
- **Within 60 nm of center – 160 mm/ 6.30” per day**
- **Within 120 miles of center – 15 mm /0.59” per day**
- **Assumes a symmetric/non-sheared hurricane with a gale radius around two degrees of latitude/120 nm. Does not take into account topography or nearby frontal zones.**

Old TAFB Method

$$\text{RAIN ACCUMULATION} = \frac{\text{DIAMETER} * \text{RAIN RATE}}{\text{VELOCITY}}$$

Convective Rainfall Rates

Average Climatological Rain Rate = 2 mm / hour

Or 0.08 in./hour

Core Rain Rate = 5 times this Average

or

Core Rain Rate = 10 mm /hour

Or about 0.40 in./hour

Reinforced by radial amounts computed within Jiang, Halverson, Simpson AMS Hurricane Conference preprint (2006)

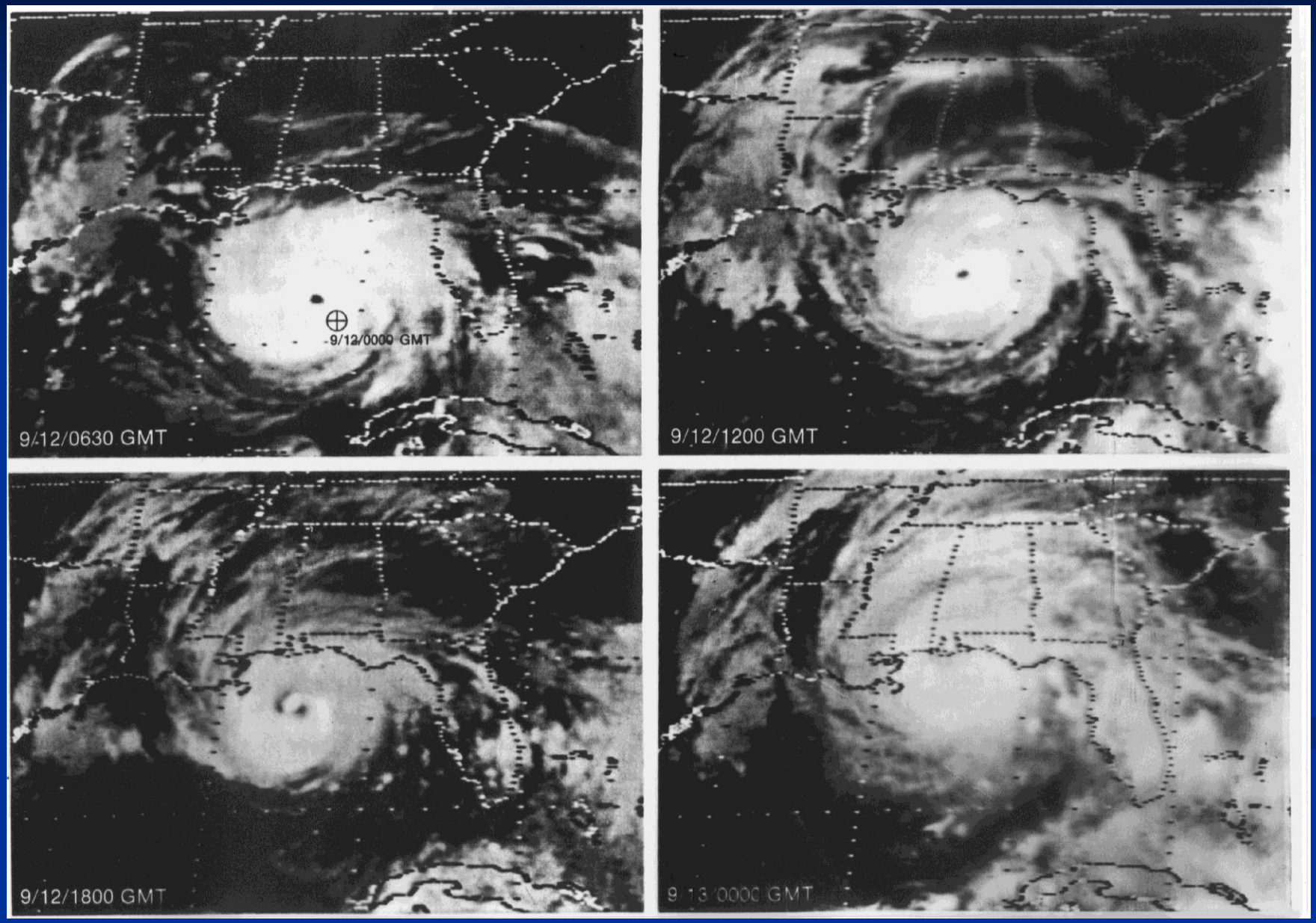
RAINFALL CALCULATION USING UNENHANCED INFRARED IMAGERY

Storm Name: FREDERIC Date: 12 SEPT 19 79

Image Date/Time		Diameter of Storm in Direction of Motion				
12 / 0630	UTC	5.5	deg * 110 km/deg =	605	km
12 / 1200	UTC	5.5	deg * 110 km/deg =	605	km
12 / 1800	UTC	4.0	deg * 110 km/deg =	440	km
12 / 0000	UTC	4.5	deg * 110 km/deg =	495	km

Mean Diameter: D = 540 km

TROPICAL CYCLONE RAINFALL ESTIMATION
HURRICANE FREDERIC, SEPTEMBER 1979
6-HOUR CONTINUITY, INFRARED



Forecast translation speed: $V = \frac{4.0}{\text{deg}} * 110 \text{ km/deg} / 18 \text{ hrs} = \frac{24}{} \text{ km/hr}$

Mean rainfall rate: $R = 0.2 \text{ cm/hr}$

Rainfall Potential:

$$P = \frac{D * R}{V}$$

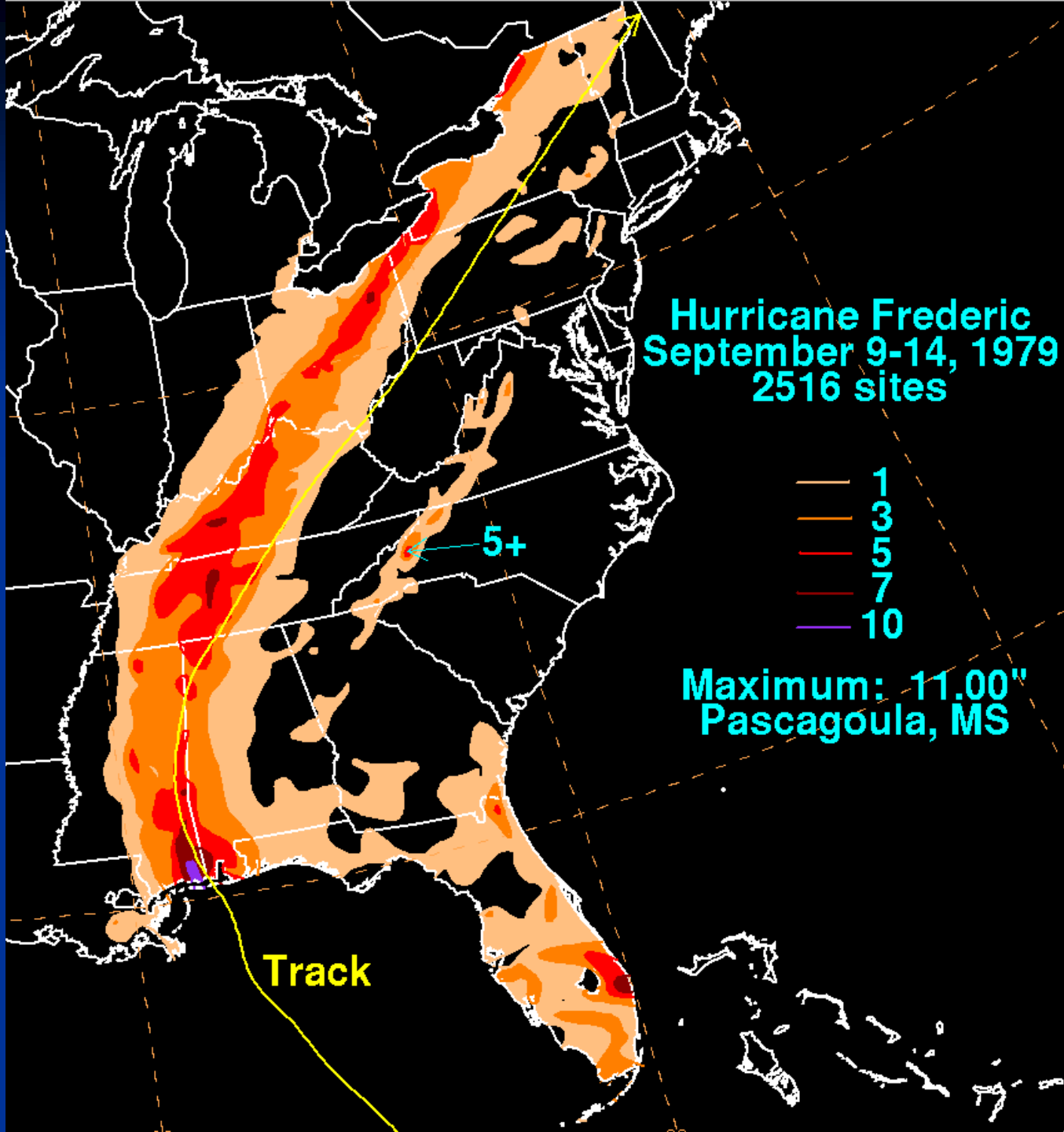
$$P = \frac{540 \text{ km} * 0.2 \text{ cm/hr}}{24 \text{ km/hr}} = 4.5 \text{ cm}$$

Core Rainfall: $C = 5 * P = 22.5 \text{ cm}$ (8.9")

Rule of Thumb:

$$T = \frac{450}{V \text{ km/hr}} = \frac{450}{24 \text{ km/hr}} = 18.8 \text{ cm}$$ (7.4")

Frederic Rainfall



NHC Satellite Tropical Disturbance Rainfall Estimates

```
000
TCCA22 KNHC 291843
STDCCA

SATELLITE TROPICAL DISTURBANCE RAINFALL ESTIMATES
NWS TPC/NATIONAL HURRICANE CENTER MIAMI FL
1815 UTC TUE AUG 29 2006


SYSTEM NAME/IDENTIFIER...T.S. ERNESTO

                                                  MAX RAINFALL
  DATE/TIME      LOCATION       MOTION       MEAN       LAST
 -----------   ------------     ------      -------    -------
 29/1815 UTC   23.9N  79.7W     315/11       6.2 IN     9.3 IN


LAST RAINFALL DISTRIBUTION...

     DISTANCE          LEFT OF CENTER      RIGHT OF CENTER
   -------------      ---------------      ---------------
   0 TO 1 DEGREE       2.5 TO  9.3 IN       4.2 TO  9.3 IN
   1 TO 2 DEGREE       0.5 TO  2.8 IN       0.3 TO  3.0 IN
   2 TO 3 DEGREE       0.1 TO  0.6 IN       1.1 TO  1.7 IN
   3 TO 4 DEGREE       0.0 TO  0.1 IN       0.0 TO  1.4 IN


                        ...LEGEND...

SYSTEM NAME/IDENTIFIER...NAME OR NUMBER ASSIGNED TO SYSTEM
                         (E.G. TROPICAL STORM ALPHA, TROPICAL
                         DISTURBANCE 01, SURFACE TROUGH)

DATE/TIME...             DAY OF MONTH AND TIME IN UNIVERSAL TIME
                         COORDINATES (UTC) IN A DY/HRMN FORMAT

LOCATION...              ESTIMATED CENTER OF SYSTEM OR ADVISORY
                         POSITION FOR TROPICAL CYCLONE IN TENTHS
                         OF DEGREES OF LATITUDE AND LONGITUDE

MOTION...                ESTIMATED DIRECTION AND SPEED OF SYSTEM
                         IN DEGREES AND KNOTS

MEAN MAXIMUM RAINFALL... THE 24-HOUR MEAN MAXIMUM ACCUMULATION OF
                         RAINFALL FOR THE SYSTEM IN INCHES BASED
                         ON FOUR SATELLITE IMAGES SIX HOURS APART

LAST MAXIMUM RAINFALL... THE MAXIMUM ACCUMULATION OF RAINFALL FOR
                         THE SYSTEM IN INCHES BASED ON THE MOST
                         RECENT SATELLITE IMAGE

RAINFALL DISTRIBUTION... THE DISTRIBUTION OF RAINFALL WITHIN FOUR
                         DEGREES (240 NM) LEFT AND RIGHT OF THE
                         SYSTEM CENTER IN ONE DEGREE (60NM)
                         INCREMENTS...LOOKING DOWNSTREAM
                         (1 IN = 25.4 MM)
```

- 3 event-driven products

Eastern Caribbean (40°W to 67°W)

TCCA21 KNHC

MIASTDECA

Central Caribbean (67°W to 80°W)

TCCA22 KNHC

MIASTDCCA

Western Caribbean/Mexico (80°W to 120°W)

TCCA23 KNHC

MIASTDWCA

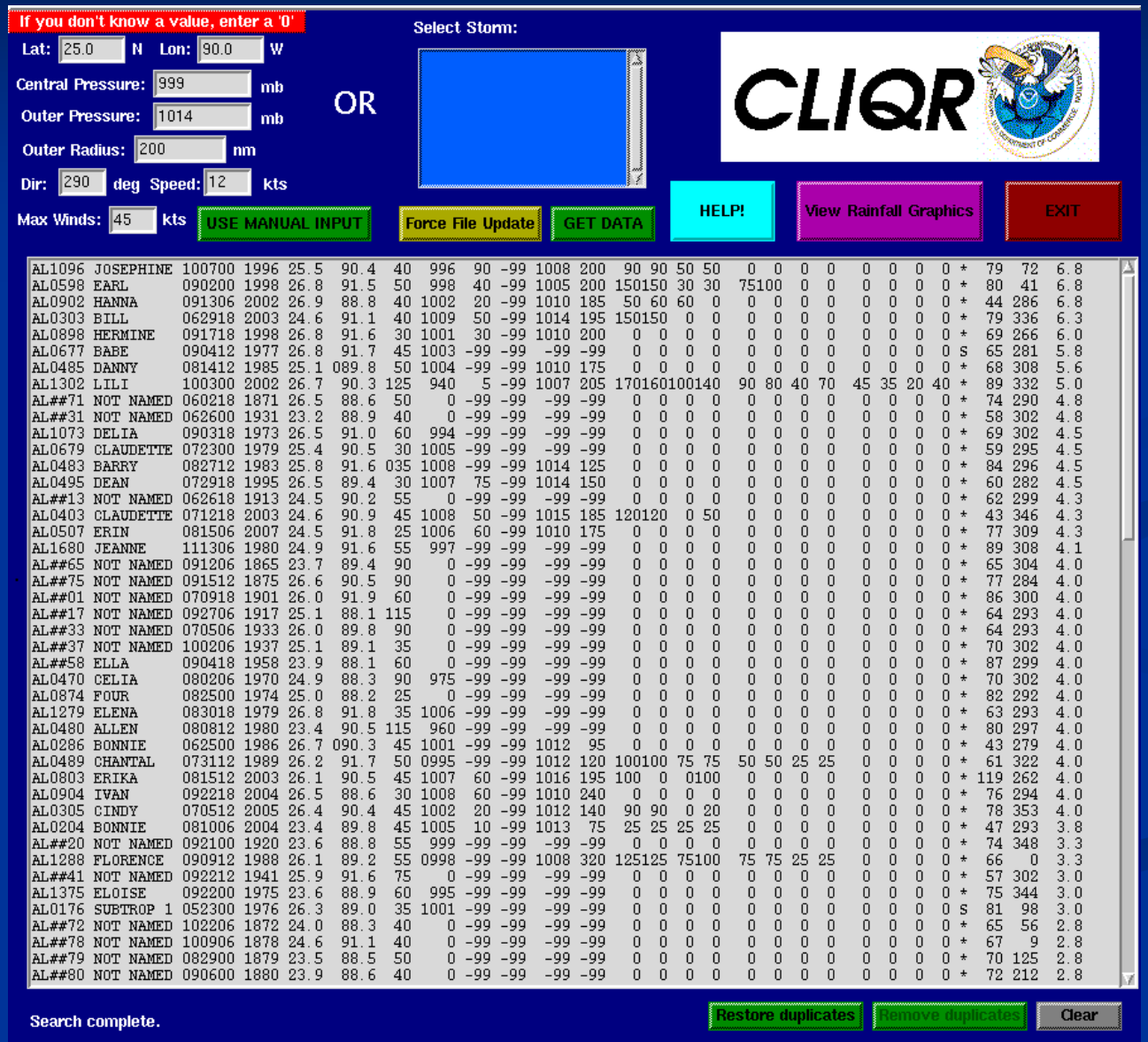
Picking an analog for a TC event

- Size is important…look at the current rain shield and compare it to storm totals/storms from the past
- How fast is it moving?
- Vertical wind shear in current/past events?
- Look for storms with similar/parallel tracks
- Is topography/prism data a consideration?
- Look for nearby fronts/depth of nearby upper troughs for current and possible analogs
- Not all TC events will have a useful analog

