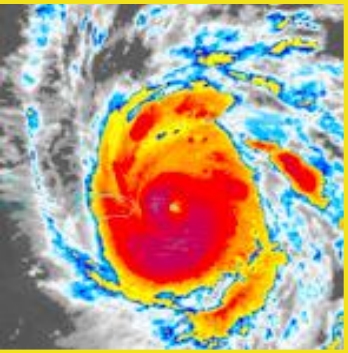
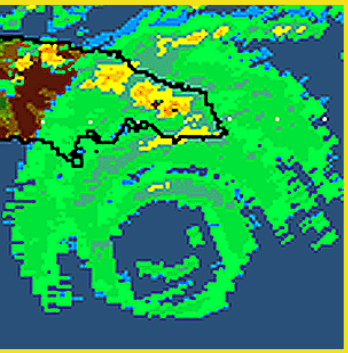




Tropical Cyclone Rainfall

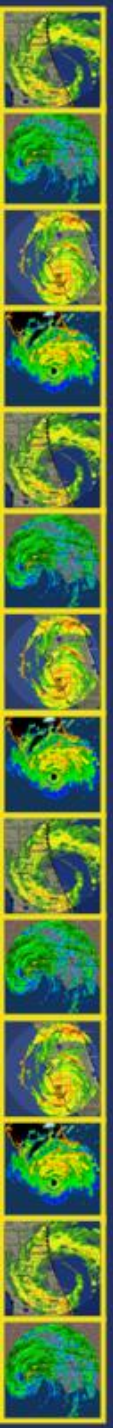
Jessica Schauer

National Hurricane Center
Tropical Analysis and Forecast Branch
Lead Forecaster

NATIONAL HURRICANE CENTER
MIAMI FL

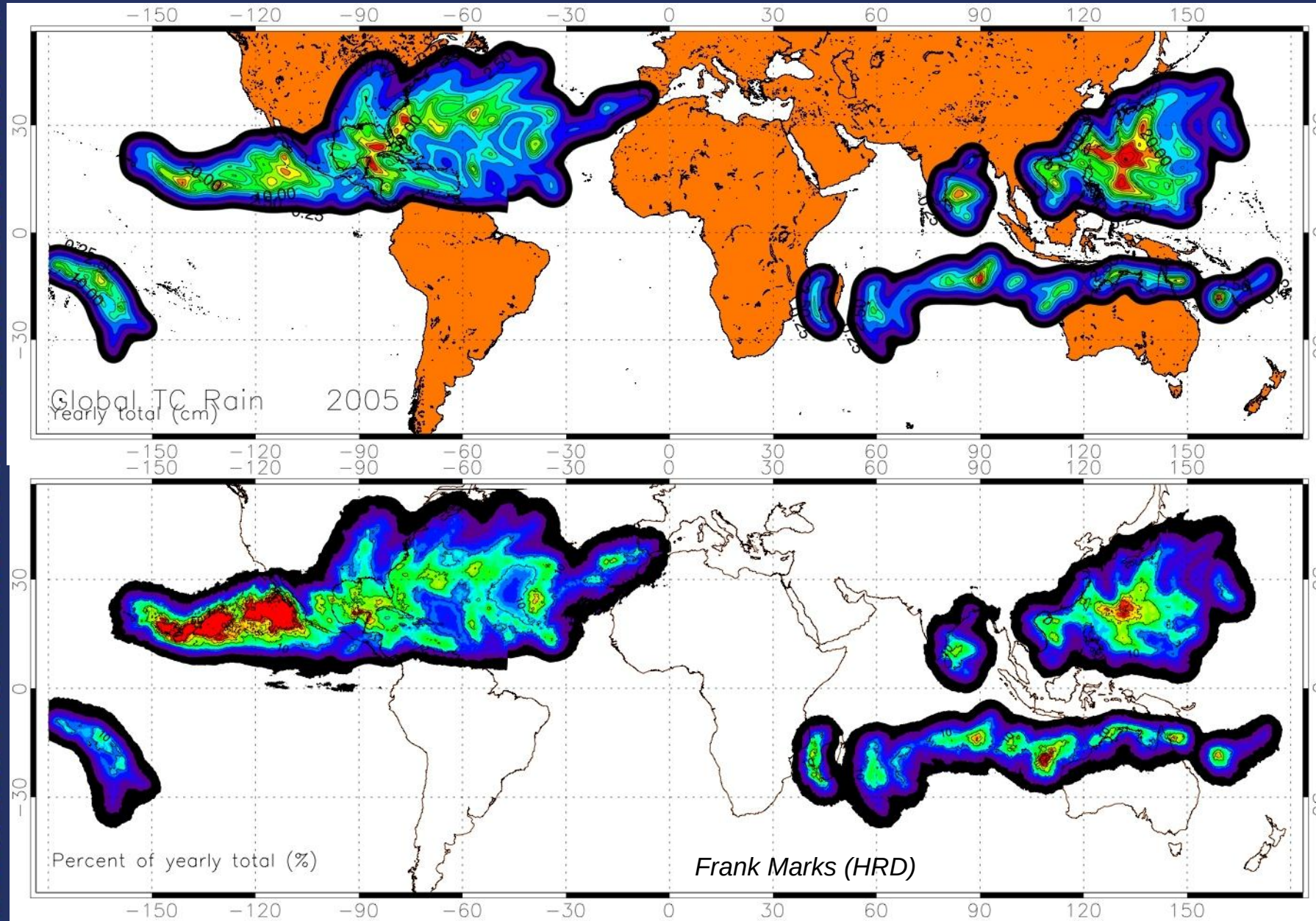
Outline

- Tropical Cyclone (TC) rainfall climatology
- Factors influencing TC rainfall
- TC rainfall forecasting tools
- TC rainfall forecasting process



Tropical Cyclone Rainfall Climatology

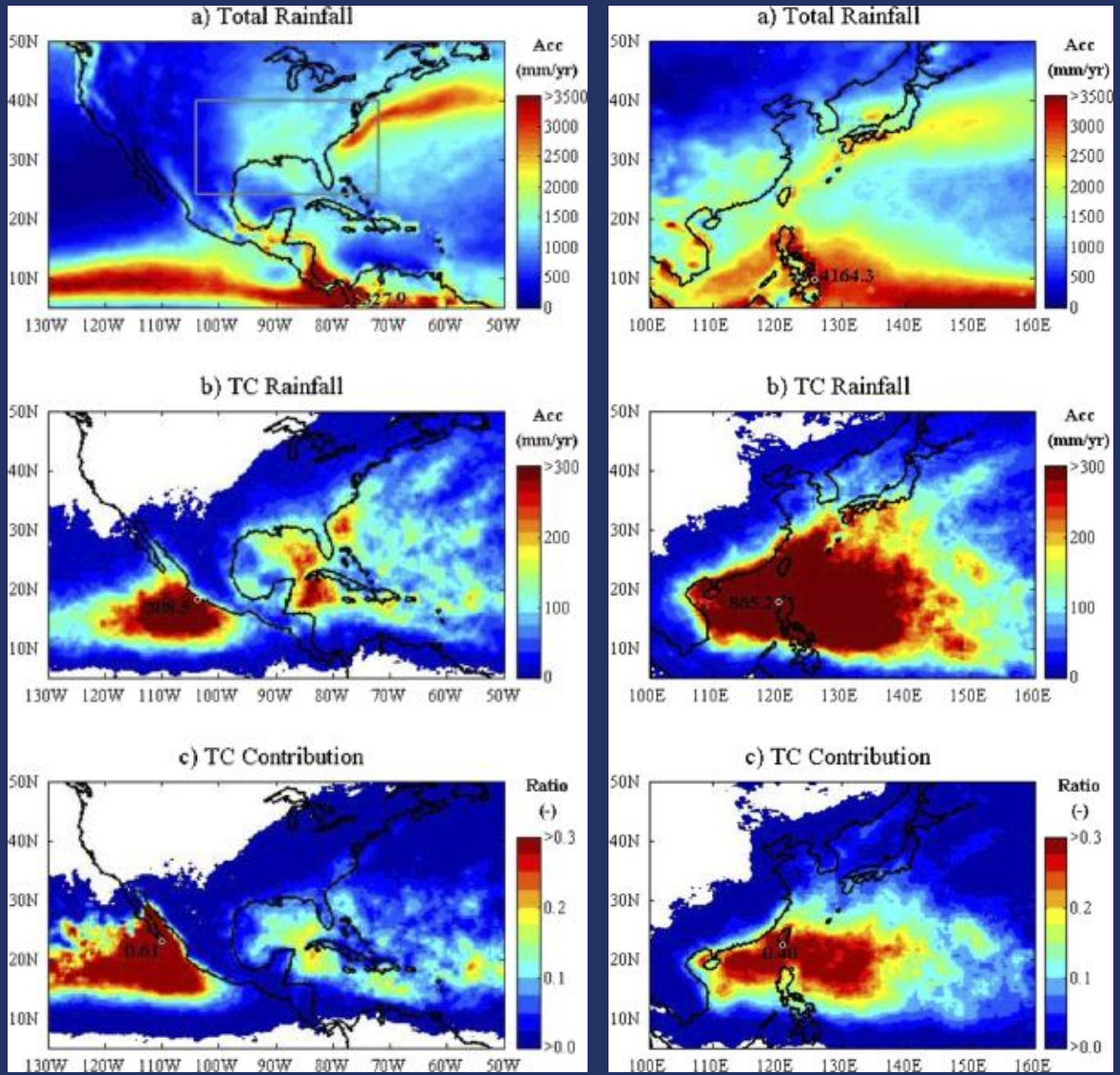
Global Annual TC Rainfall and Percent of Total Annual Rainfall (2005)