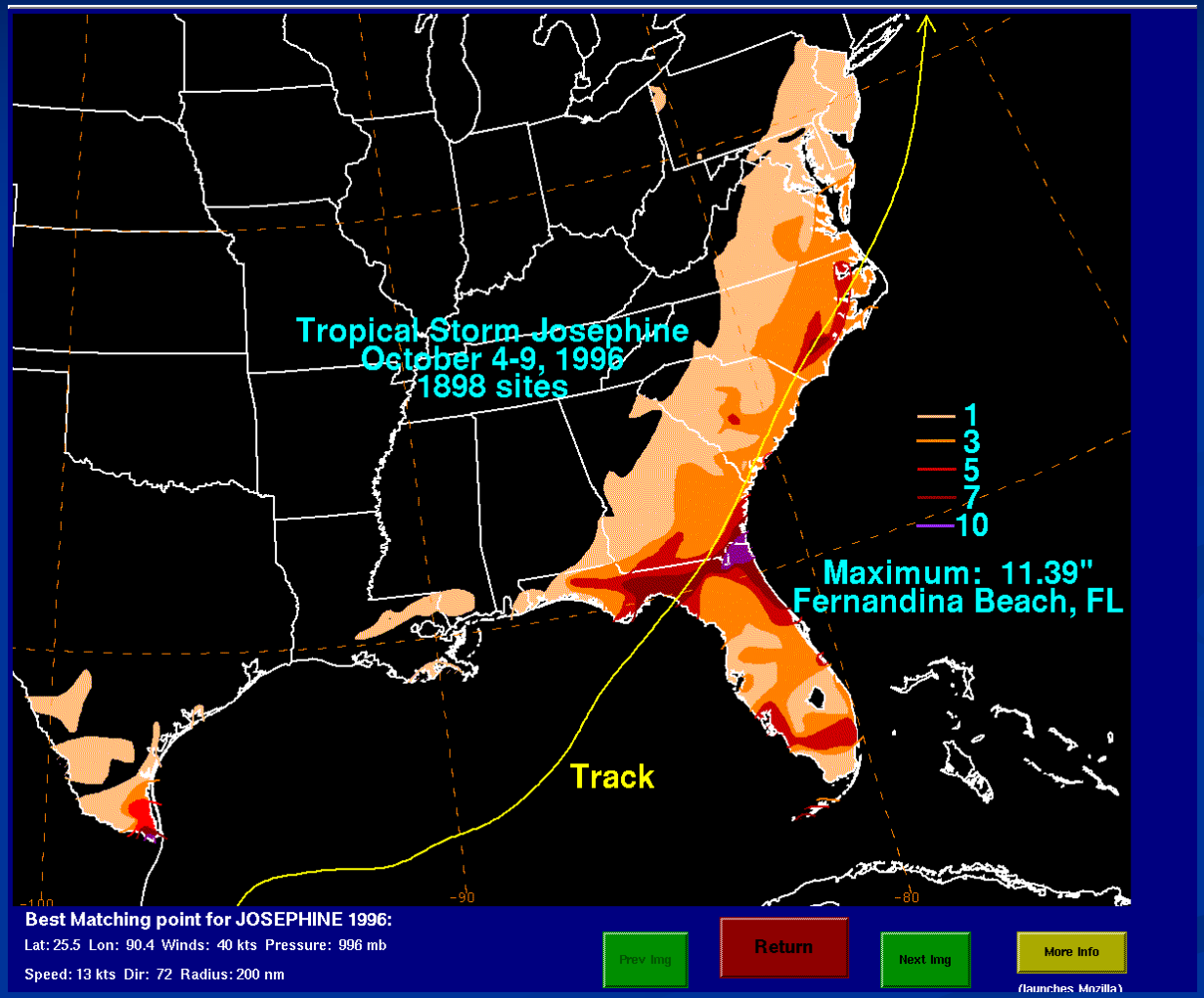
CLIQR

- Scripts utilize extended best track database from NHC, modified by additional information from HPC/NHC map series and NHC Atlantic non-developing system database
- Storm matches made primarily upon current position, forward motion, and storm size. In 2009, NHC five day track will be included
- Uses a 9 point system. The system's point total can be seen in the last column of text output
- Output generated using CHGHUR/objective guidance messages from NHC, but can also be utilized using manual input
- Simplified output online for active systems at: http://www.hpc.ncep.noaa.gov/tropical/rain/web/cliqr.html

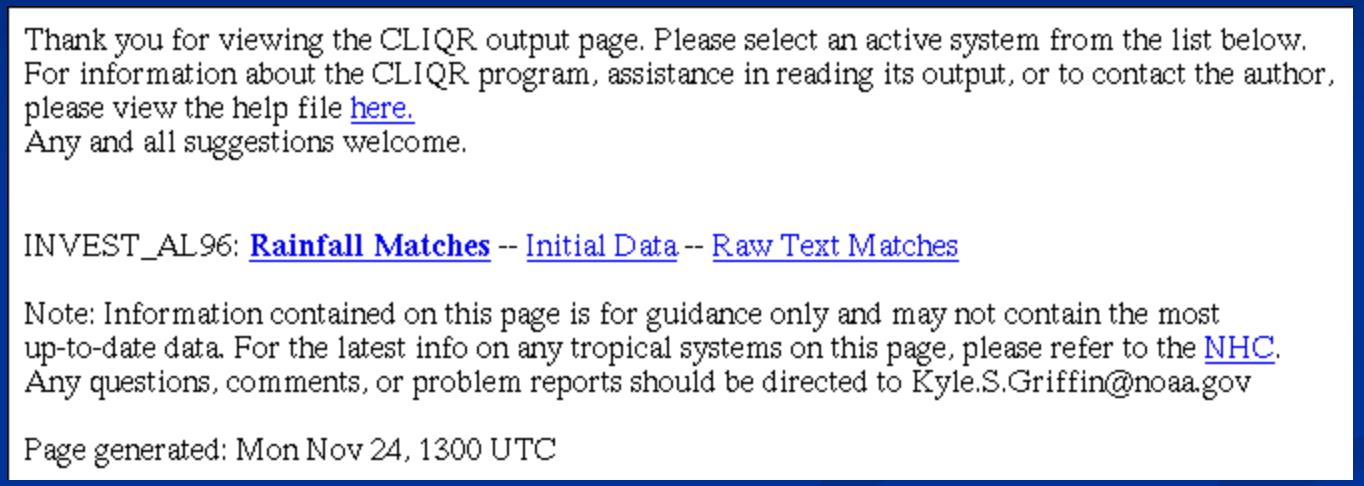
CLIQR GUI using manual input



CLIQR output via magenta "View Rainfall Graphics" button



CLIQR web output for active systems



Thank you for viewing the CLIQR output page. Please select an active system from the list below.
For information about the CLIQR program, assistance in reading its output, or to contact the author, please view the help file here.
Any and all suggestions welcome.

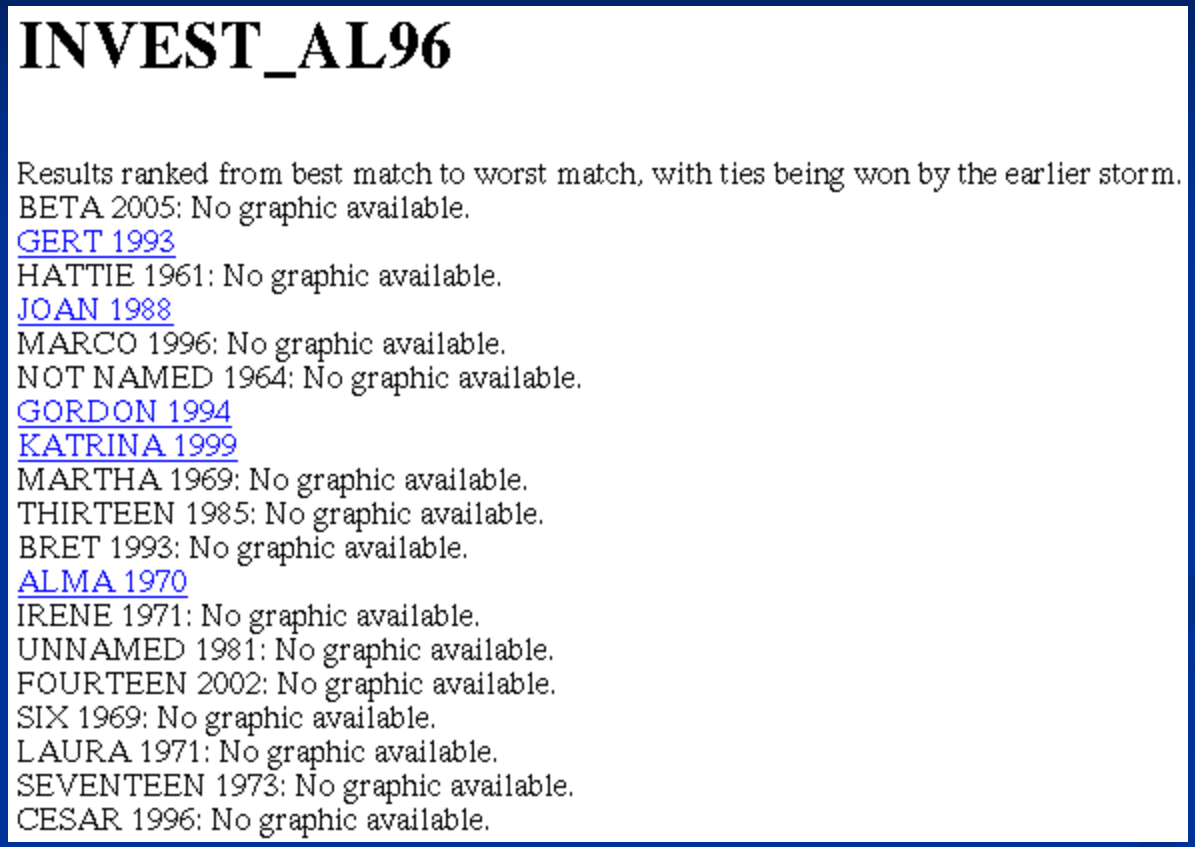
INVEST_AL96: **Rainfall Matches** -- Initial Data -- Raw Text Matches

Note: Information contained on this page is for guidance only and may not contain the most up-to-date data. For the latest info on any tropical systems on this page, please refer to the NHC.
Any questions, comments, or problem reports should be directed to Kyle.S.Griffin@noaa.gov

Page generated: Mon Nov 24, 1300 UTC

- http://www.wpc.ncep.noaa.gov/tropical/rain/web/cliqr.html

CLIQR matching storm list (Rainfall Matches hyperlink)