TC Rainfall Contribution 1998-2009 TRMM Multi - satellite Precipitation Analysis

Americas

Southeast Asia



Average Annual Rainfall

Average Annual TC Rainfall

TC Contribution to Annual Rainfall

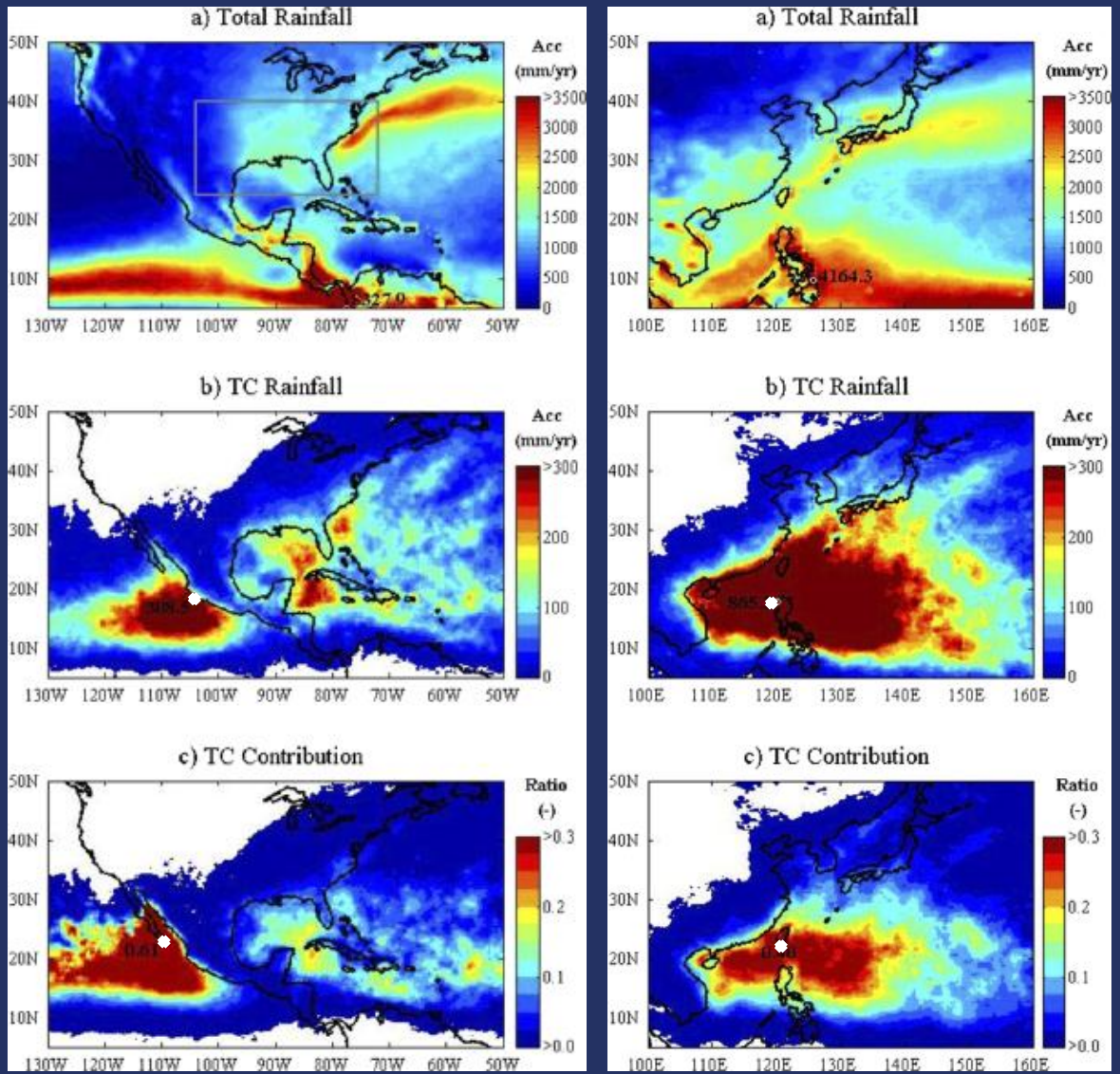
Prat and Nelson 2013

NATIONAL HURRICANE CENTER Miami, FL

TC Rainfall Contribution 1998-2009 TRMM Multi - satellite Precipitation Analysis

Americas

Southeast Asia



Average Annual Rainfall

Average Annual TC Rainfall

TC Contribution to Annual Rainfall

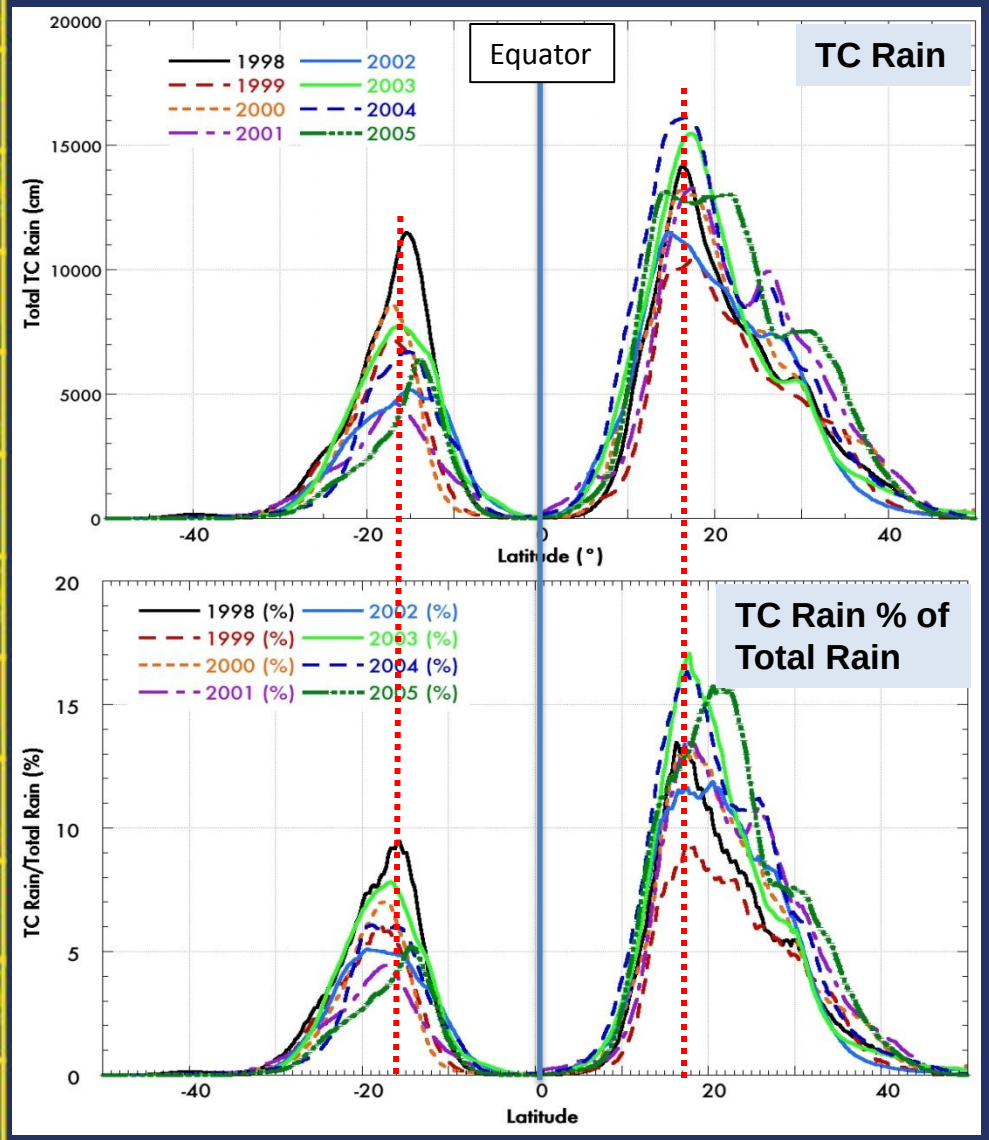
Highest Americas: 308.5 mm/yr

Asia: 865.2 mm/yr

Highest Americas: 61%

Asia: 40%

Global TC Rainfall



- TC rainfall makes up a larger percentage of total rainfall during years when global rainfall is low
- Asymmetric - generally more TC rainfall in the Northern Hemisphere
  - TCs produce 10-17% of global rain from 15-25°N
  - TCs produce 5-10% of global rain from 15-25°S

Frank Marks (HRD)

Biggest TC Rain Producers By Country/Island

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)
China (mainland)	2749.0 mm	108.21”	Carla (1967)
Cuba	2550.0 mm	100.39”	Flora (1963)
Dominica	422.3 mm	16.63”	Jeanne (2004)
Dominican Rep.	1001.5 mm	39.43”	Flora (1963)
Guadeloupe	508.0 mm	20.00”	Marilyn (1995)
Guatemala	600 mm	23.62”	Mitch (1998)
Haiti	1447.8 mm	57.00”	Flora (1963)
Honduras	912.0 mm	35.89”	Mitch (1998)
Jamaica	3429.0 mm	135.00”	November 1909 Hurricane
Repub. of Korea	898.0 mm	35.35”	Rusa (2002)
Martinique	680.7 mm	26.80”	Dorothy (1970)
Mexico	1576.0 mm	62.05”	Wilma (2005)
Nicaragua	1597.0 mm	62.87”	Mitch (1998)
Panama	695.0 mm	27.36”	Mitch (1998)
Puerto Rico	1058.7 mm	41.68”	T.D. #19 (1970)
St. Lucia	668.0 mm	26.30”	Tomas (2010)
St. Martin/Maarten	866.6 mm	34.12”	Lenny (1999)
Venezuela	339.0 mm	13.30”	Brett (1993)

Original Source: David Roth HPC (2006)

NATIONAL HURRICANE CENTER MIAMI FL

Biggest TC Rain Producers By Country/Island

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NATIONAL HURRICANE CENTER MIAMI FL

Characteristics of TC Precipitation

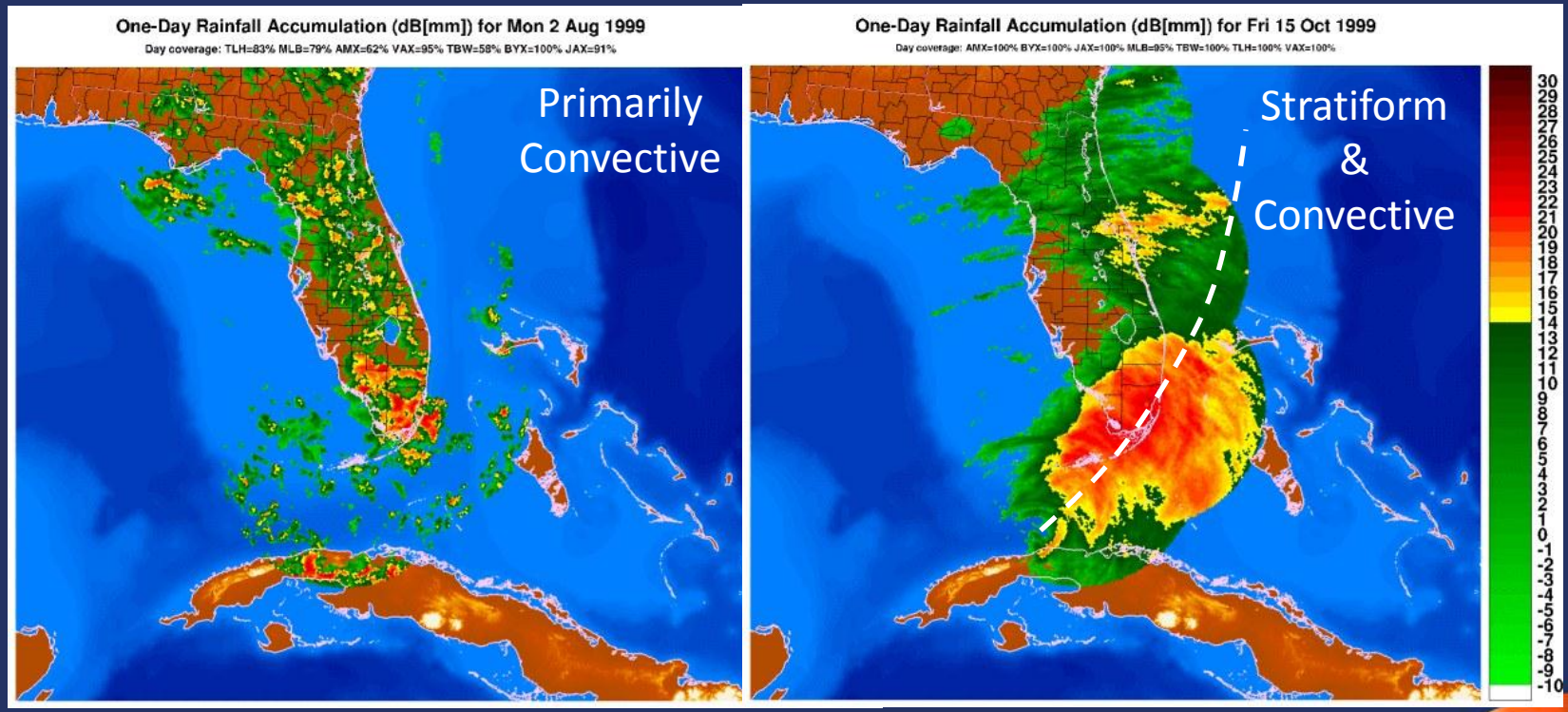
Stratiform and Convective Mechanisms

Stratiform Rain ~50% of Total Rain from TC

NOAA/HRD - Daily Radar Rainfall Estimate Study

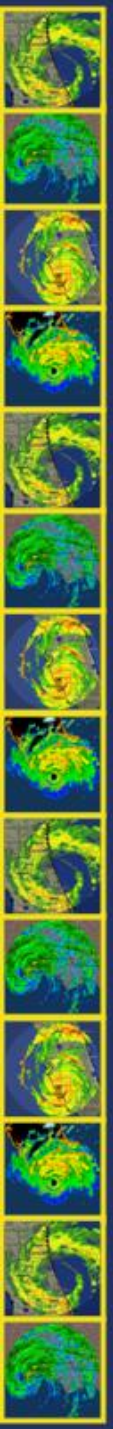
Typical warm season 1-day total

Hurricane Irene 1-day total



Hurricane Irene (15 October 1999)

Frank Marks (HRD)



Factors Influencing Tropical Cyclone Rainfall

What Factors Influence Rainfall from Tropical Cyclones?

- Movement – slow forward motion can produce more rain
- Storm size – the larger the storm, the greater the area typically receiving rain
- Storm track – factor in the location of the rain
- Diurnal cycle – heaviest rainfall generally near the storm center overnight, outer band rainfall during the day
- Topography – enhances rainfall in upslope areas, but decreases rainfall past the spine of the mountains
- Moisture – Entrainment of dry air can redistribute and/or reduce the amount of precipitation; increased moisture can increase rainfall
- Interaction with other meteorological features (troughs, fronts, jets) and extratropical transition can greatly modify rainfall distribution

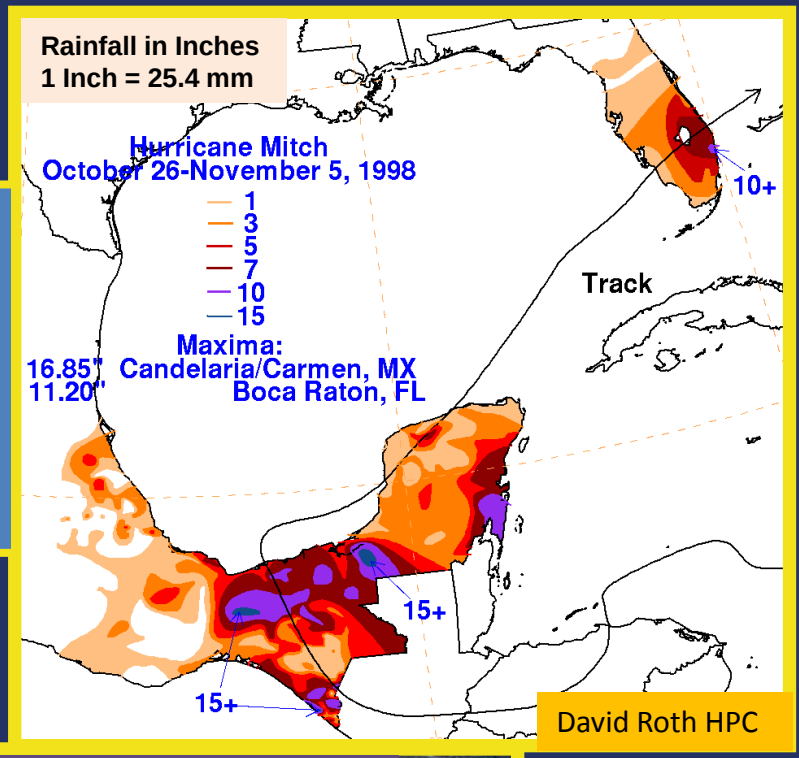
NATIONAL HURRICANE CENTER MIAMI FL

Factors Influencing TC Rainfall

Storm Motion

- Slow vs. fast moving TCs
- TCs with a turning or looping track vs. straight mover

Hurricane Mitch fatalities:
Honduras: 5,677
Nicaragua: 2,863
Guatemala: 258
El Salvador: 239

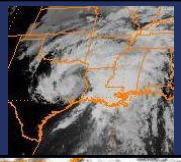
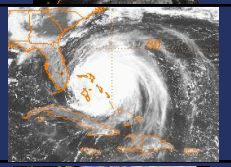
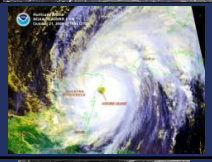
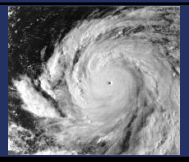


David Roth HPC

Factors Influencing TC Rainfall

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

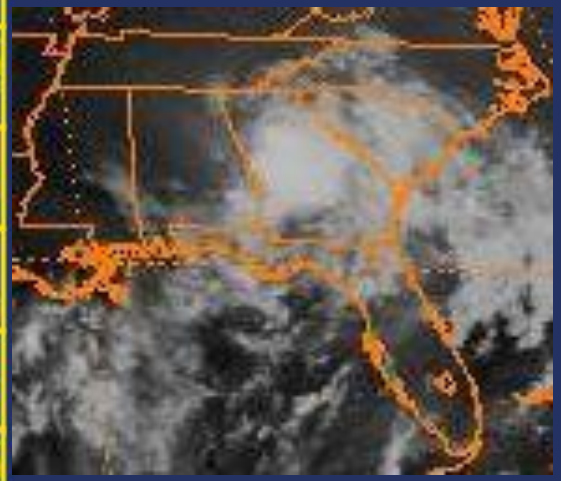
Factors Influencing TC Rainfall

Time of Day

Alberto, July 4-5, 1994

04/18z

00z



05/06z

12z

18z

NATIONAL HURRICANE CENTER
Miami, FL

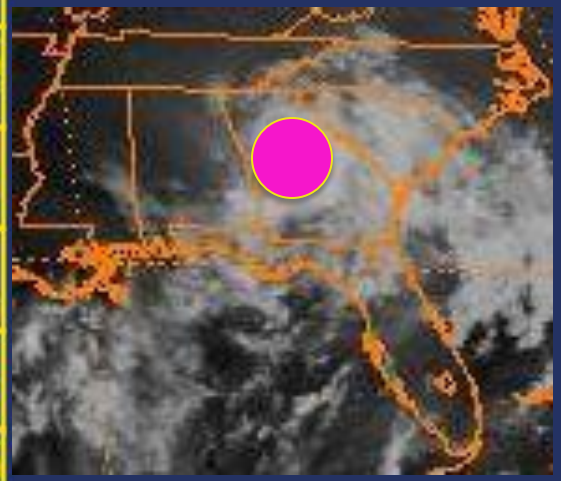
Factors Influencing TC Rainfall

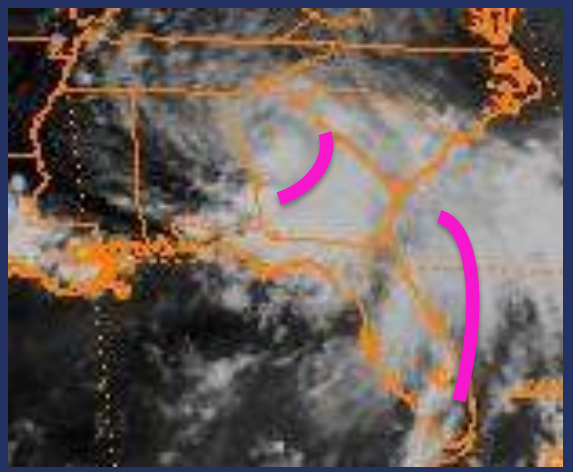
Time of Day

Alberto, July 4-5, 1994

04/18z

00z





05/06z

12z

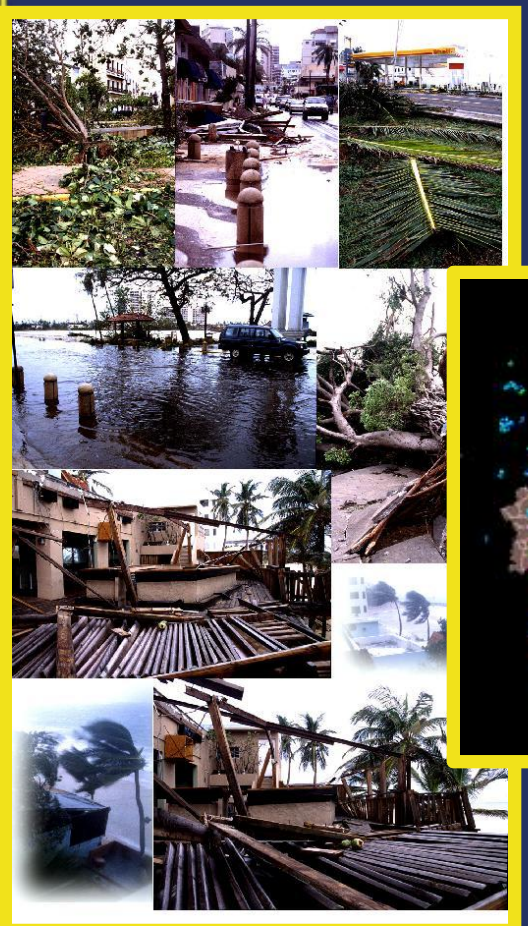
18z

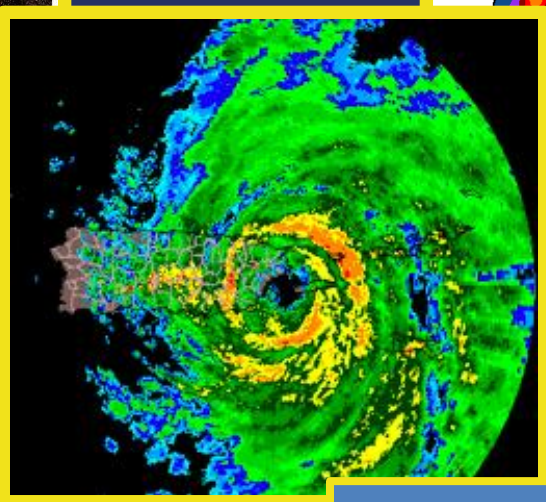
NATIONAL HURRICANE CENTER
MIAMI FL

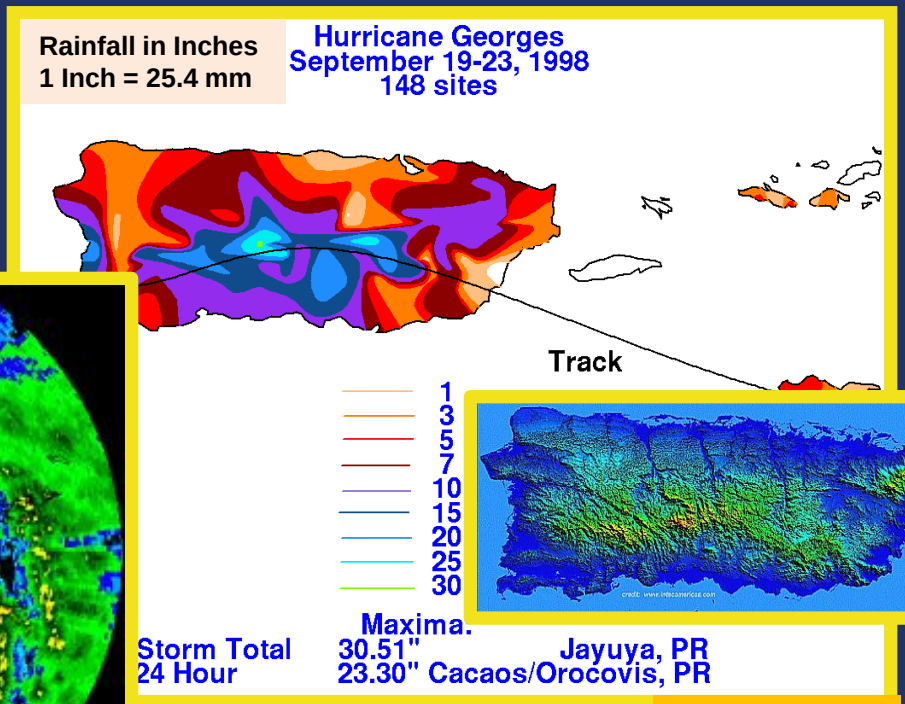
Factors Influencing TC Rainfall

Terrain Impacts

Heaviest rainfall favors mountains perpendicular to the wind







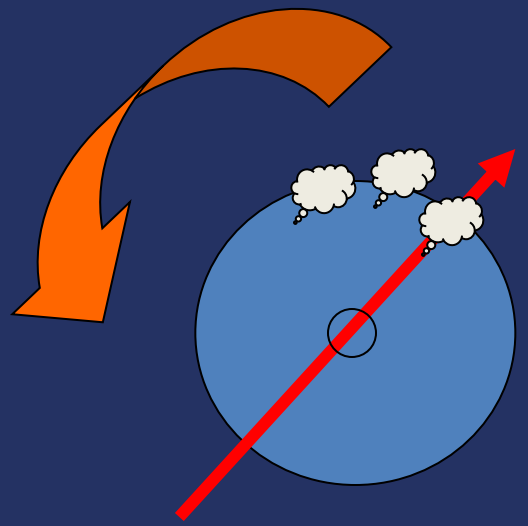
David Roth HPC

Hurricane Georges in Puerto Rico
$1.75 billion in damage
28,005 homes destroyed

Factors Influencing TC Rainfall

Vertical Wind Shear

- Heaviest rain tends to fall left and downwind of the shear vector in the Northern Hemisphere
- If the shear is strong enough, all rainfall may move away from the center (exposed center)



Factors Influencing TC Rainfall

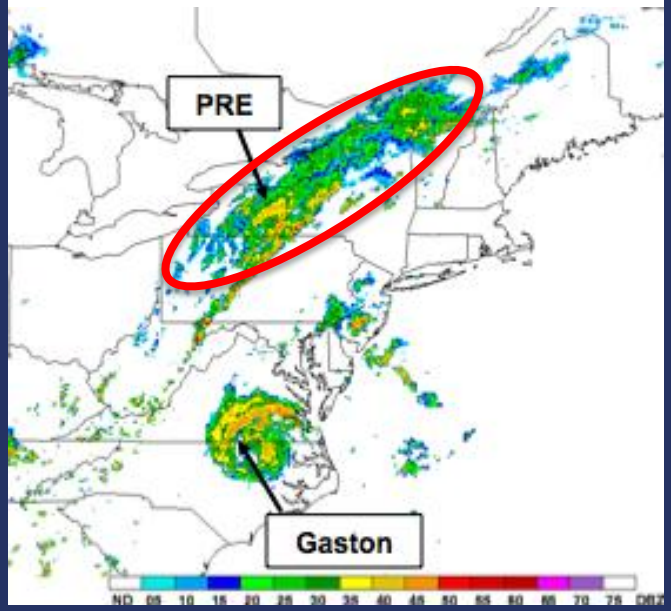
Environmental Steering in Northern Hemisphere

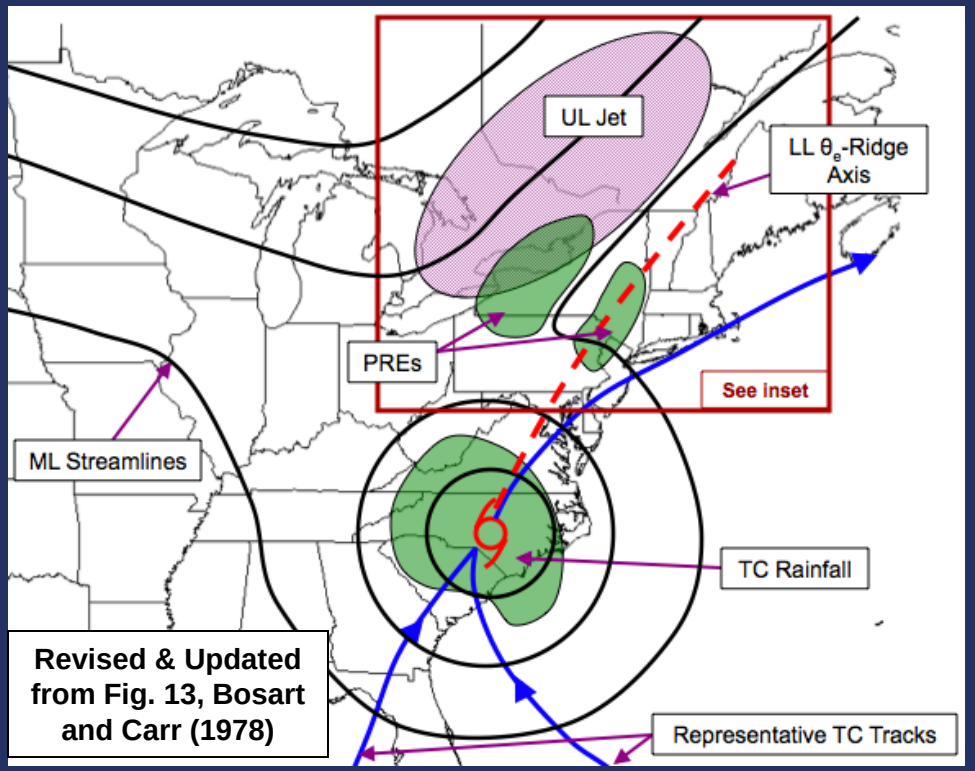
- TCs that move into a break in the subtropical ridge often produce most of the rain *right* of their track
- TCs that recurve due to significant upper troughs in the westerlies often produce most of their rain *left* of their track
  - Rainfall may spread well in advance of the TC due to interaction with the upper jet on the leading edge of the trough
- Very slow moving TCs and symmetrical TCs produce the most rainfall *near the center*
  - Usually cyclical with maximum rainfall at night