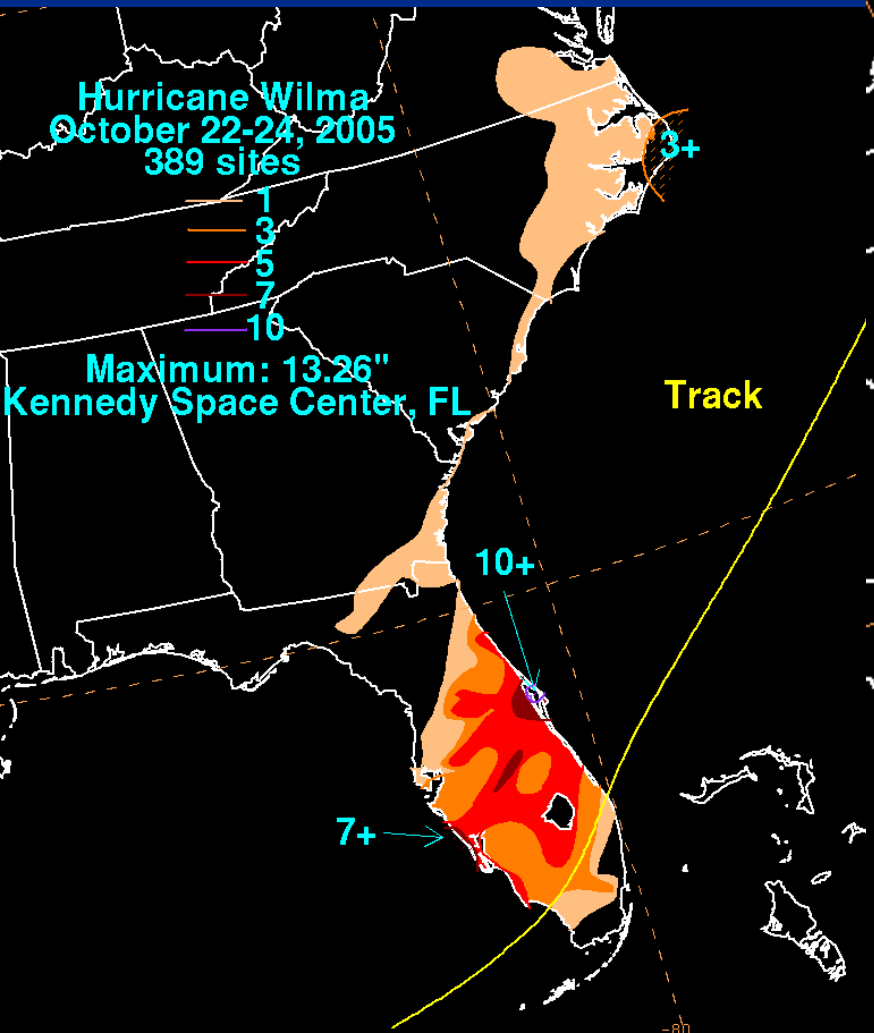


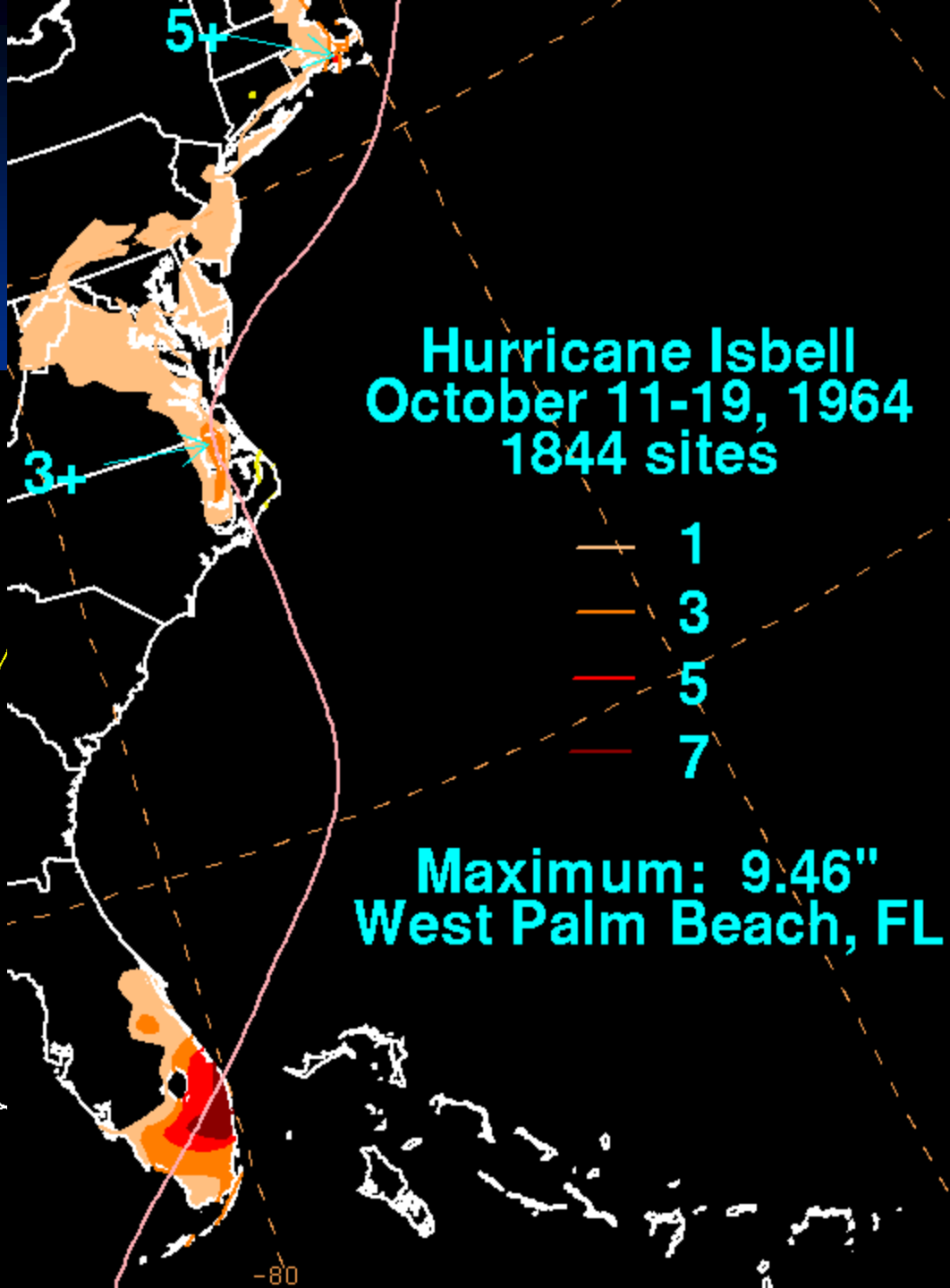
INVEST_AL96

Results ranked from best match to worst match, with ties being won by the earlier storm.
BETA 2005: No graphic available.
GERT 1993
HATTIE 1961: No graphic available.
JOAN 1988
MARCO 1996: No graphic available.
NOT NAMED 1964: No graphic available.
GORDON 1994
KATRINA 1999
MARTHA 1969: No graphic available.
THIRTEEN 1985: No graphic available.
BRET 1993: No graphic available.
ALMA 1970
IRENE 1971: No graphic available.
UNNAMED 1981: No graphic available.
FOURTEEN 2002: No graphic available.
SIX 1969: No graphic available.
LAURA 1971: No graphic available.
SEVENTEEN 1973: No graphic available.
CESAR 1996: No graphic available.

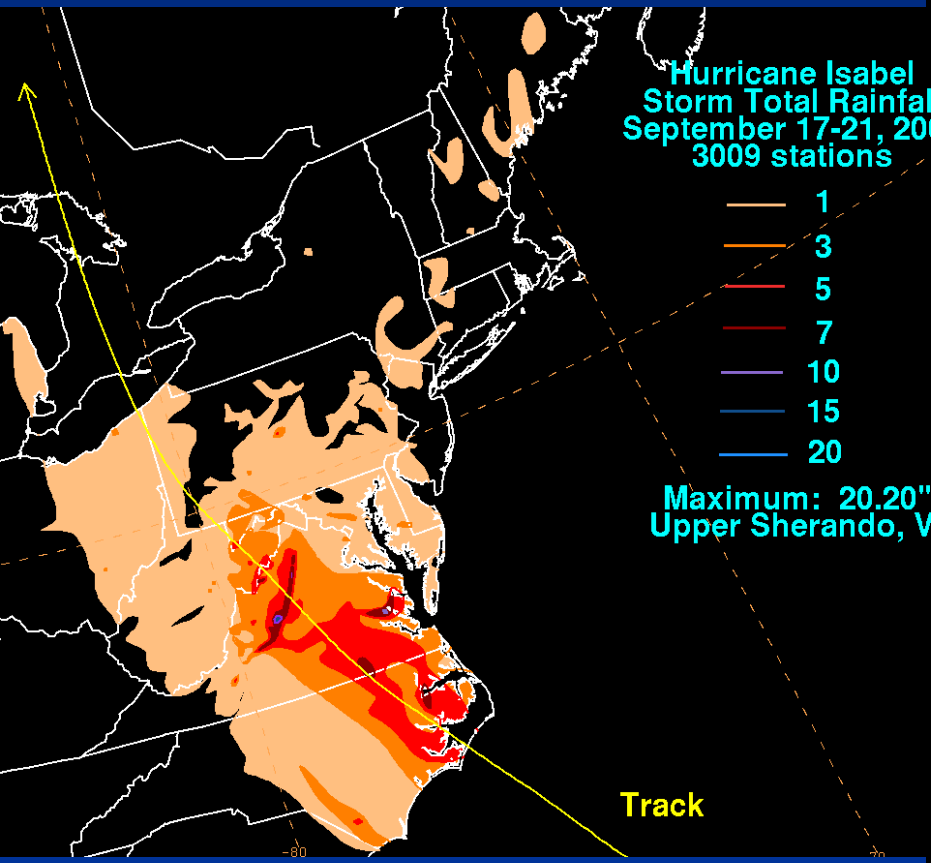
- Simplified list links to relevant storm total rainfall graphic through hyperlink. Future revisions include columns separating the Puerto Rico impacts from North American impacts to help web user.

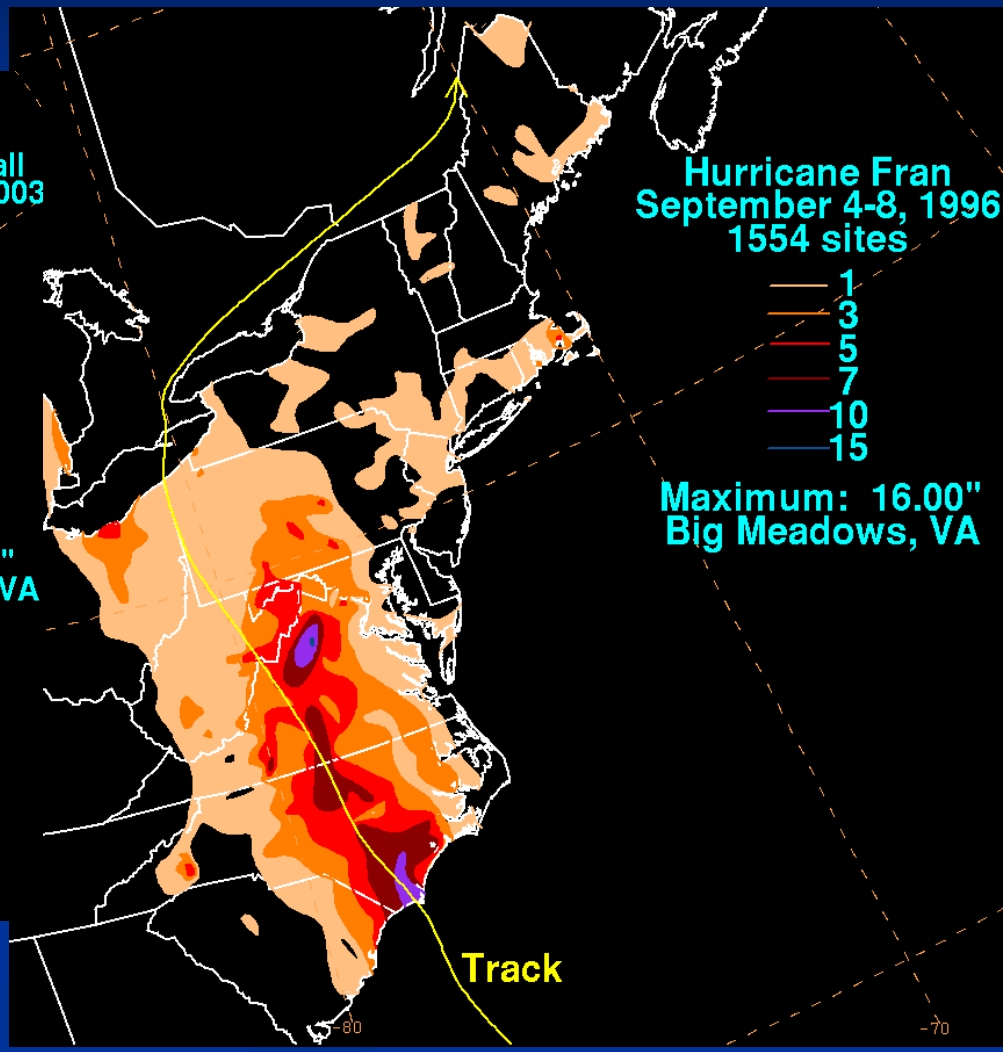
Isbell (1964) vs. Wilma (2005)





Isabel (2003) vs. Fran (1996)

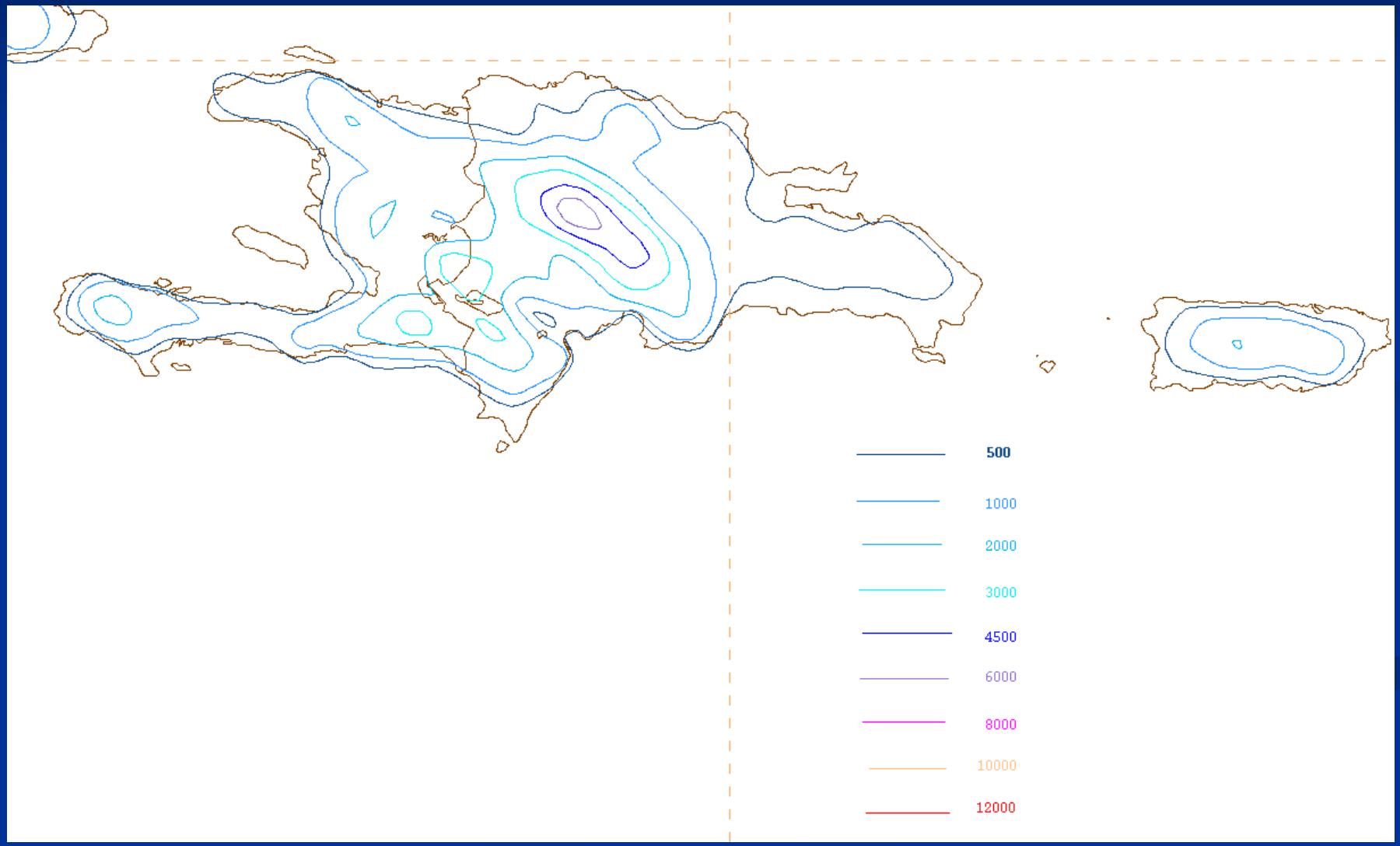




Example

A Tropical Storm has formed east of the Leeward Islands. It is expected to move west-northwest near 12 knots over the next 5 days, becoming a hurricane prior to reaching Florida, and it is smaller than average in size. Wind shear is expected to pick up out of the northeast in a couple days. What is the rain potential for Puerto Rico and the Dominican Republic?