Factors Influencing TC Rainfall

Predecessor Rainfall Events

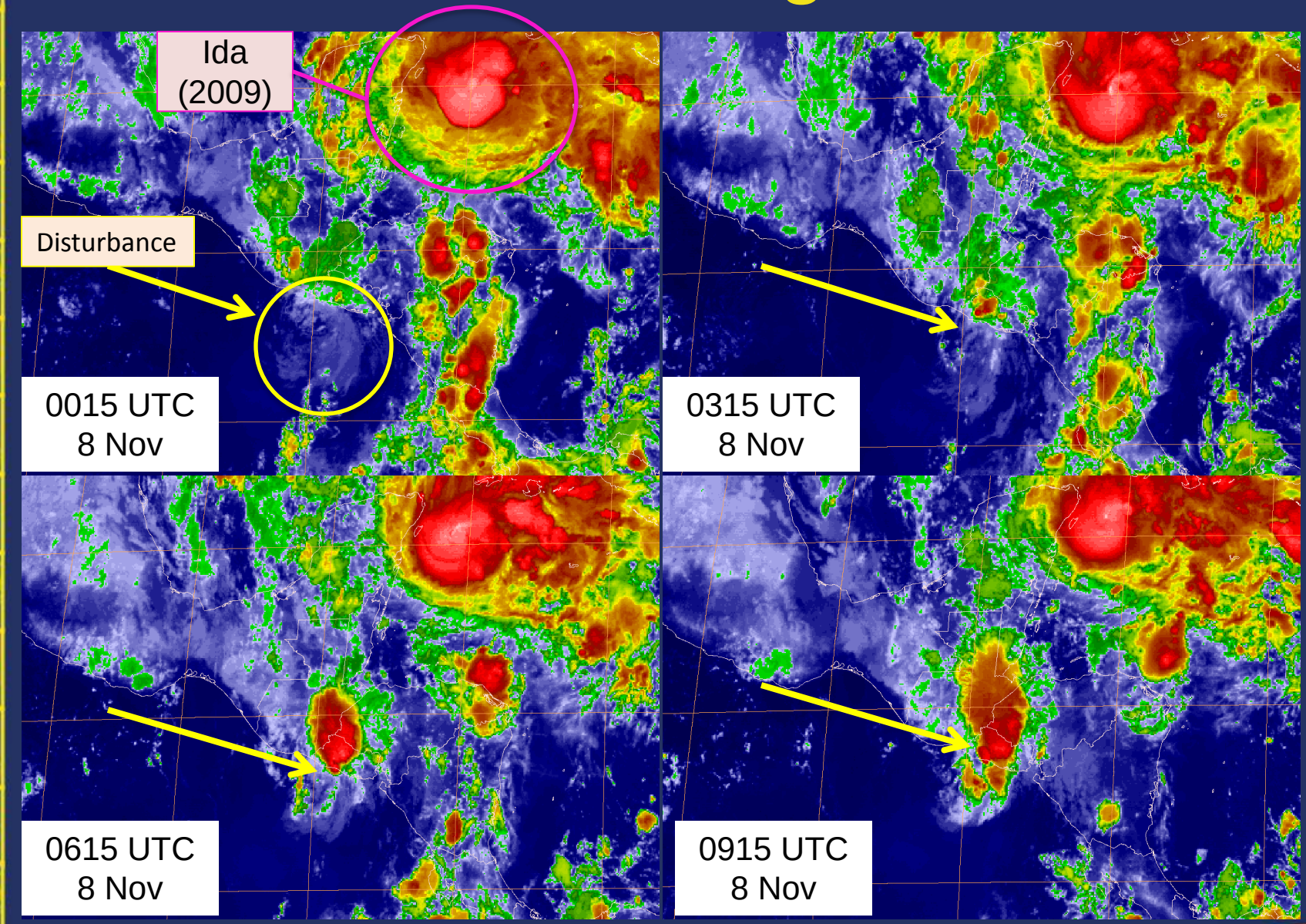
Predecessor Rainfall Event (PRE)
Image from Matt Cote and Lance Bosart – SUNY Albany





- Moisture transport well ahead of TC itself
- Coherent area of rain displaced north of the TC (near a front or over terrain)
- Maximum rainfall rates can exceed 200 mm in 24 hr
- Occurs for approximately 1 of 3 landfalling TCs in U.S.

Factors Influencing TC Rainfall



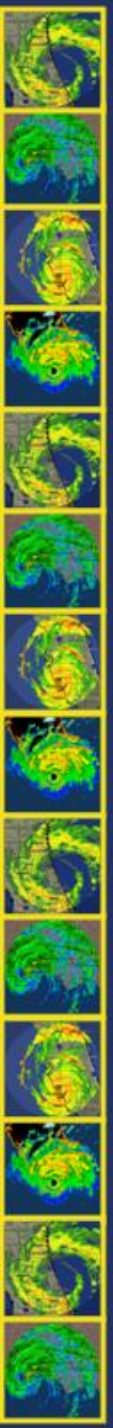
"Twin" Disturbance or Other Secondary Features

Where is Flooding from Tropical Cyclones Likely to Occur?

- Areas where the ground is already saturated (low flash flood guidance values)
- Valleys/watersheds
- Areas of terrain enhancement
- Areas with poor drainage or prone to runoff
- Areas with directed drainage that can be overwhelmed

Costa Rica stream flooding

Clear Cut Areas in Haiti



TC Rainfall Forecasting Tools

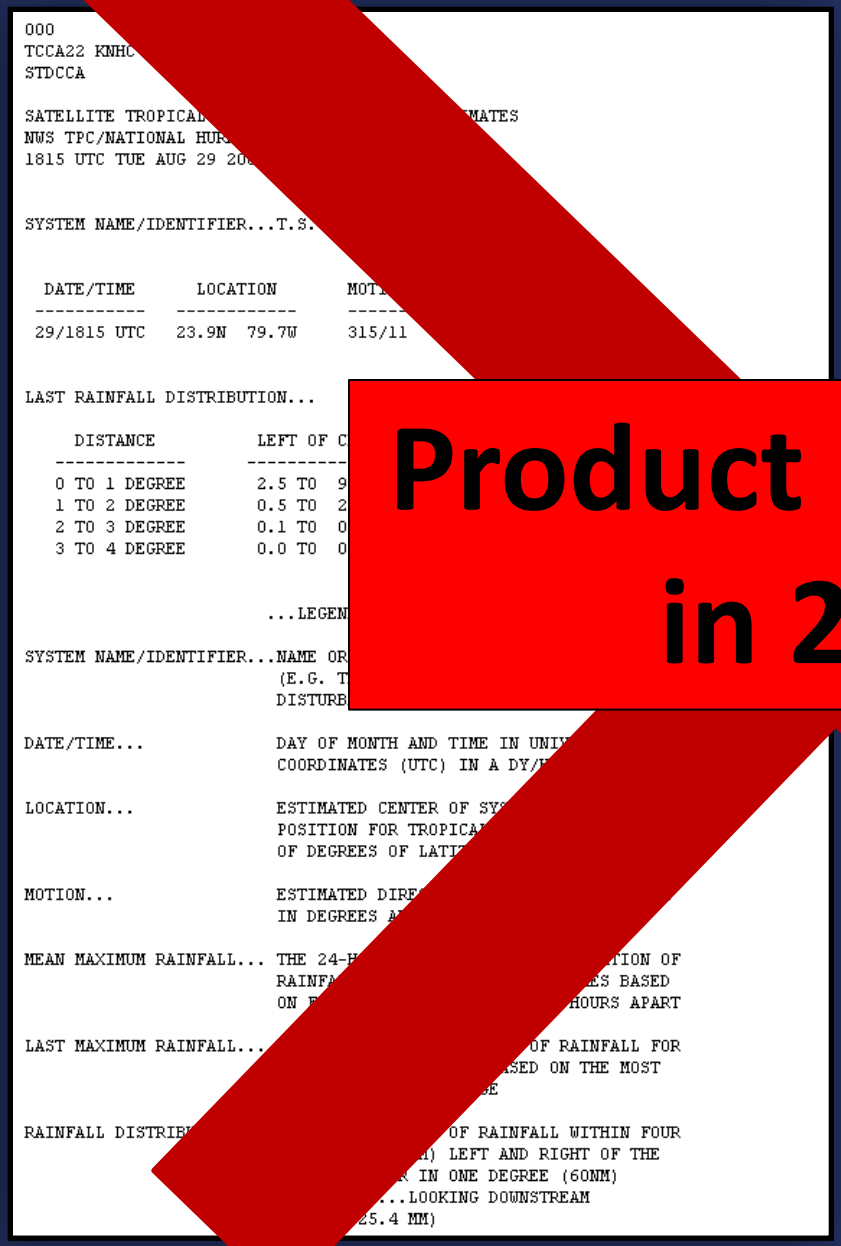
NHC Satellite Tropical Disturbance Rainfall Estimates

```
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)
```

TCCA Products

- Estimate rainfall rates for tropical cyclones based on the cloud top temperature data acquired using infrared satellite imagery (Griffith-Woodley technique)
- Uses the infrared imagery to determine the size of the area receiving rain
- Calculates a maximum or “core” rainfall amount
- Apportions the rainfall into a distribution where 50% of the total area average rainfall occurs in the coldest 10% of the cloud top area.

NHC Satellite Tropical Disturbance Rainfall Estimates



Product Replaced in 2013

TCCA Products

- Estimates for tropical cyclones in the cloud top temperature acquired using infrared satellite imagery (Griffith-
- imagery to of the area
- um or "core" mount
- the rainfall into a dis here 50% of the total area a fall occurs in the coldest cloud top area.

NATIONAL HURRICANE CENTER Miami, FL

Changes to NHC Rainfall Product

Limitation of old product:

Rainfall is not physically related to cloud-top temperature (IR)

Improvements:

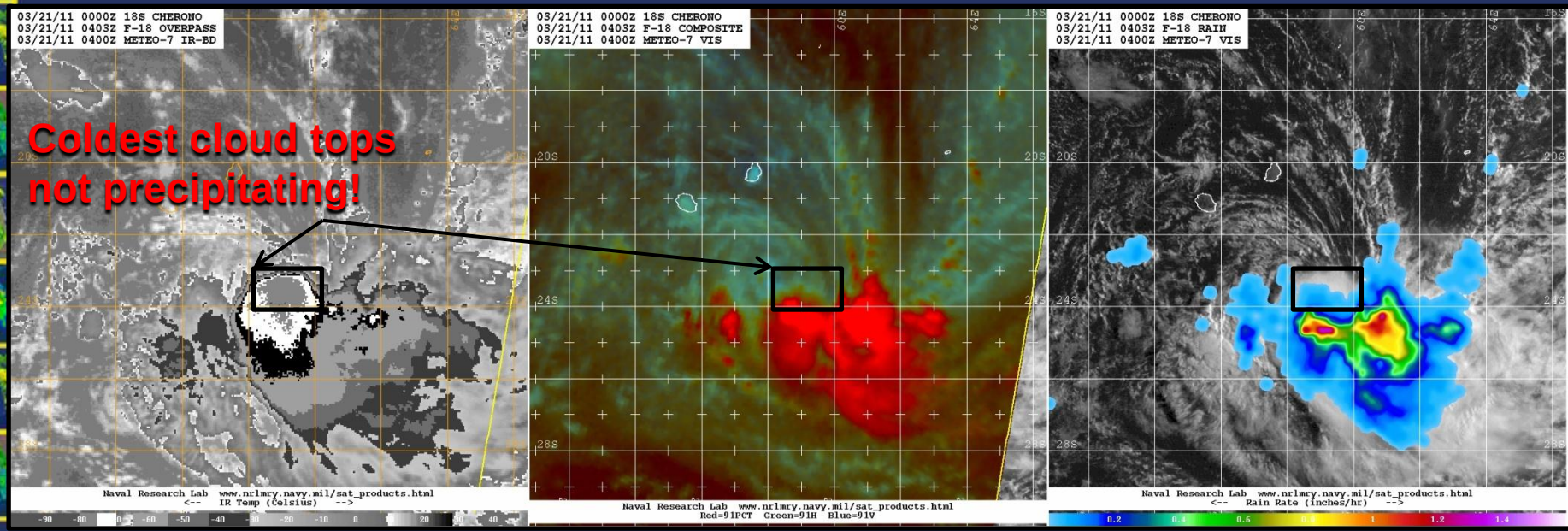
Incorporate microwave (MW) satellite data (rainfall rates)

- NHC uses two different merged satellite rainfall estimation techniques to replace the IR-only method:
  - NRL-Blend and QMORPH incorporate available MW data and propagate precipitation forward in time via IR
  - Training on the NRL-Blend technique:

    http://www.nrlmry.navy.mil/training-bin/training.cgi
- As a third product, NHC uses an old GFS forecast, or GFS "hindcast":
  - A model forecast has the advantage of dynamics, topography, moisture, etc.

NHC Rainfall Product: Why Microwave?