Elevation of Hispaniola/Puerto Rico



Considerations

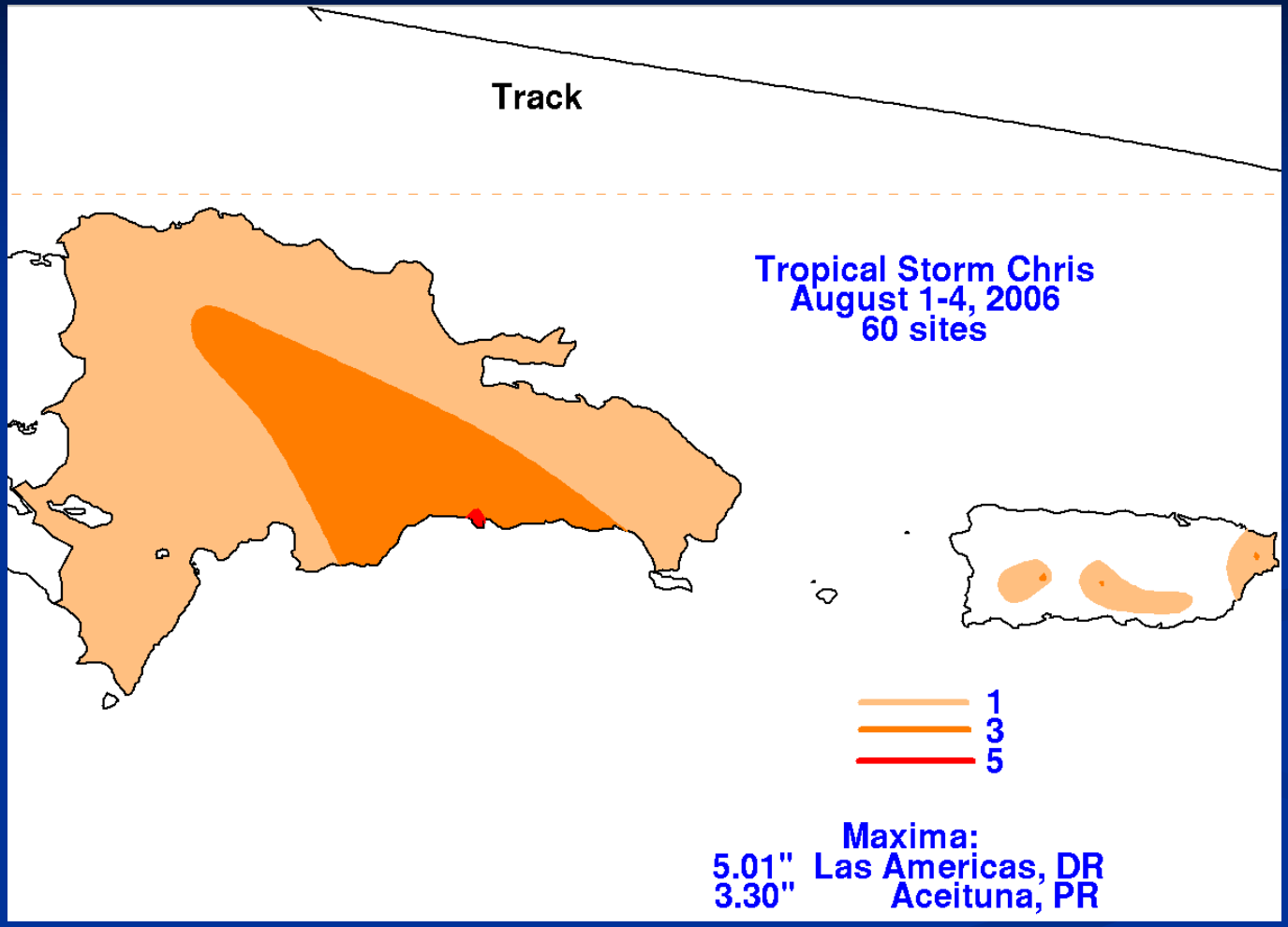
Factors leading to higher rainfall

- Convection should be concentrated in its southern quadrant due to wind shear
- Significant topography in Dominican Republic and Puerto Rico

Factors leading to lower rainfall

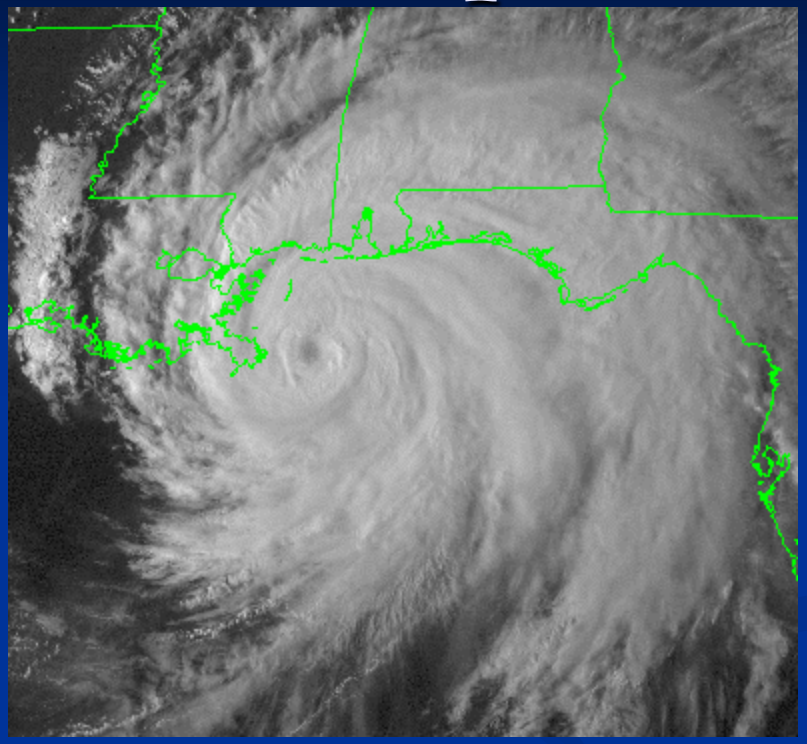
- Smaller than average
- Vertical wind shear is expected to increase
- Moving greater than 6 knots
- Core of system expected to pass north of the islands

Result



- System moved closer than expected to Dominican Republic and dissipated as it reached Cuba (Chris 2006)

Example



- An average sized category 2 hurricane is moving towards the Gulf coastal plain of the United States. The forecast is for the storm to recurve at 3 knots into the Deep South with no wind shear anticipated.

Considerations

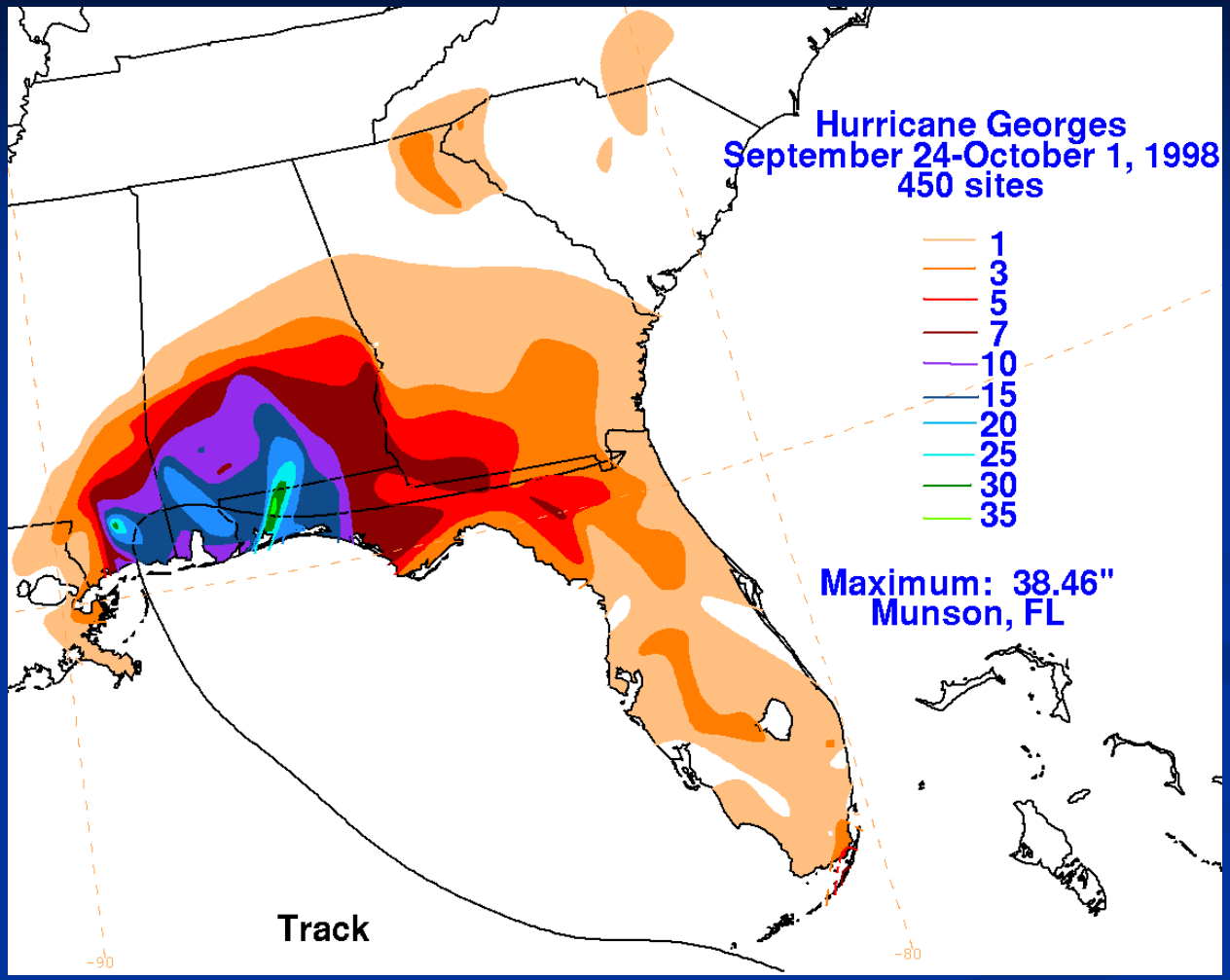
Factors leading to higher rainfall

- No wind shear
- Movement under 6 knots
- Tropical cyclone moving into a larger landmass
- Could be an area within the track's radius of curvature which receives training

Factors leading to lower rainfall

- None

Result

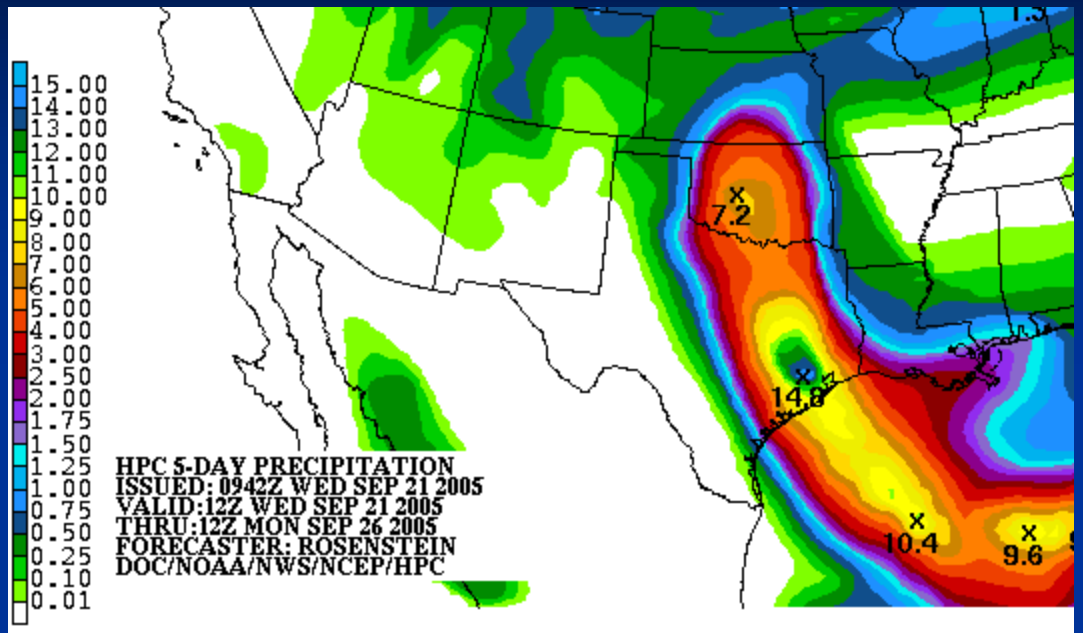


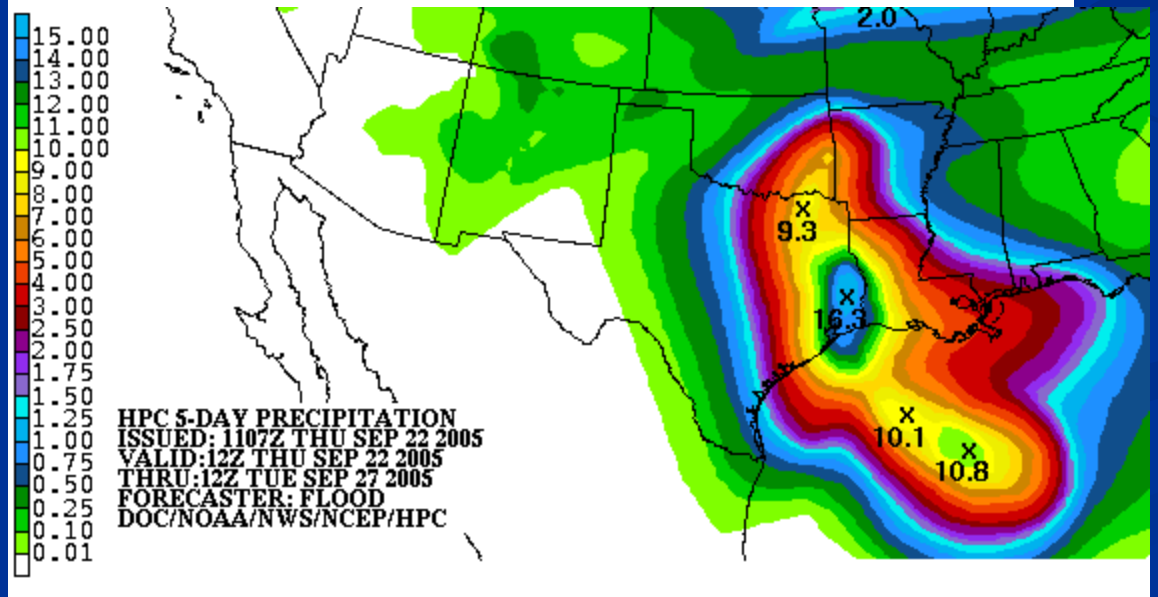
- System well-forecasted, so a wetter than average impact was well-anticipated (though initially underforecast)