- Geostationary IR data provides excellent spatiotemporal resolution, but is not optimal for rain estimation
- Microwave provides improved rainfall accuracy but at low temporal resolution
- Recently-developed quantitative precipitation estimate (QPE) products leverage each method's strength…



Experimental NHC Rainfall Product: Text

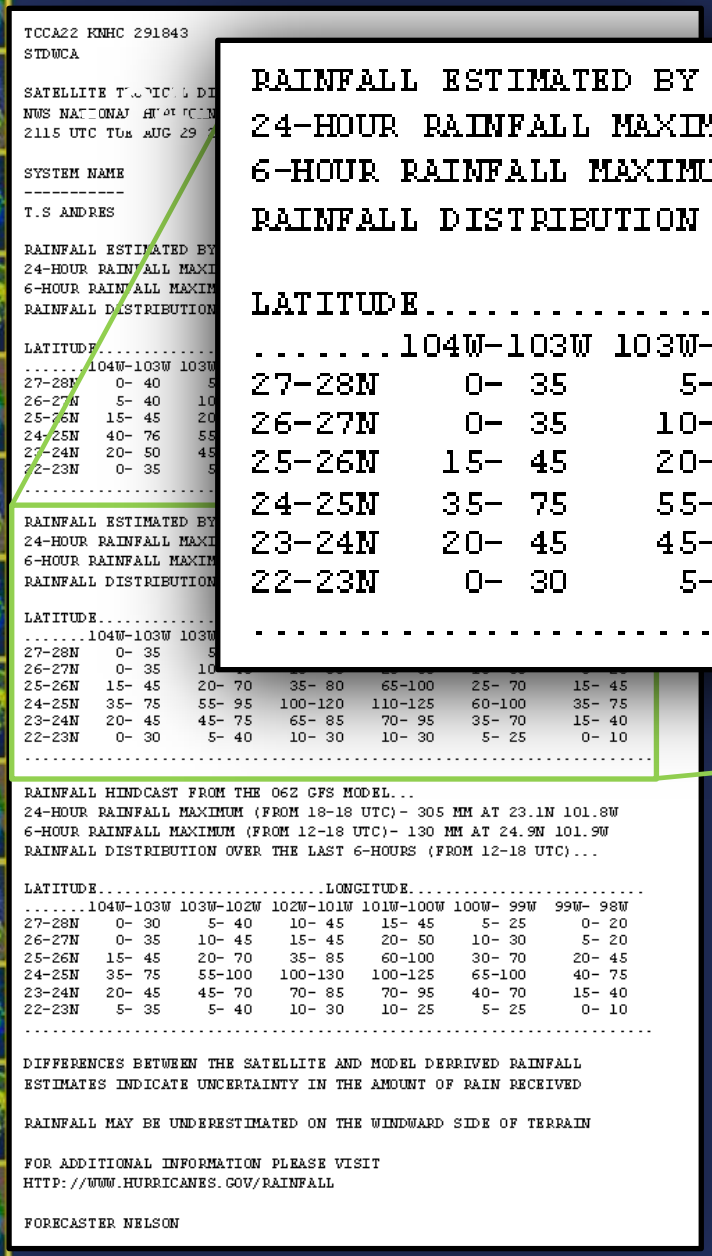
```
TCCA22 KNHC 291843
STDWCA

SATELLITE TROPICAL DISTURBANCE RAINFALL ESTIMATES
NWS NATIONAL HURRICANE CENTER MIAMI FL
2115 UTC TUE AUG 29 2009

SYSTEM NAME                    DATE/TIME          LOCATION
-----------                    ---------          --------
T.S ANDRES                     29/1800 UTC        17.2N 102.3W

RAINFALL ESTIMATED BY SATELLITE VIA QMORPH...
24-HOUR RAINFALL MAXIMUM (FROM 18-18 UTC)- 235 MM AT 23.3N  99.2W
6-HOUR RAINFALL MAXIMUM (FROM 12-18 UTC)- 150 MM AT 24.2N 100.5W
RAINFALL DISTRIBUTION IN MM OVER THE LAST 6-HOURS (FROM 12-18 UTC)...

LATITUDE.........................LONGITUDE.........................
.......104W-103W 103W-102W 102W-101W 101W-100W 100W- 99W  99W- 98W
27-28N     0- 40      5- 40     10- 45     10- 45     10- 30      0- 20
26-27N     5- 40     10- 45     15- 55     20- 50     15- 30      5- 20
25-26N    15- 45     20- 70     35- 85     60-100     30- 70     20- 45
24-25N    40- 76     55-100    100-130    110-150     60-100     40- 75
23-24N    20- 50     45- 70     70- 90     70- 95     40- 65     15- 40
22-23N     0- 35      5- 40     10- 30     10- 25      5- 25      0- 10
.....................................................................

RAINFALL ESTIMATED BY SATELLITE VIA NRL-BLEND.
24-HOUR RAINFALL MAXIMUM (FROM 18-18 UTC)- 295 MM AT 23.3N  98.7W
6-HOUR RAINFALL MAXIMUM (FROM 12-18 UTC)- 125 MM AT 24.6N 100.2W
RAINFALL DISTRIBUTION IN MM OVER THE LAST 6-HOURS (FROM 12-18 UTC)...

LATITUDE.........................LONGITUDE.........................
.......104W-103W 103W-102W 102W-101W 101W-100W 100W- 99W  99W- 98W
27-28N     0- 35      5- 40     10- 45     10- 45      5- 25      0- 20
26-27N     0- 35     10- 45     15- 50     20- 50     10- 30      5- 20
25-26N    15- 45     20- 70     35- 80     65-100     25- 70     15- 45
24-25N    35- 75     55- 95    100-120    110-125     60-100     35- 75
23-24N    20- 45     45- 75     65- 85     70- 95     35- 70     15- 40
22-23N     0- 30      5- 40     10- 30     10- 30      5- 25      0- 10
.....................................................................

RAINFALL HINDCAST FROM THE 06Z GFS MODEL.
24-HOUR RAINFALL MAXIMUM (FROM 18-18 UTC)- 305 MM AT 23.1N 101.8W
6-HOUR RAINFALL MAXIMUM (FROM 12-18 UTC)- 130 MM AT 24.9N 101.9W
RAINFALL DISTRIBUTION OVER THE LAST 6-HOURS (FROM 12-18 UTC)...

LATITUDE.........................LONGITUDE.........................
.......104W-103W 103W-102W 102W-101W 101W-100W 100W- 99W  99W- 98W
27-28N     0- 30      5- 40     10- 45     15- 45      5- 25      0- 20
26-27N     0- 35     10- 45     15- 45     20- 50     10- 30      5- 20
25-26N    15- 45     20- 70     35- 85     60-100     30- 70     20- 45
24-25N    35- 75     55-100    100-130    100-125     65-100     40- 75
23-24N    20- 45     45- 70     70- 85     70- 95     40- 70     15- 40
22-23N     5- 35      5- 40     10- 30     10- 25      5- 25      0- 10
.....................................................................

DIFFERENCES BETWEEN THE SATELLITE AND MODEL DERRIVED RAINFALL
ESTIMATES INDICATE UNCERTAINTY IN THE AMOUNT OF RAIN RECEIVED

RAINFALL MAY BE UNDERESTIMATED ON THE WINDWARD SIDE OF TERRAIN

FOR ADDITIONAL INFORMATION PLEASE VISIT
HTTP://WWW.HURRICANES.GOV/RAINFALL

FORECASTER NELSON
```

Rainfall product still available in text format like the old product

Differences in content and format compared to the old product:

- **6-hour quantitative precipitation estimates from 3 methods**
  - **Presented as a range of rainfall within a 1ºx1º box**
  - **Covers total area of 6ºx6º centered near disturbance**
- **Earth-relative coordinates (i.e. no reference to “left-of-center”/”right of center”)**

Experimental NHC Rainfall Product: Text



TCCA22 KNHC 291843
STDWCA

SATELLITE T...
NWS NATIONAL ...
2115 UTC TUE AUG 29 ...

SYSTEM NAME

T.S ANDRES

RAINFALL ESTIMATED BY ...
24-HOUR RAINFALL MAXI...
6-HOUR RAINFALL MAXIM...
RAINFALL DISTRIBUTION...

LATITUDE.....
.....104W-103W 103W...
27-28N 0- 40 5...
26-27N 5- 40 10...
25-26N 15- 45 20...
24-25N 40- 76 55...
23-24N 20- 50 45...
22-23N 0- 35 5...
.....

RAINFALL ESTIMATED BY ...
24-HOUR RAINFALL MAXI...
6-HOUR RAINFALL MAXIM...
RAINFALL DISTRIBUTION...

LATITUDE.....
.....104W-103W 103W...
27-28N 0- 35 5...
26-27N 0- 35 10...
25-26N 15- 45 20- 70 35- 80 65-100 25- 70 15- 45
24-25N 35- 75 55- 95 100-120 110-125 60-100 35- 75
23-24N 20- 45 45- 75 65- 85 70- 95 35- 70 15- 40
22-23N 0- 30 5- 40 10- 30 10- 30 5- 25 0- 10
.....

RAINFALL HINDCAST FROM THE 06Z GFS MODEL...
24-HOUR RAINFALL MAXIMUM (FROM 18-18 UTC)- 305 MM AT 23.1N 101.8W
6-HOUR RAINFALL MAXIMUM (FROM 12-18 UTC)- 130 MM AT 24.9N 101.9W
RAINFALL DISTRIBUTION OVER THE LAST 6-HOURS (FROM 12-18 UTC)...

LATITUDE.....LONGITUDE.....
.....104W-103W 103W-102W 102W-101W 101W-100W 100W- 99W 99W- 98W
27-28N 0- 30 5- 40 10- 45 15- 45 5- 25 0- 20
26-27N 0- 35 10- 45 15- 45 20- 50 10- 30 5- 20
25-26N 15- 45 20- 70 35- 85 60-100 30- 70 20- 45
24-25N 35- 75 55-100 100-130 100-125 65-100 40- 75
23-24N 20- 45 45- 70 70- 85 70- 95 40- 70 15- 40
22-23N 5- 35 5- 40 10- 30 10- 25 5- 25 0- 10
.....

DIFFERENCES BETWEEN THE SATELLITE AND MODEL DERRIVED RAINFALL
ESTIMATES INDICATE UNCERTAINTY IN THE AMOUNT OF RAIN RECEIVED

RAINFALL MAY BE UNDERESTIMATED ON THE WINDWARD SIDE OF TERRAIN

FOR ADDITIONAL INFORMATION PLEASE VISIT
HTTP://WWW.HURRICANES.GOV/RAINFALL

FORECASTER NELSON

RAINFALL ESTIMATED BY SATELLITE VIA NRL-BLEND...
24-HOUR RAINFALL MAXIMUM (FROM 18-18 UTC)- 295 MM AT 23.3N 98.7W
6-HOUR RAINFALL MAXIMUM (FROM 12-18 UTC)- 125 MM AT 24.6N 100.2W
RAINFALL DISTRIBUTION IN MM OVER THE LAST 6-HOURS (FROM 12-18 UTC)...

LATITUDE.....LONGITUDE.....

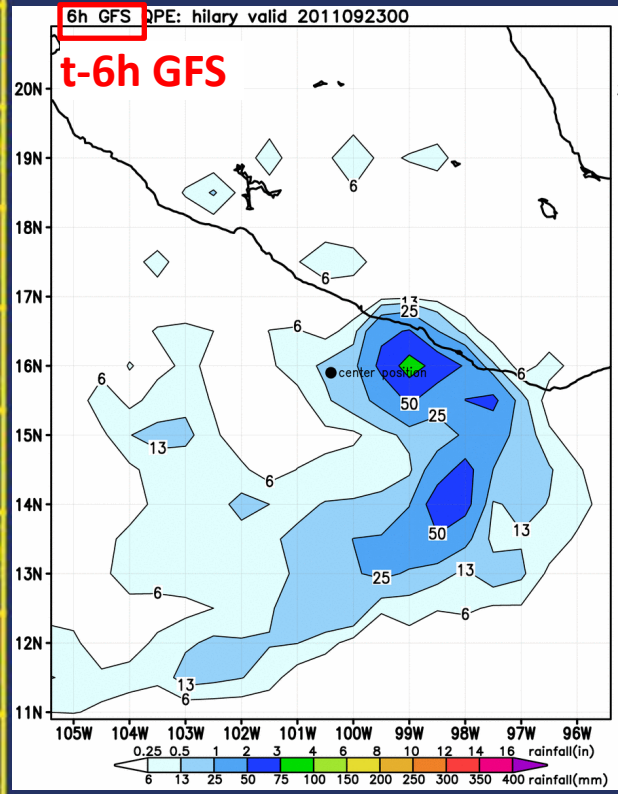
.....104W-103W	103W-102W	102W-101W	101W-100W	100W- 99W	99W- 98W
27-28N 0- 35	5- 40	10- 45	10- 45	5- 25	0- 20
26-27N 0- 35	10- 45	15- 50	20- 50	10- 30	5- 20
25-26N 15- 45	20- 70	35- 80	65-100	25- 70	15- 45
24-25N 35- 75	55- 95	100-120	110-125	60-100	35- 75
23-24N 20- 45	45- 75	65- 85	70- 95	35- 70	15- 40
22-23N 0- 30	5- 40	10- 30	10- 30	5- 25	0- 10

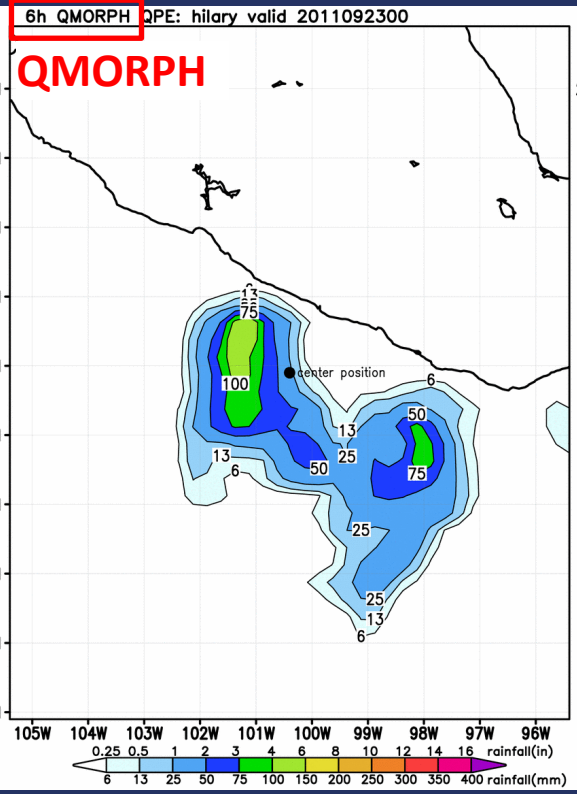
.....