Production of TC QPF

- ***Forecasts made in six-hourly increments from Hour 6-84 and in two 48 hour chunks for Hours 84-132 and 132-180 twice a day by 3 forecasters (Day 1, Day 2/3, and Medium Range temps/pops)***
- Start With Model Closest to TPC Forecast (usually GFS)
- Locate relevant synoptic scale boundaries/coastal front
- Use conceptual models/current structure to modify/shift QPF (TRaP and recent satellite/radar imagery for current structure)
- Look at storm-relative shear/H2 winds to further shift/limit QPF
- Use climatology (PRISM, r-CLIPER, TC Rainfall Climatology) to:
  - Temper down forecast bias/act as a reality check
  - Depict areas of terrain that could be significantly impacted
  - Help Create TC rainfall statements for the Public Advisories
- Forecasts issued at by 06/18z (Days 1-3) and 12z/0z (Days 4-5, 6-7 and 7-day accumulation graphic)

Dependence on TPC track - Rita





Threat/Bias for 5 Day QPF

September 21/12z Forecast

0.25 .453 1.52 H G .498 1.39
0.50 .350 1.46 H G .414 1.35
1.00 .197 .961 H G .258 1.24
2.00 .030 .725 H G .168 .858
3.00 .013 1.28 H G .093 1.06
4.00 .009 2.61 H G .069 1.86
5.00 .000 3.49 H G .021 3.01
6.00 .000 4.23 H G .018 4.69

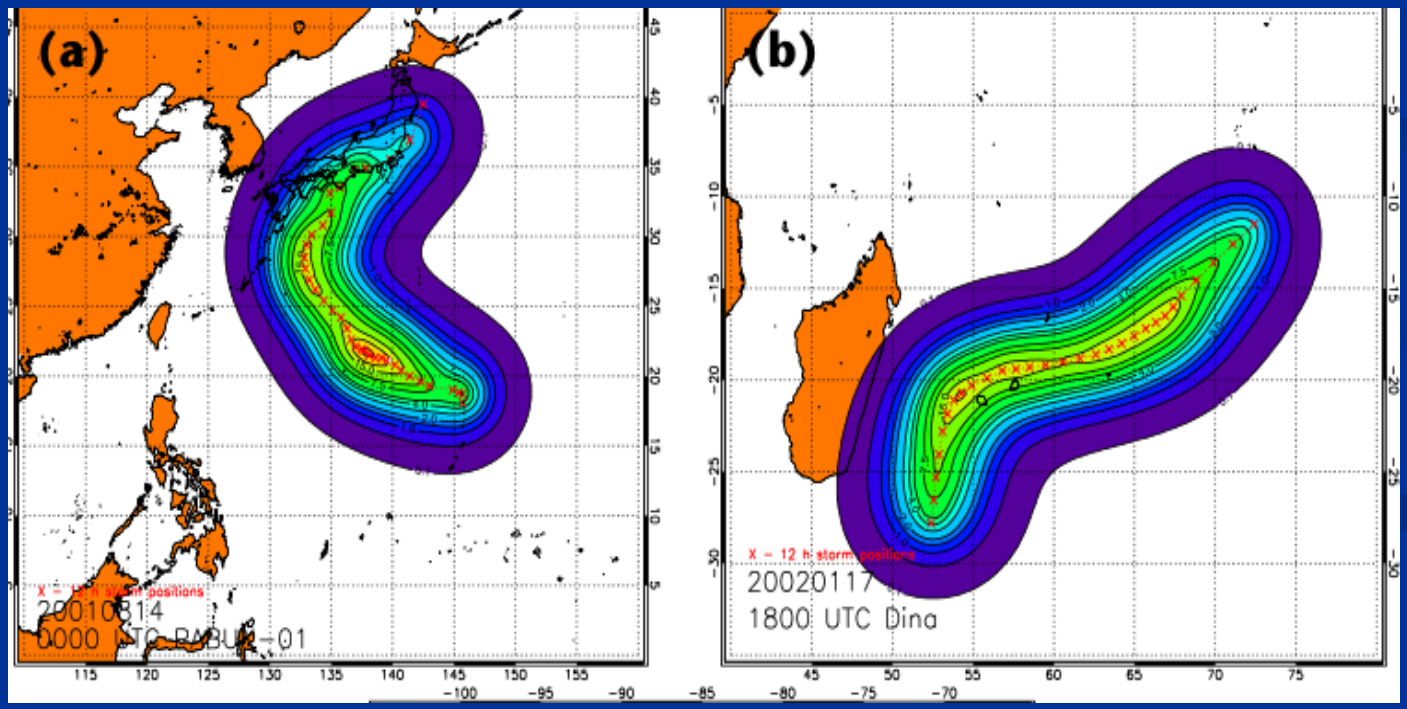
September 22/12z Forecast

0.25 .536 1.33 H G .541 1.08
0.50 .468 1.18 H G .534 .978
1.00 .367 1.07 H G .366 .781
2.00 .164 .777 H G .234 .792
3.00 .163 1.35 H G .224 .916
4.00 .128 2.50 H G .199 1.63
5.00 .090 3.74 H G .174 2.18
6.00 .090 5.71 H G .161 2.98

Specialized Tropical Cyclone QPF Guidance

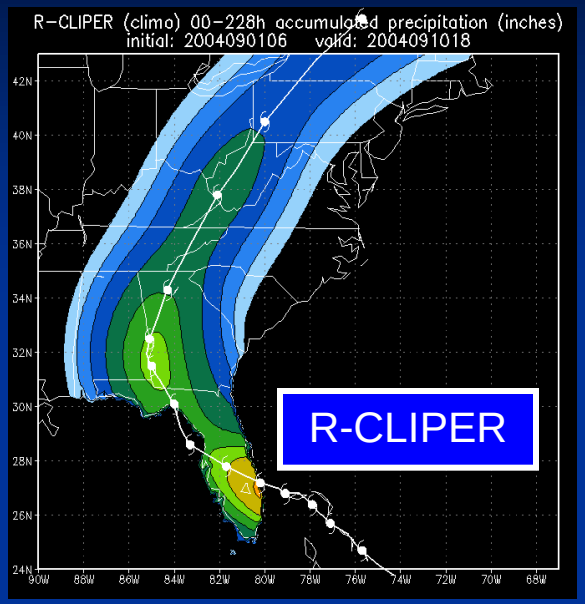
R-CLIPER

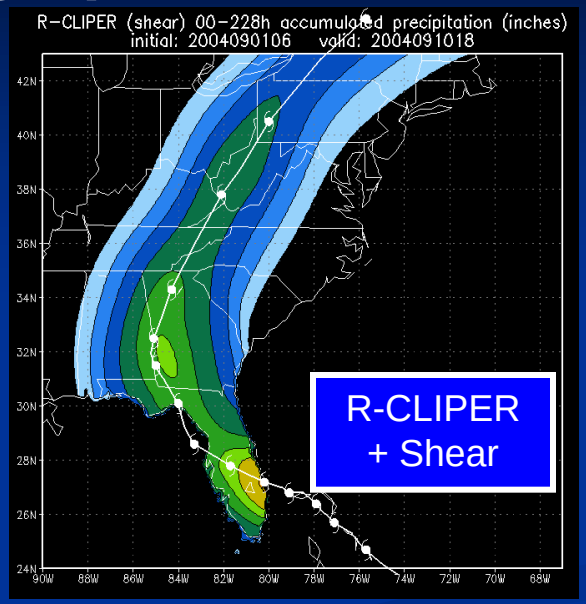
- R-CLIPER (Rainfall Climatology Parametric Model)
  - Statistical model developed from TMI data and rain gauges
  - Simple model creates a rainfall swath dependent on storm track, intensity, and size
  - Operational at 0.25^{o} X 0.25^{o} hourly resolution
  - Asymmetries are not taken into account

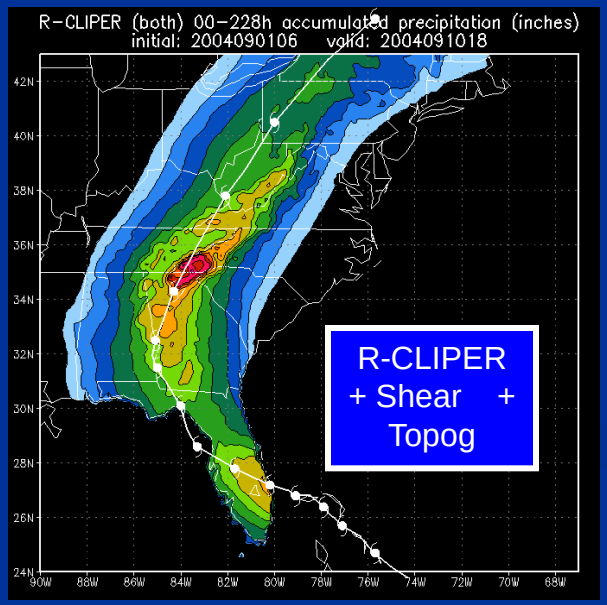


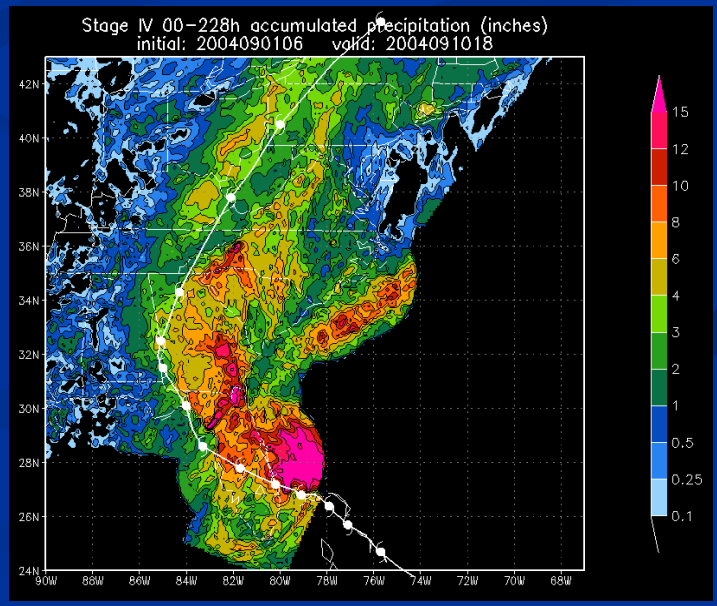
R-CLIPER Improvements

- **Includes shear and topographic effects in 2007**









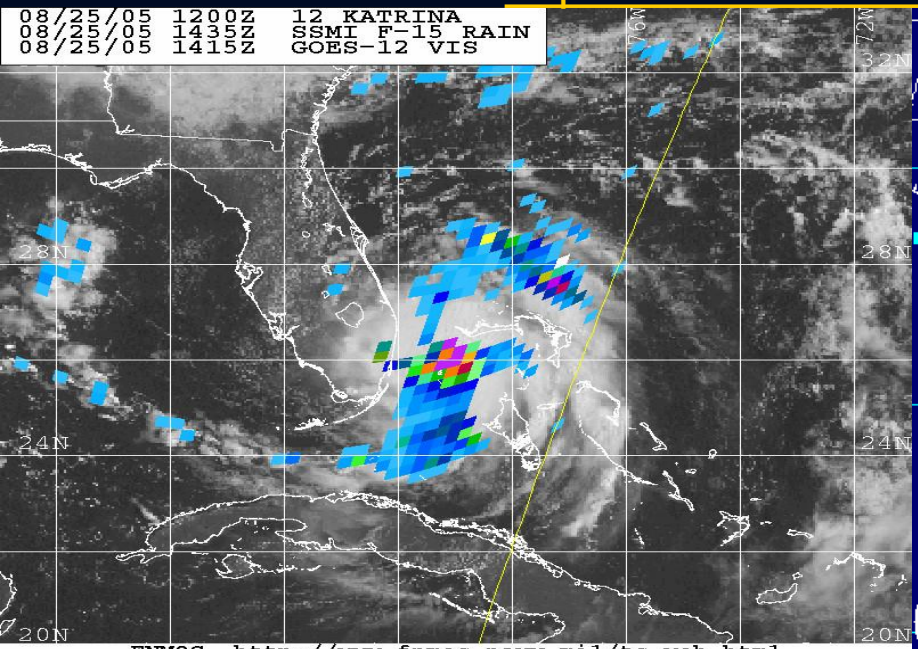
TRaP

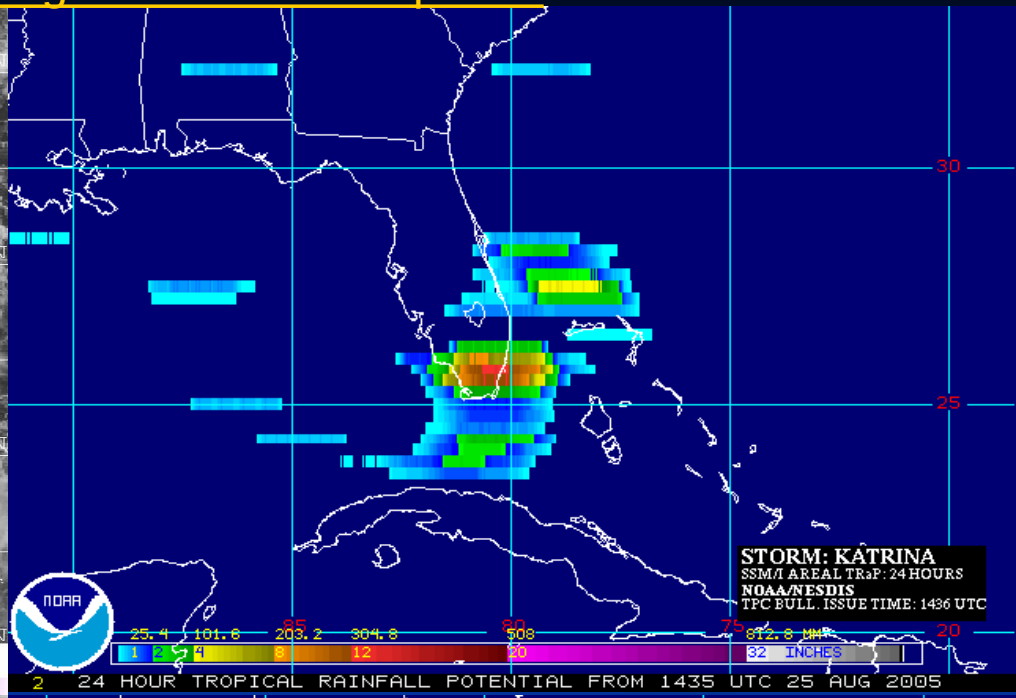
- **Can be found at NOAA/NESDIS Satellite Analysis Branch (SAB)**

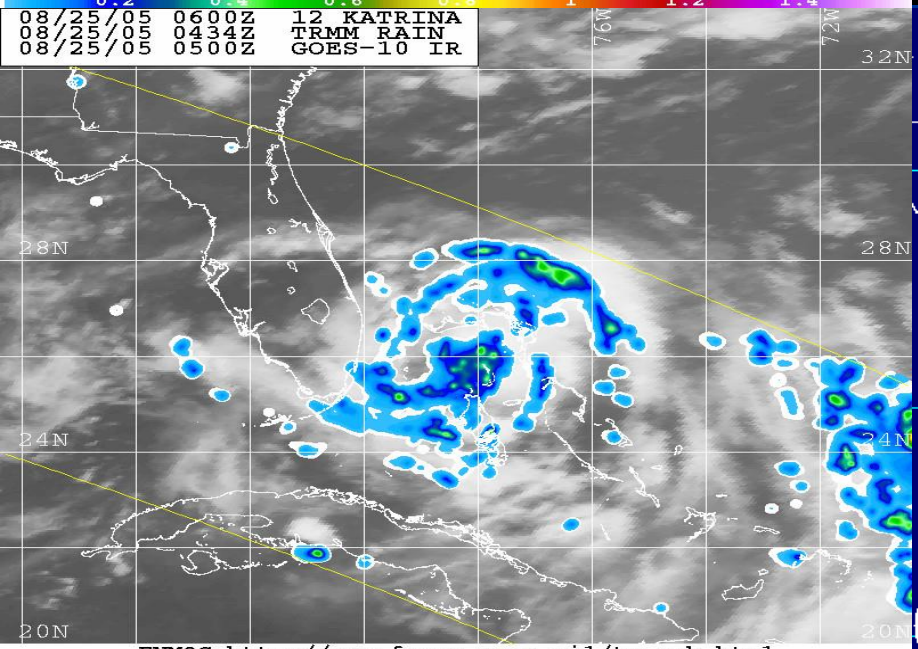
http://www.ssd.noaa.gov/PS/TROP/trap.html

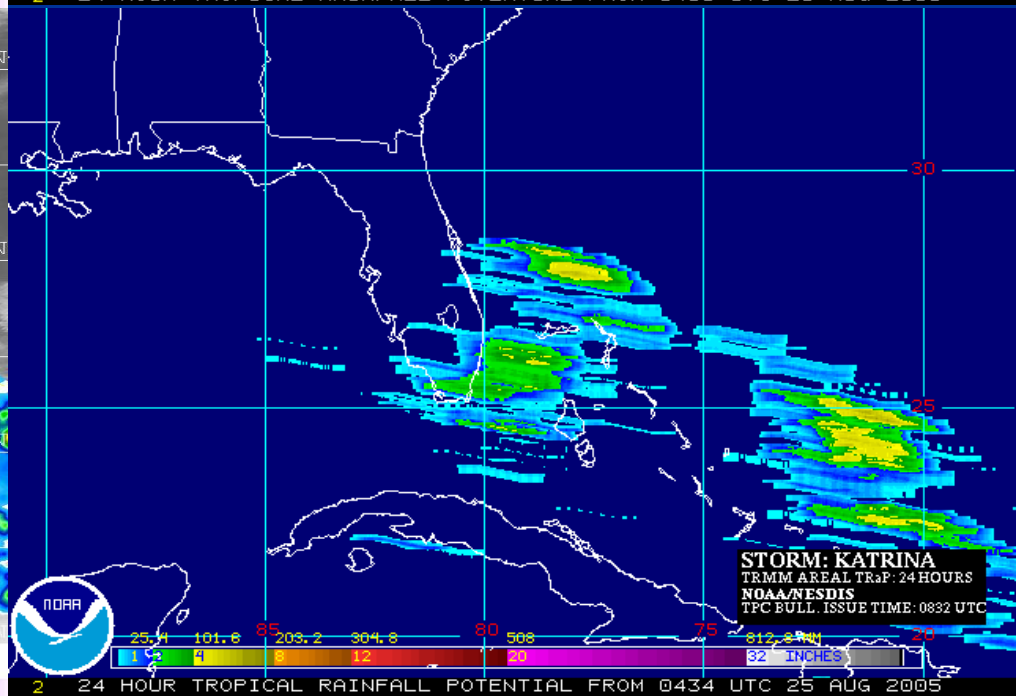
- **Uses microwave rain rate images from SSM/I, TRMM, and AMSU and extrapolates along TC forecast track. METOP and SSMI/S, part of AMSU, expected by the end of the year**
- **Only available when a microwave pass "catches" the storm mostly within the swath**
- **Depends on official forecast of TC track from NHC, CPHC, etc.**