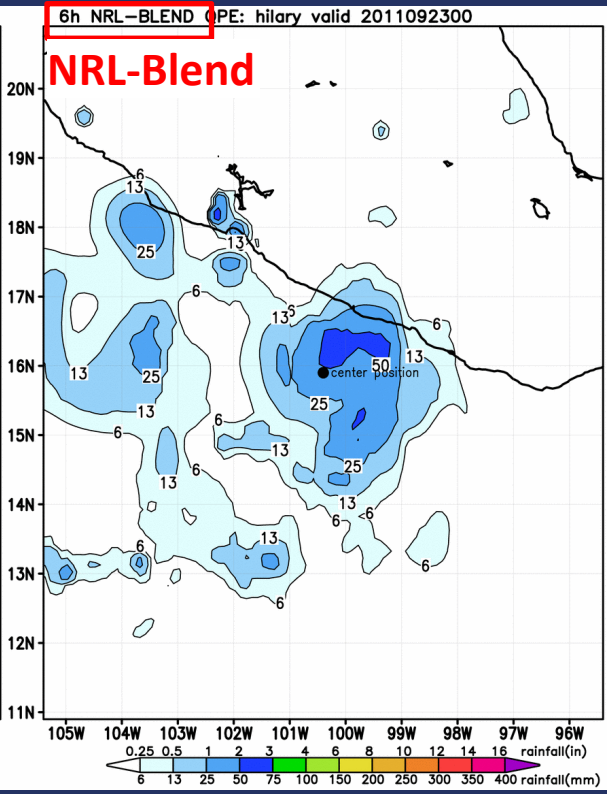
- Lat-lon grid of rainfall accumulation
- 6-h accumulation ranges (in mm)
- Differences in the 3 rainfall estimates reveal uncertainty

Experimental NHC Rainfall Product: QPE Graphics

6-hour quantitative precipitation *estimates* from 3 methods:





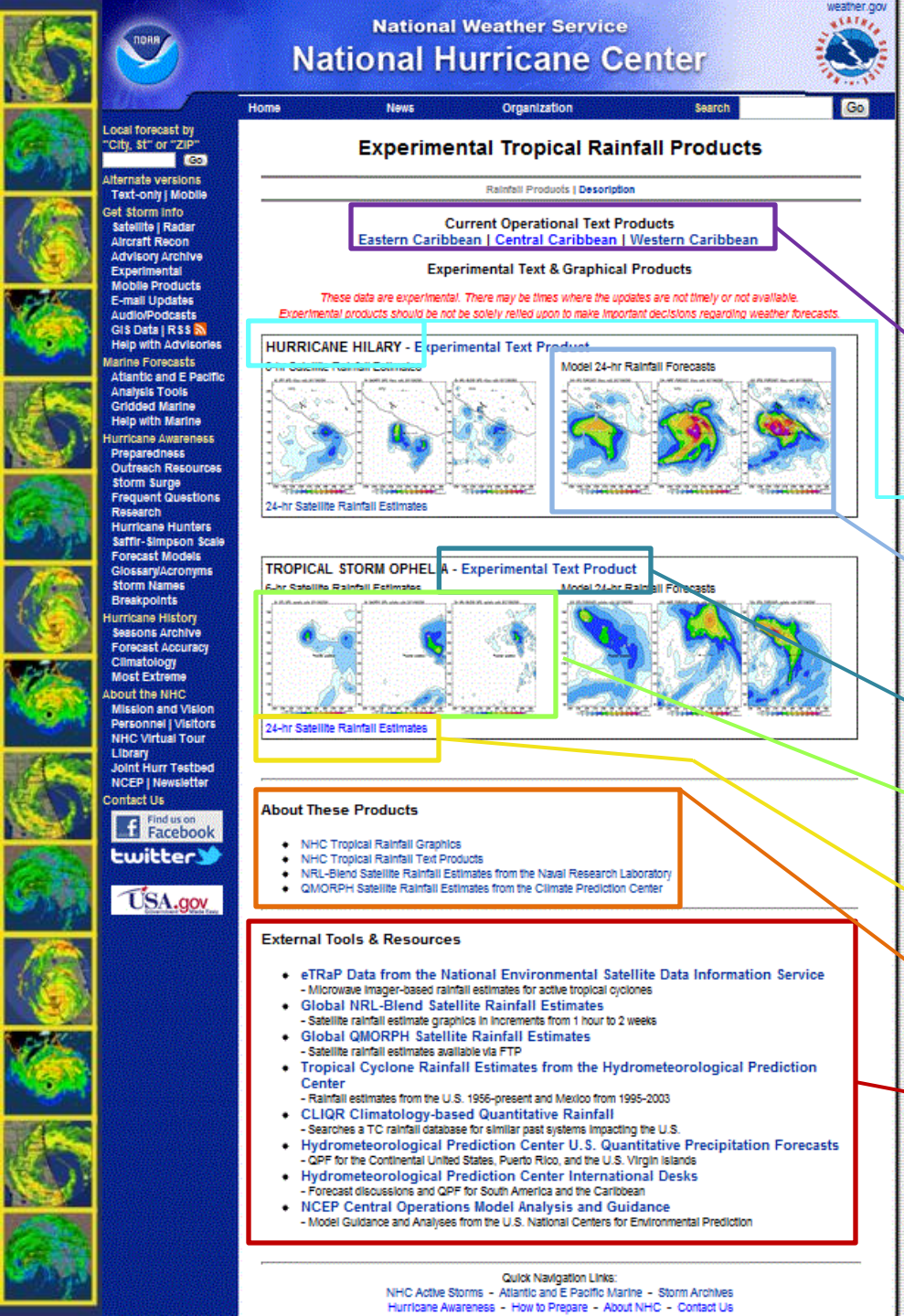


These 6-hour QPE graphics correspond to the values in the tables in the text product.

24-hour quantitative precipitation estimate graphics are also available.

New NHC Rainfall Webpage

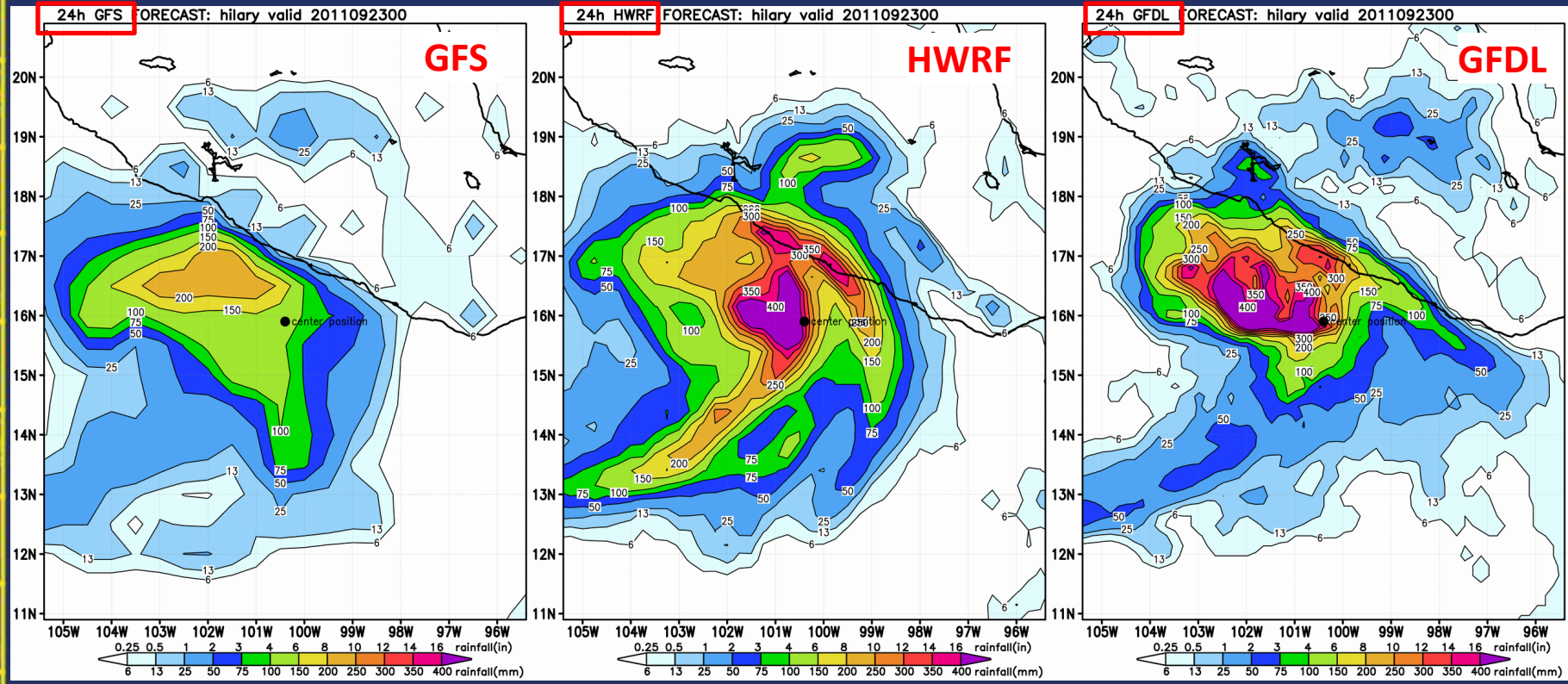
http://www.nhc.noaa.gov/experimental/rainfall/



- Links to the “old” text product
- Tropical cyclone or disturbance identifier
- 24-hr model quantitative precipitation forecast (QPF) graphics
- Link to the “new” text product
- 6-hour quantitative precipitation estimate (QPE) graphics
- Link to 24-hour QPE graphics
- Product descriptions
- Other tropical rainfall tools and resources

Experimental NHC Rainfall Product: QPF Graphic

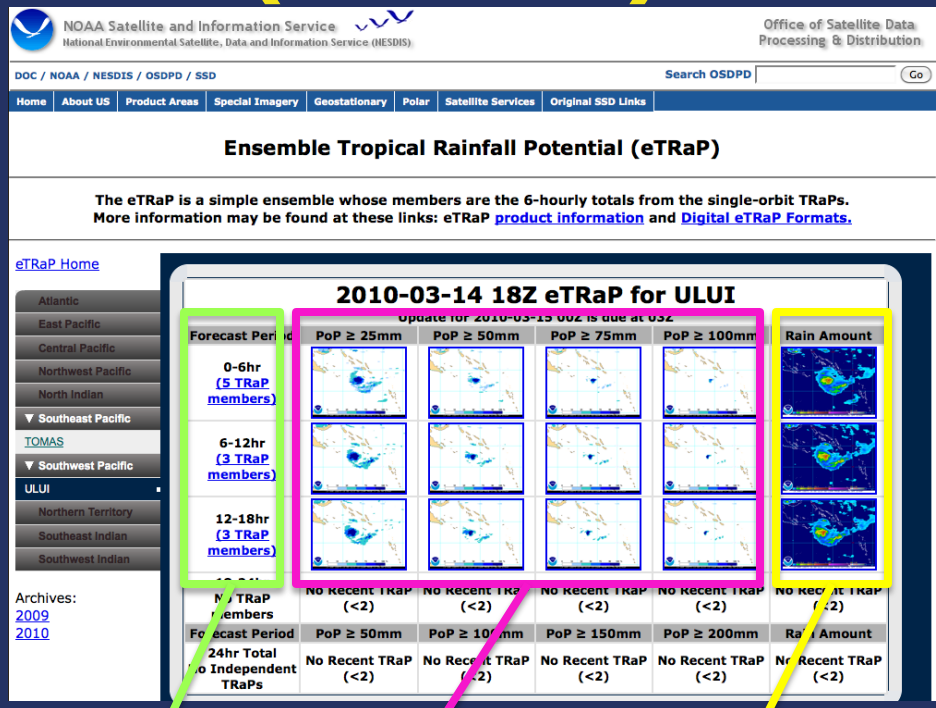
24-hour quantitative precipitation *forecasts* from 3 models:



Ensemble Tropical Rainfall Potential Product (eTRaP)

- 6-hourly Day 1 forecasts: Extrapolates polar orbiting satellite rain rate along TC forecast tracks

  (AMSU, TRMM, SSMI, & AMSRE)
- A satellite "member" is included when its path passes over the TC
- "Members" are weighted according to age of pass and past performance of sensor
- Official forecast of TC track & at least 2 members needed to create a forecast
- Updated daily at 0315, 0915, 1515, and 2115 UTC



Forecast Period

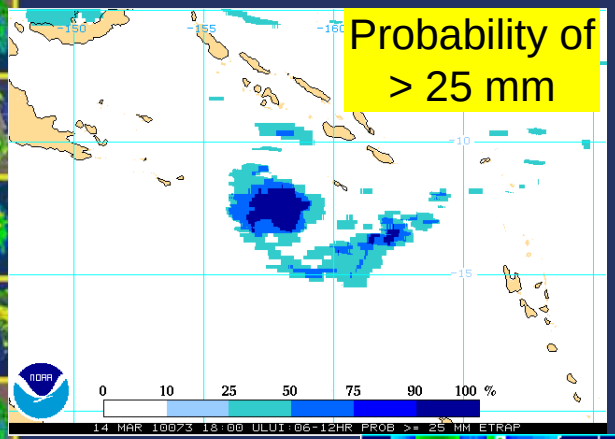
Probability of excedence

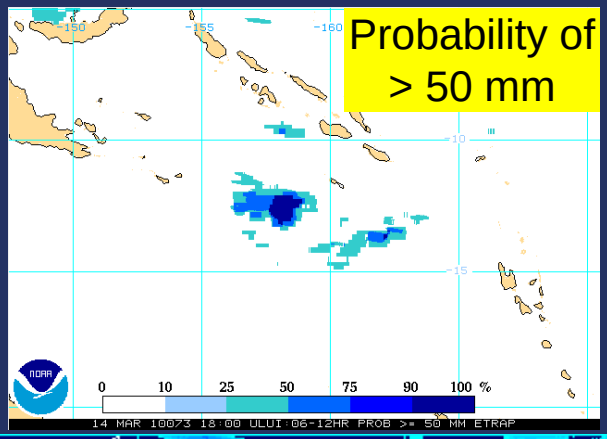
Quantitative Precipitation Forecast

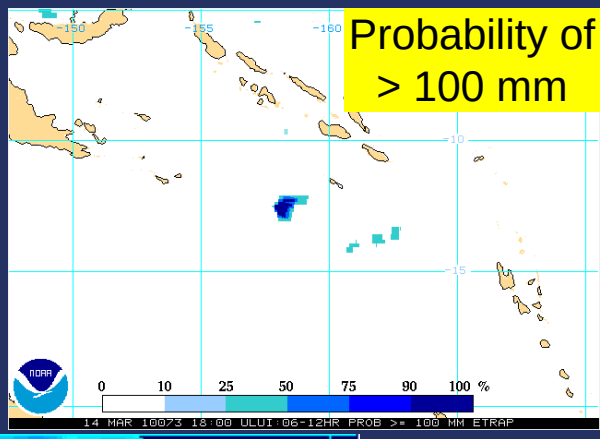
http://www.ssd.noaa.gov/PS/TROP/etrap.html