TRaP: http://www.ssd.noaa.gov/PS/TROP/trap.html

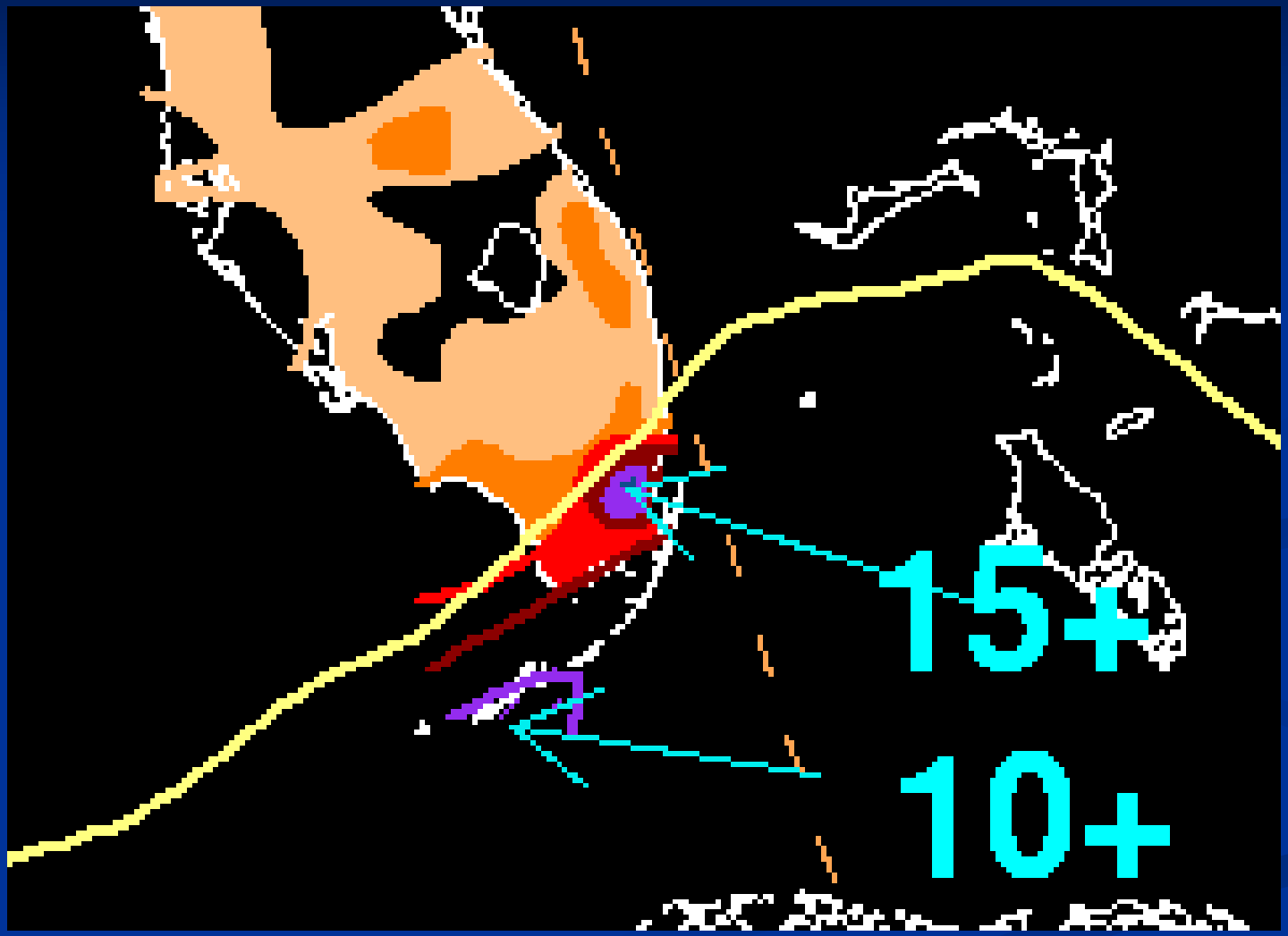




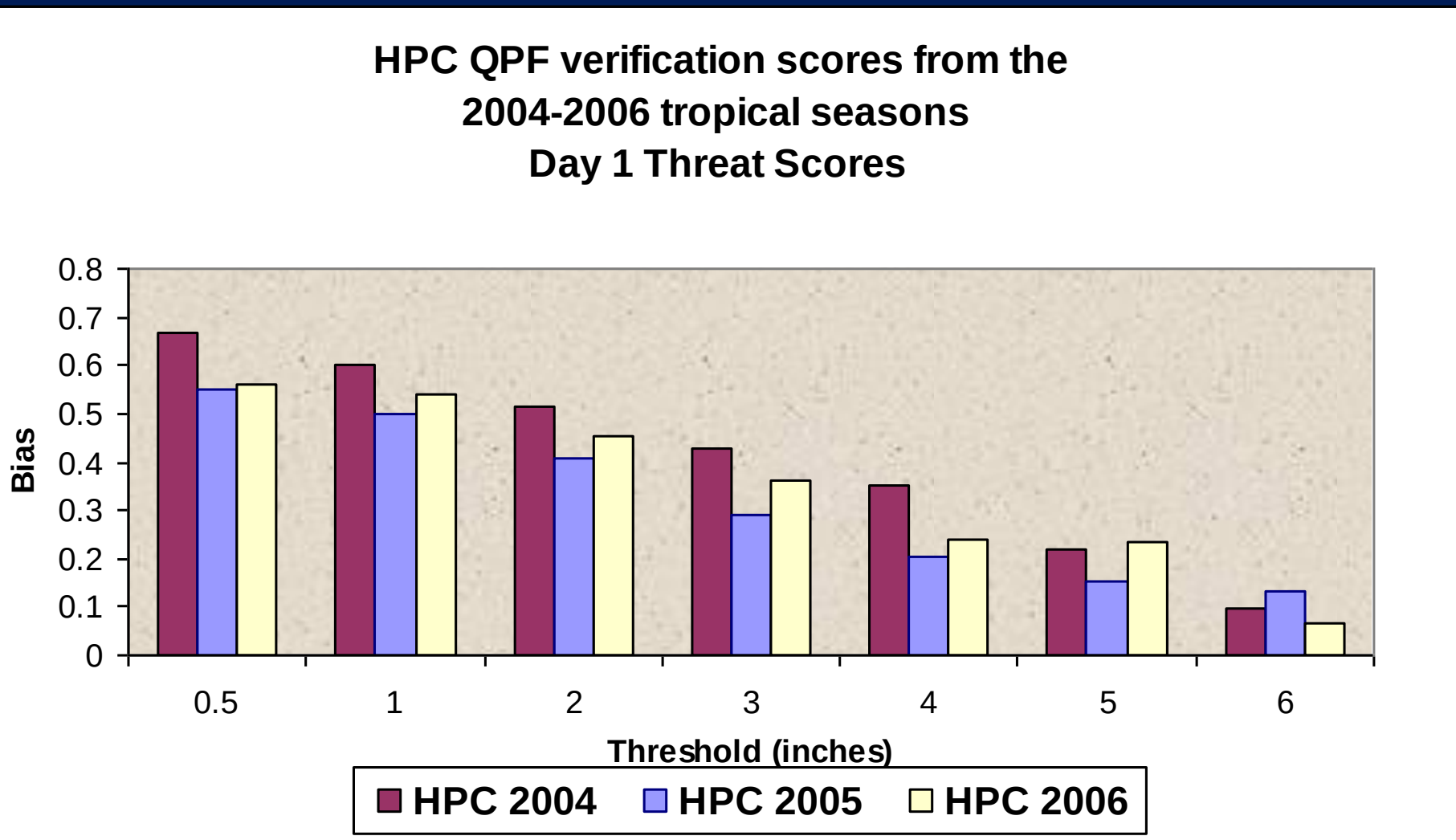




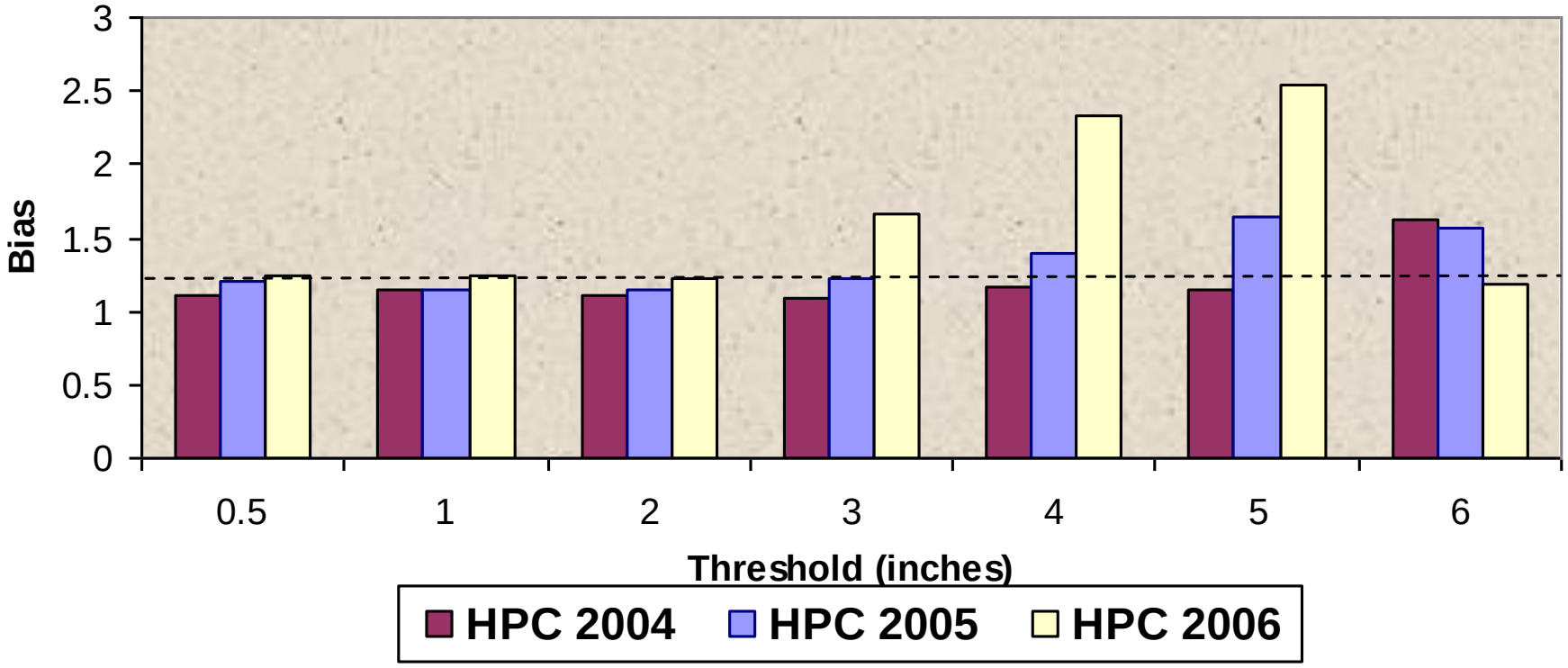
Katrina Rainfall



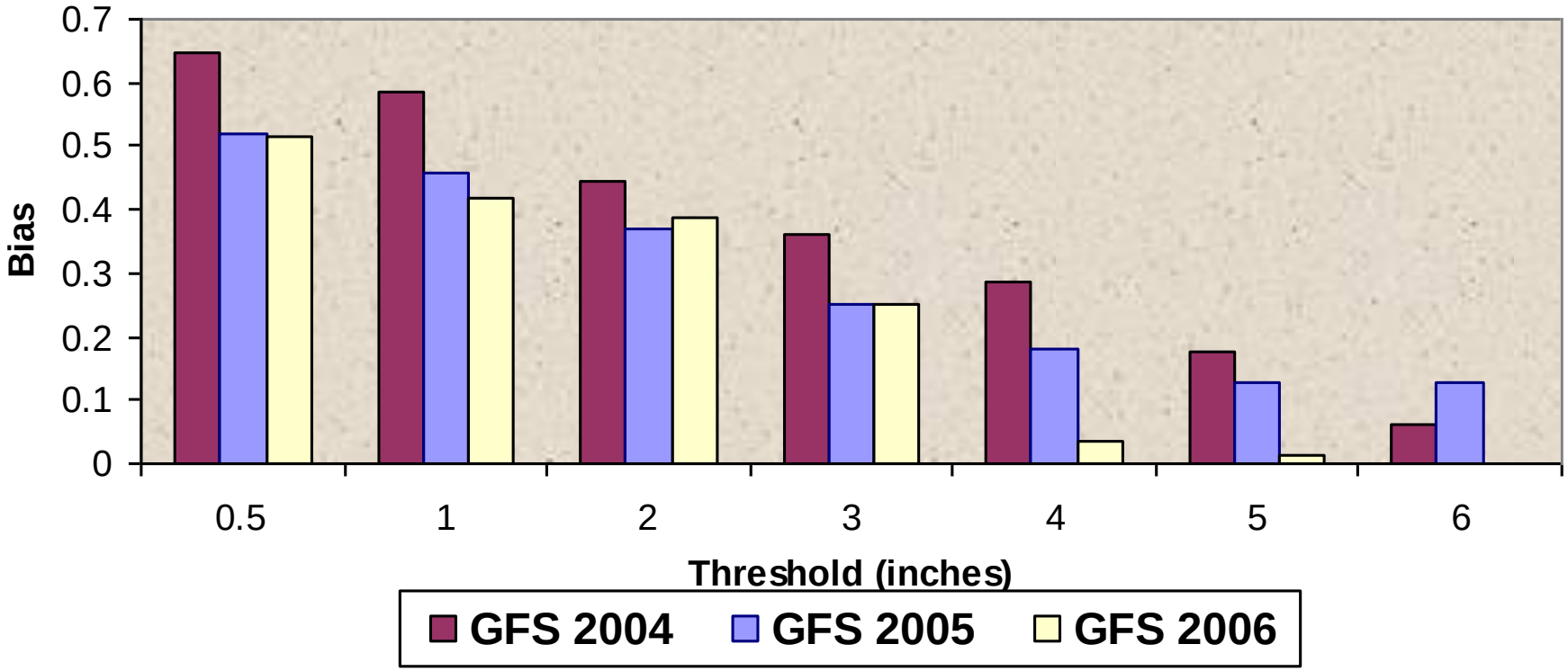
WPC tropical cyclone QPF verification 2004-2008


HPC QPF verification scores from the
2004-2006 tropical seasons
Day 1 Threat Scores
Bias
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.5
1
2
3
4
5
6
Threshold (inches)
HPC 2004
HPC 2005
HPC 2006

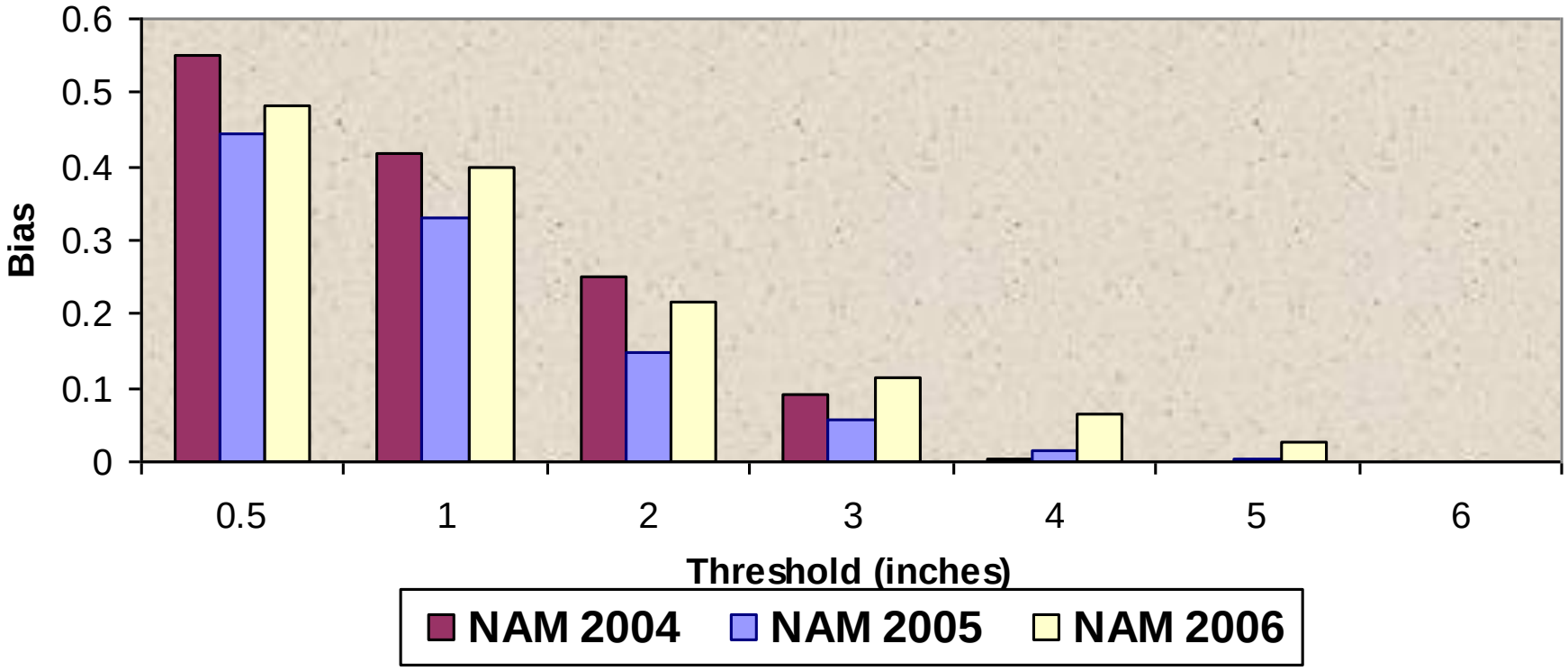
HPC QPF verification scores from the 2004-2006 tropical seasons
Day 1 Bias



GFS QPF verification scores from the 2004-2006 tropical seasons
Day 1 Threat Scores

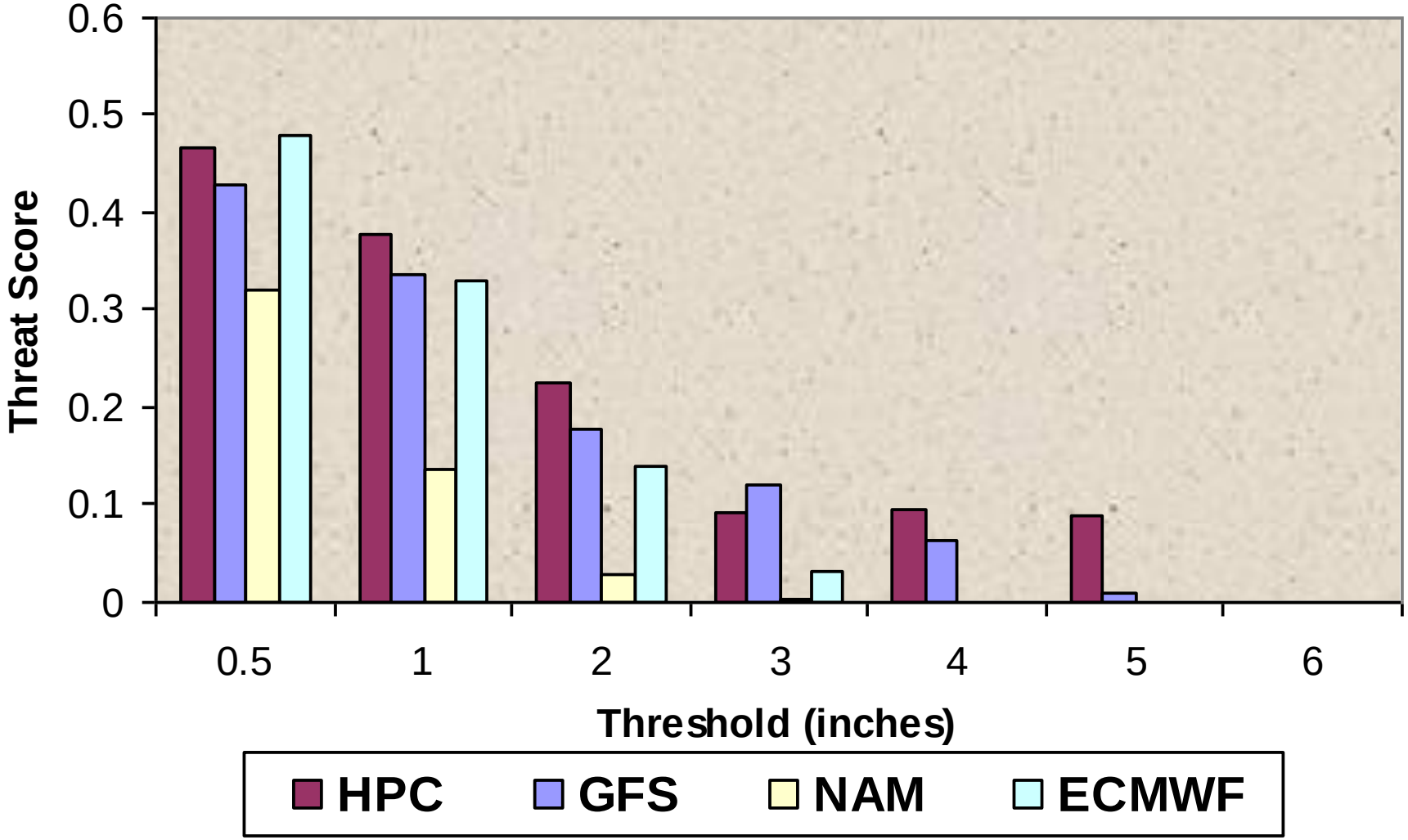


NAM QPF verification scores from the 2004-2006 tropical seasons Day 1 Threat Scores



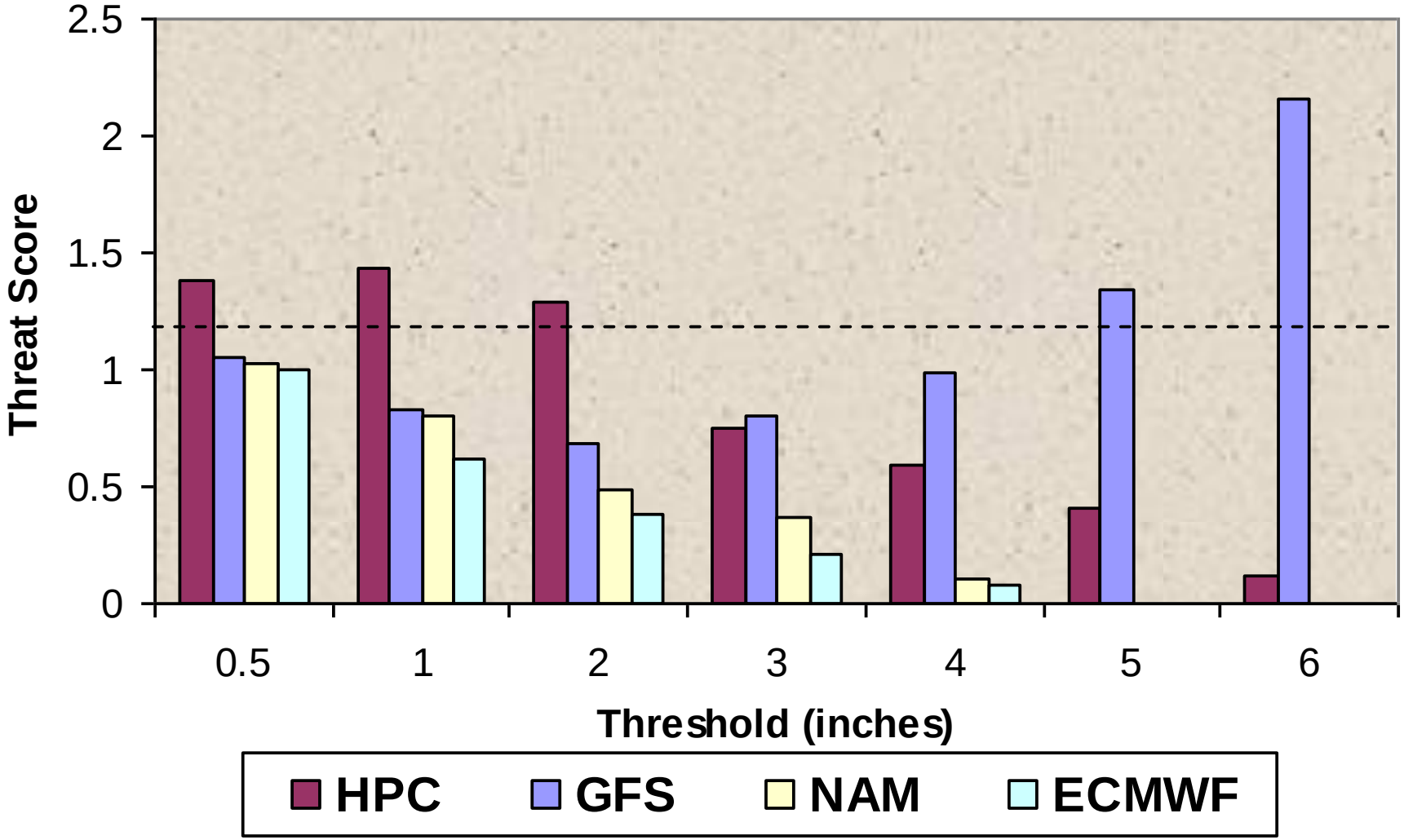
Summary Statistics for Landfalling Tropical Cyclones-2007