NATIONAL HURRICANE CENTER MIAMI FL

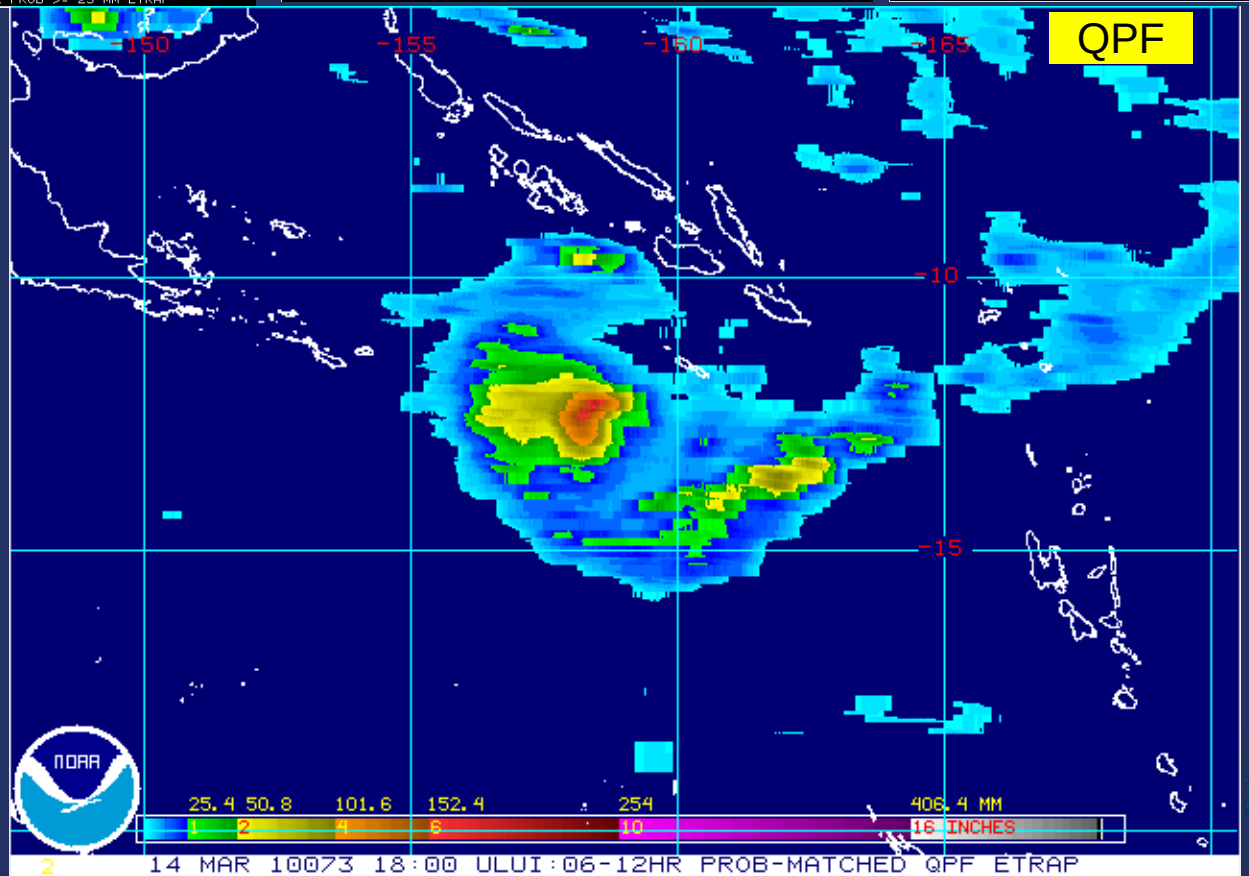
eTRaP: http://www.ssd.noaa.gov/PS/TROP/etrap.html







Typhoon Ului
06-12 hr
eTRaP
forecast



CLIQR: Picking an Analog for a TC Rainfall Event

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

- Look at the current rain shield size and compare it to TCs from the past
- How fast is the TC moving?
- Vertical wind shear in current/past events?
- Look for storms with similar or parallel tracks
- Is topography a consideration?
- Look for nearby fronts and examine the depth of nearby upper troughs for current event and possible analogs
- Not all TC events will have a useful analog

Tropical Cyclone Rainfall Data

http://www.wpc.ncep.noaa.gov/tropical/rain/tcrainfall.html

Tropical Cyclone Rainfall Data

This page is under construction...so new information will be added as time allows. Data is available for tropical and subtropical cyclones that impacted the U.S. from 1963 onward to the present, and Mexico between 1995 and 2003, as well as some older historic storms. The image of Hurricane Floyd shown to the left was provided by the Operational Satellite Events Imagery web page of NOAA. Please select the page of your choice from the following list.

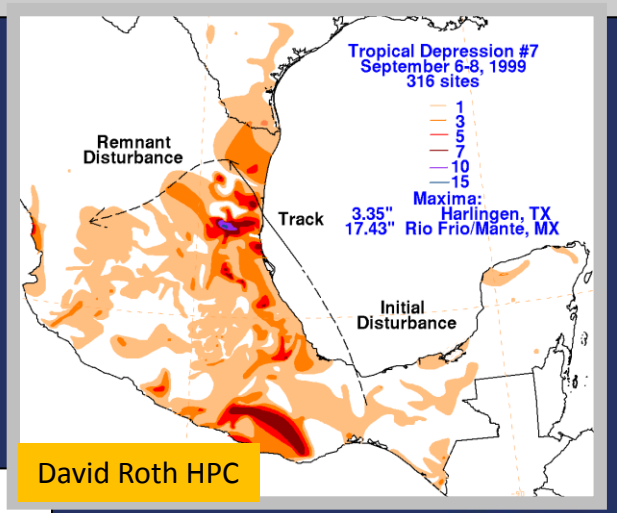
Select Storm By Name	Rainfall analogs to current tropical cyclones	Select Storm By Year
Select Storm By Region Of Impact	Select Storm By Point Of Entry	Tropical Cyclone Maxima Per U. S. State
Tropical Cyclone Maxima Per Mexican State	Point Maxima for Tropical Cyclones	Tropical Cyclone Averages and Maxima per Duration
Tropical Cyclone Rainfall Forecasting	Tropical Cyclone Rainfall Slideshow (in Powerpoint format)	Methodology for climatology
Acknowledgments	Milestones	

For any questions, comments, suggestions, e-mail David.Roth@noaa.gov
Last updated May 26, 2009

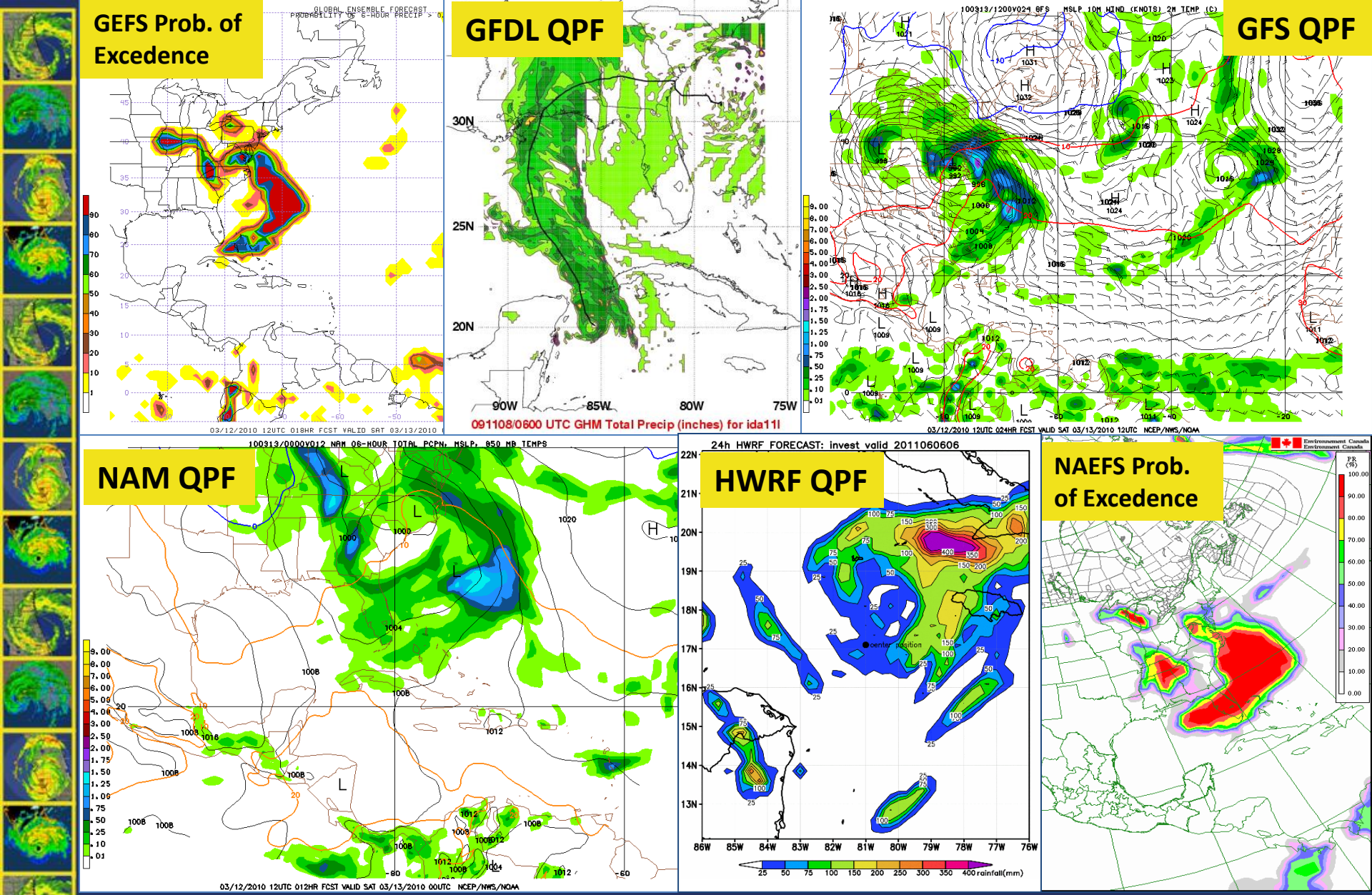
CLIQR Matching TC List (Rainfall Matches Accessible via Hyperlink)

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.



Available for active TCs at:
www.wpc.ncep.noaa.gov/tropical/rain/web/cliqr.html

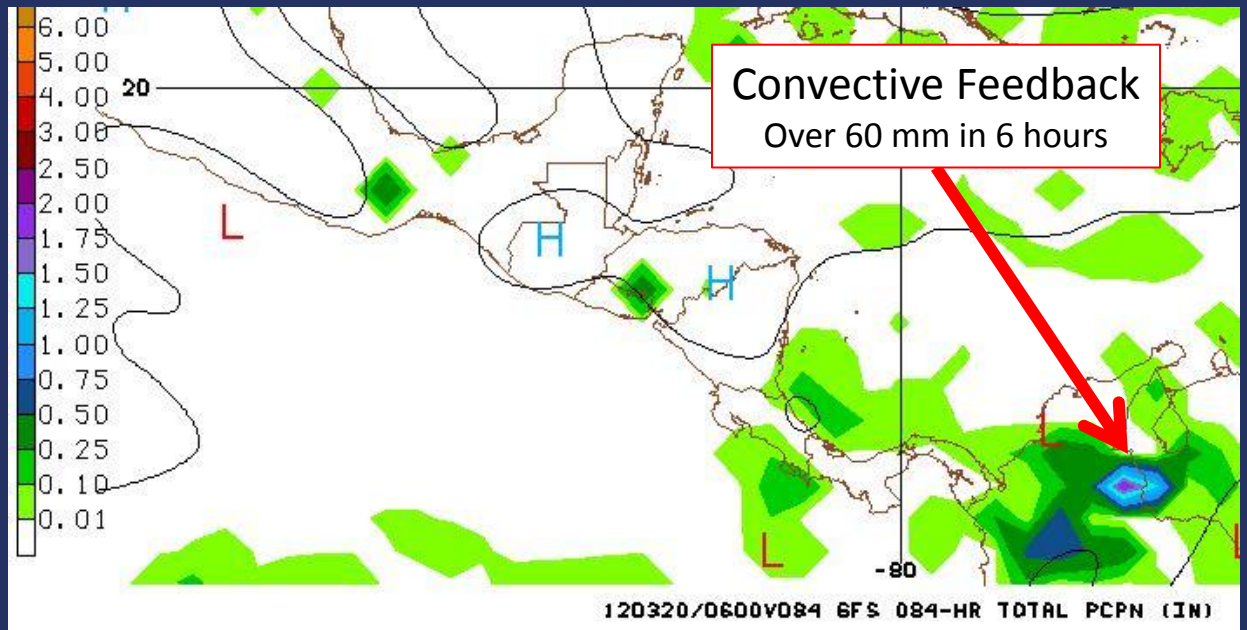


Model Forecasts

NATIONAL HURRICANE CENTER
MIAMI FL

NCEP Model QPF Biases

- **NCEP models are updated frequently which makes it difficult to isolate distinct biases**
- Run-to-run consistency increases confidence of occurrence
- Grid-scale feedback problems
  - Updraft overtakes the grid cell
  - WPC estimates that QPF maximum amounts are reasonable about half the time when convective feedback is noted, but the location can be far off (Roth, 2008)