Day 1 Threat Scores

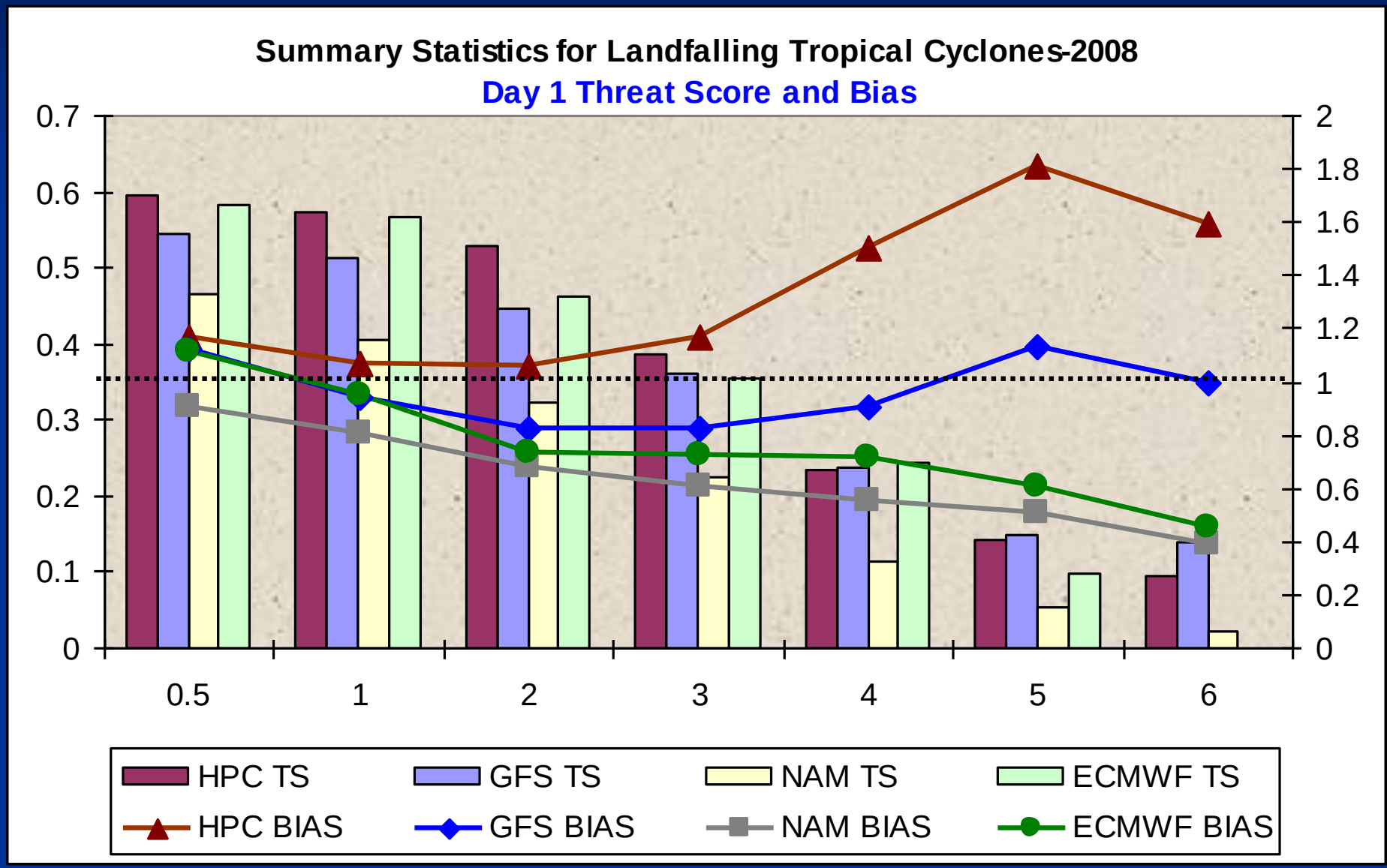


Summary Statistics for Landfalling Tropical Cyclones-2007

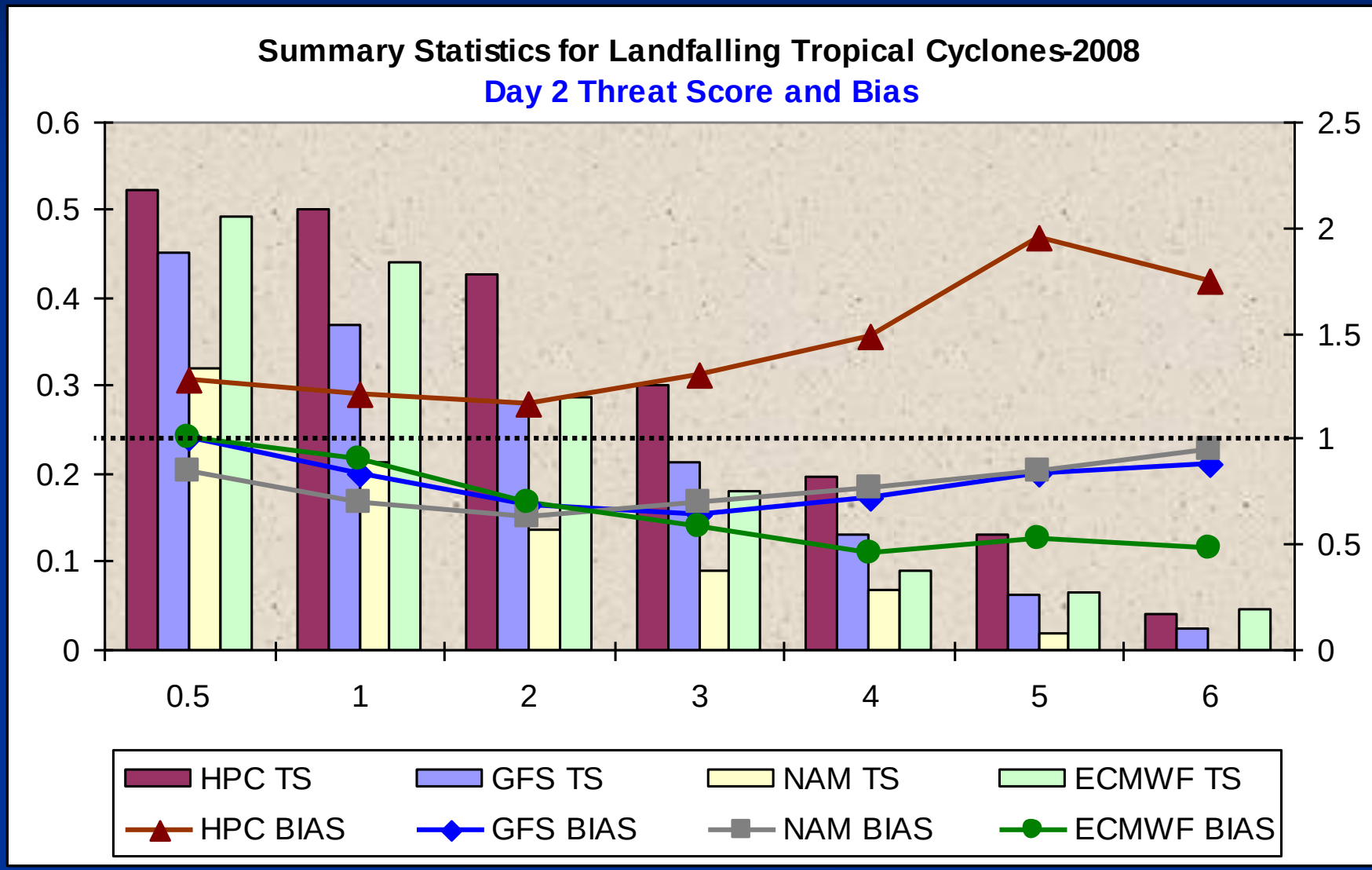
Day 1 Bias



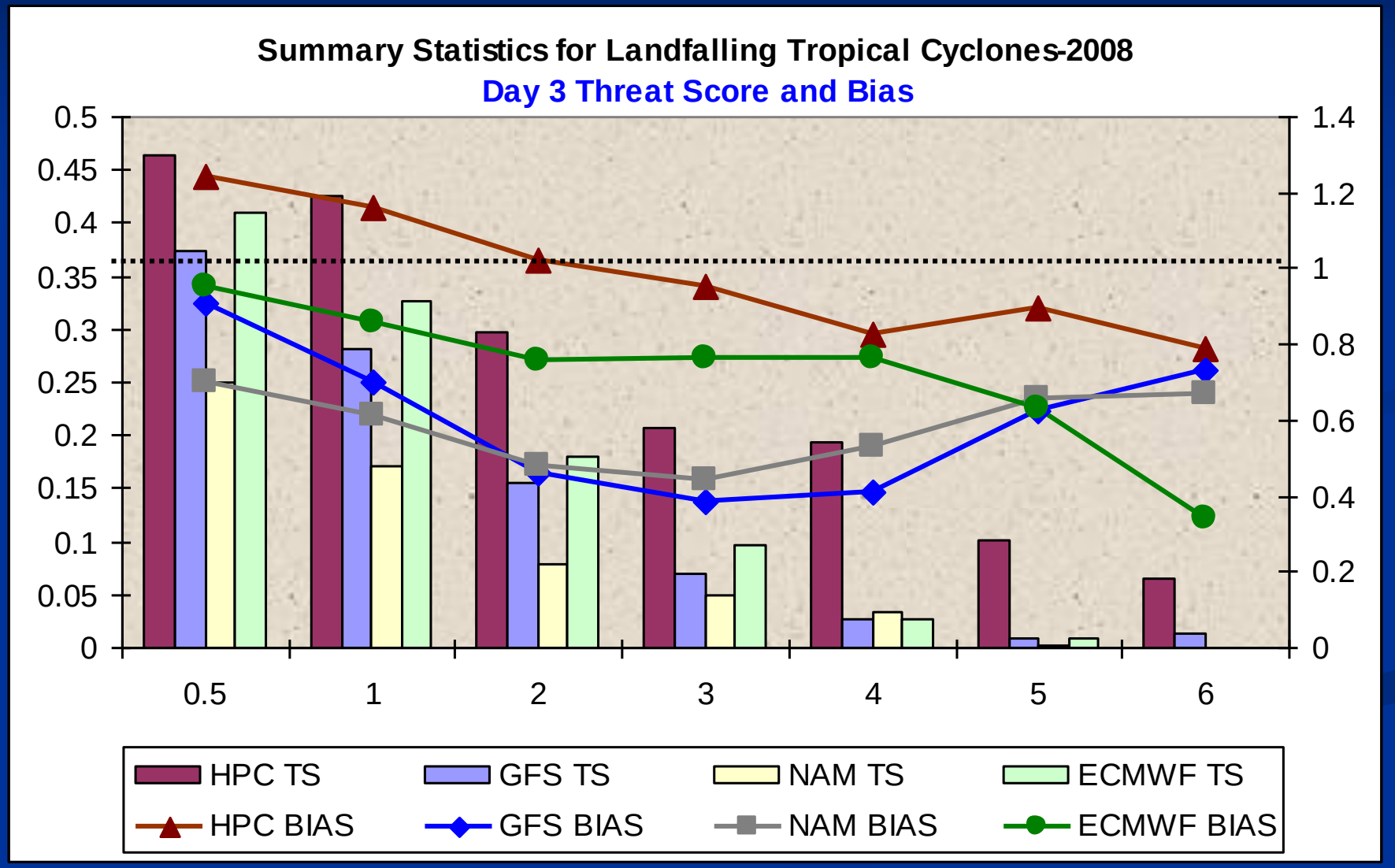
Day 1 Threat Scores and Bias



Day 2 Threat Score/Bias



Day 3 Threat Score/Bias



Summary

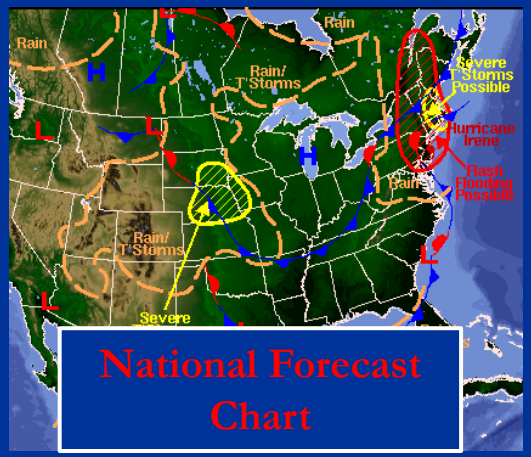
- Tropical cyclones lead to 10-20% of annual rainfall in South and Eastern U.S. While tropical cyclones lead to a smaller percent of annual rainfall for the Desert Southwest regionally on an annual basis, individual events can lead to a significant portion of the annual rainfall on a local basis.
- Tropical cyclone QPF pattern depends on storm size, forecast track, vertical wind shear, topography, depth of upper trough causing recurvature, and SST field the cyclone moves over prior to landfall
- While climatology is important to keep in mind, TC QPF is heavily based on the guidance which has the best verification and is closest to expected TC track (usually GFS). NAM and ECMWF both show low biases for higher rainfall amounts.

Summary

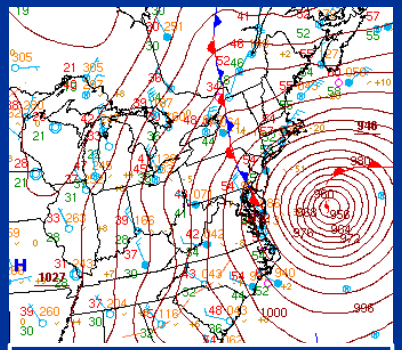
- WPC has the tools and focused mission to add value to the raw model output and frame local issues in a big-picture context

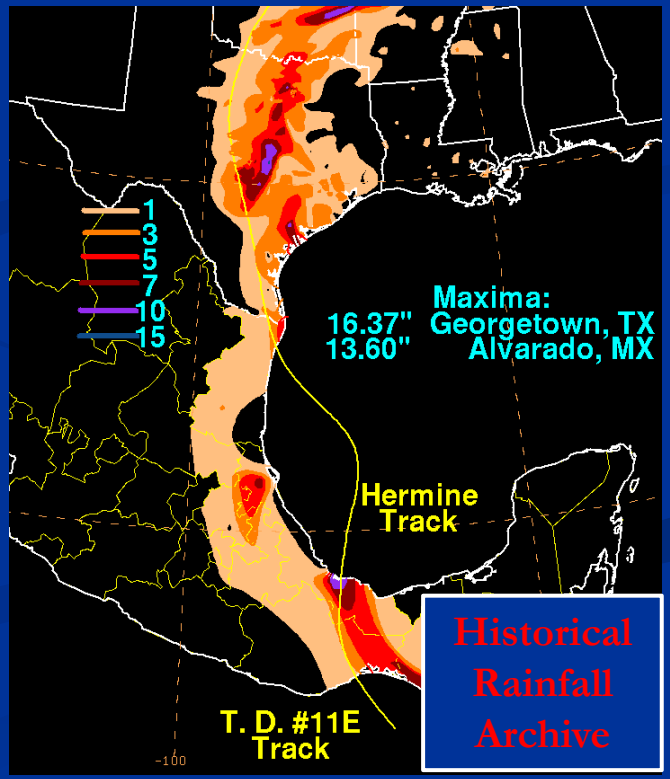
- Ramping up attention to the mesoscale… facilitating a collaborative process

- Very attentive to tropical cyclones, as they influence all of our products



National Forecast Chart


WPC/NHC/OPC Unified Analysis



Historical Rainfall Archive