Where to Find Model QPFs

- **NHC Tropical Rainfall Webpage (storm-specific GFS, HWRF, and GFDL forecasts)**

http://www.nhc.noaa.gov/experimental/rainfall/

- **NCEP models (GFS, NAM, GEFS, NAEFS) including tropical guidance (HWRF and GFDL)**

http://mag.ncep.noaa.gov

- **Canadian Global GEM**

http://www.weatheroffice.gc.ca/model_forecast/global_e.html

- **Canadian Global GEM Ensembles**

http://www.weatheroffice.gc.ca/ensemble/index_e.html

- **NAVGEM**

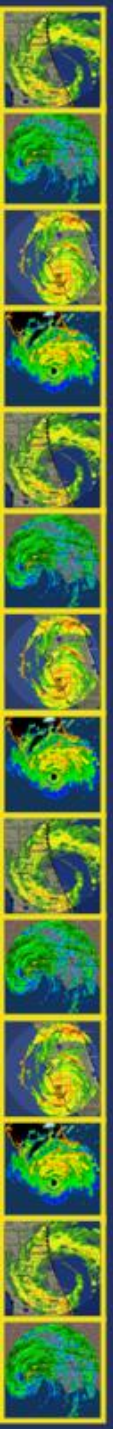
http://www.nrlmry.navy.mil/metoc/nogaps/

- **ECMWF**

http://schumacher.atmos.colostate.edu/weather/ecmwf.php

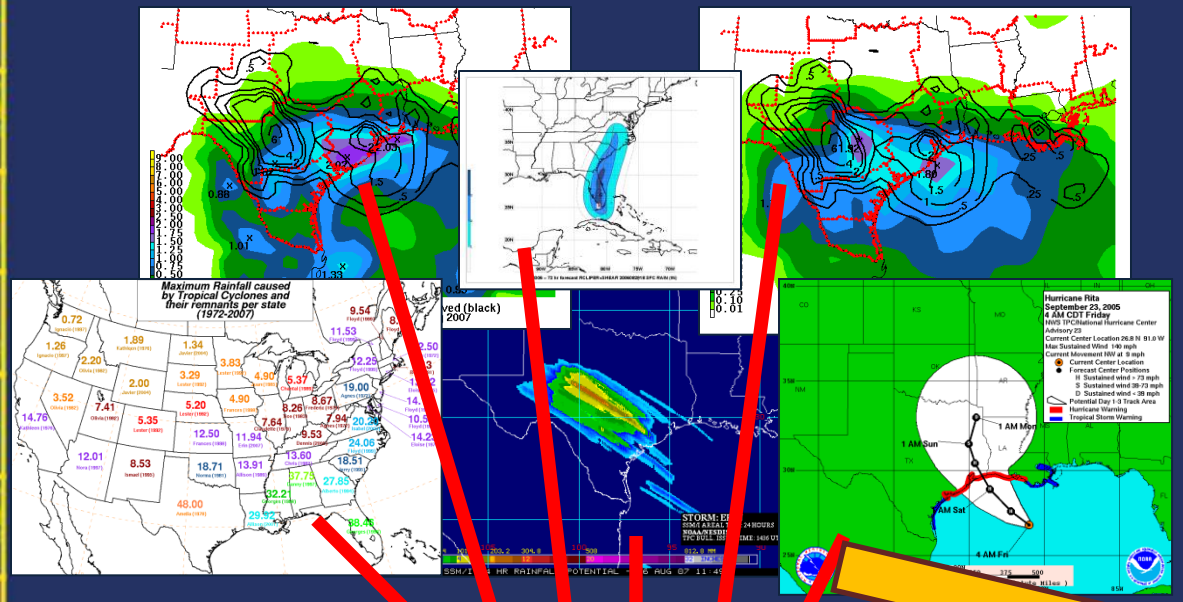
- **Penn State Tropical Atlantic E-Wall**

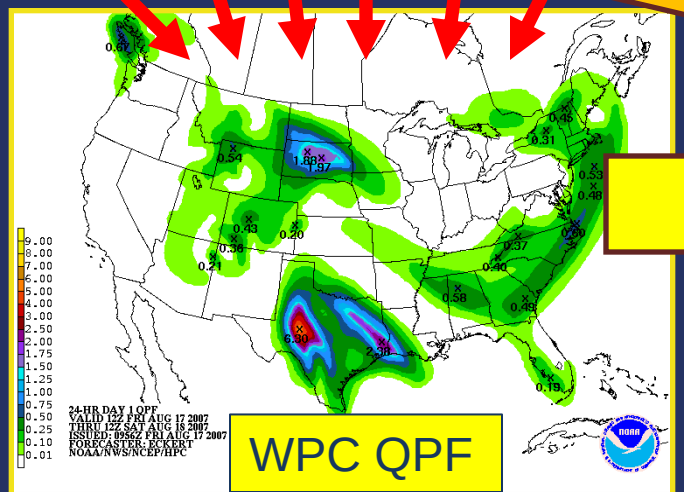
http://mp1.met.psu.edu/~fxg1/ewalltropatl.html



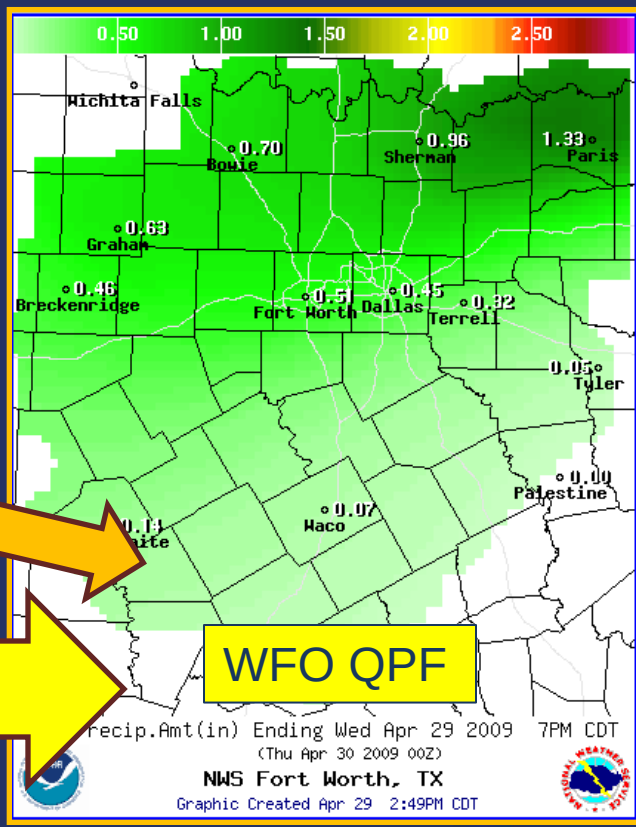
TC QPF Forecast Process

NWS Tropical Cyclone Quantitative Precipitation Forecasts (QPF)



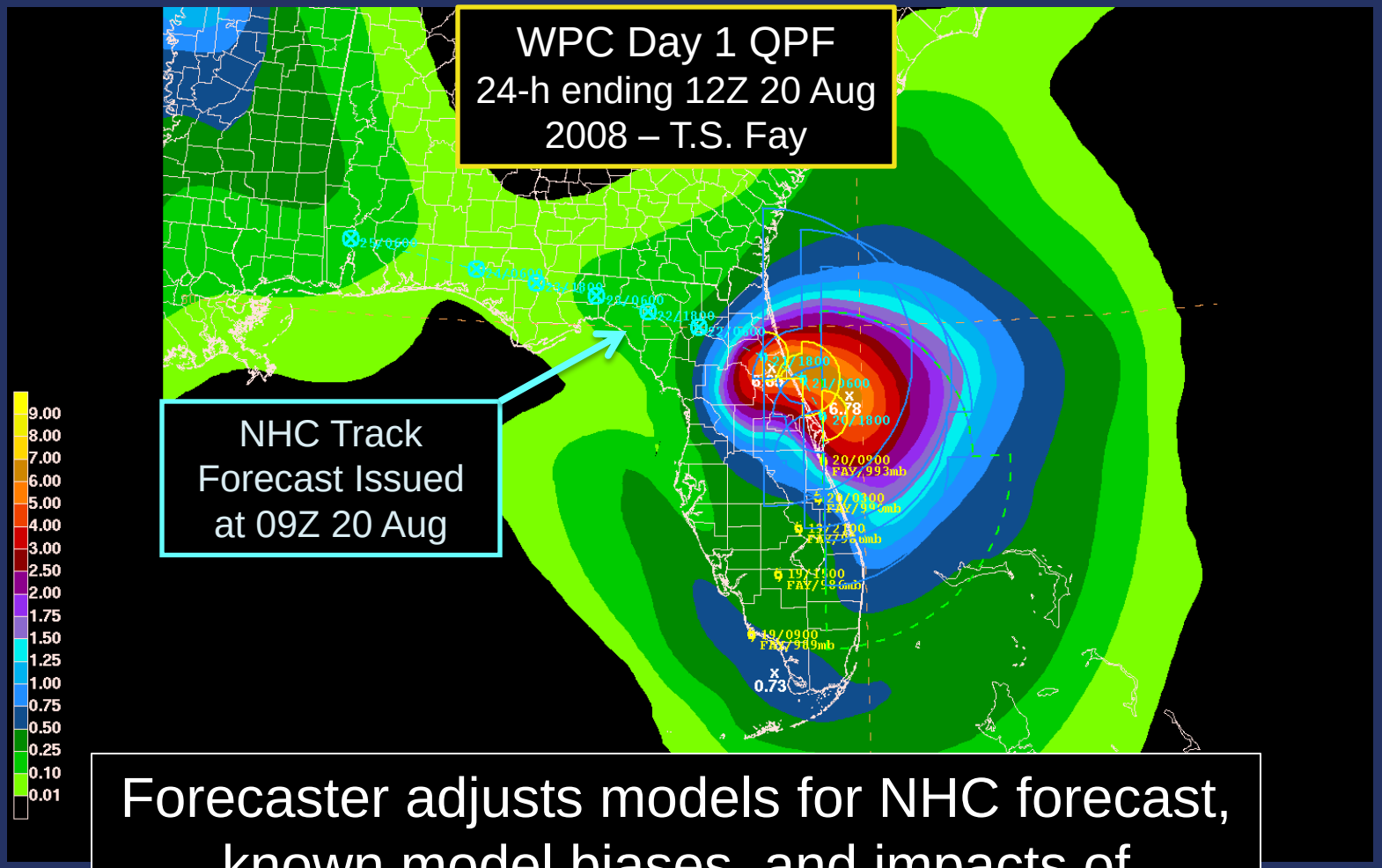


WPC QPF



WFO QPF

Forecaster Improvements over the Models



Forecaster adjusts models for NHC forecast, known model biases, and impacts of surrounding meteorological features

Production of Tropical Cyclone Related QPF

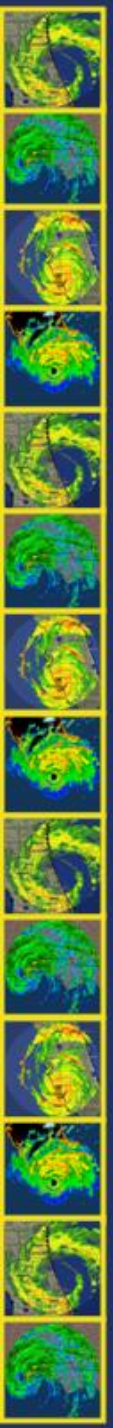
- Look at TC rainfall statements in NHC Public Advisories
- Start With Model Closest to NHC track forecast
- Locate relevant synoptic scale and meso-scale boundaries
- Use eTRaP and recent satellite/radar imagery for current structure/rainfall rates
- Use conceptual models, current structure, and pattern recognition to modify/shift QPF
- Identify areas of orographic enhancement

Production of Tropical Cyclone Related QPF

- Look at forecast upper level winds to further adjust QPF for shear
- Determine how a change in available moisture could increase, decrease, or redistribute rainfall
- Use climatology (CLIQR, R-CLIPER, TC Rainfall Climatology) to:
  - Increase/decrease amounts
  - Adjust numerical guidance biases
  - Reality check
  - Highlight areas significantly impacted by terrain effects

In Conclusion

- Remember the factors that influence TC rainfall (size of storm, time of day, speed etc.)
- Evaluate the quality of the model data available to you compared to the current conditions
- Assess the amount of shear in the environment How will it influence rainfall?
- Are there past TCs that resemble the rainfall distribution and forecast of the TC?
- Use all of the tools available (eTRaP, TCCA products from NHC, NWP models, etc.)
- Remember, heavy rain can also occur well away from the TC itself (PRE, secondary disturbances, etc.)



Thank You

Questions?

- http://onlinelibrary.wiley.com/doi/10.1002/wrcr.20527/full
- http://trmm.chpc.utah.edu/cyclone/
- http://www.usclivar.org/sites/default/files/meetings/Villarini_Presentation_Clivar.pdf

NHC Satellite Tropical Disturbance Rainfall Estimates

The TCCA products:

- Estimate rainfall rates for tropical cyclones based on the cloud top temperature data acquired using infrared satellite imagery (Griffith-Woodley technique)
- Uses the infrared imagery to determine the size of the area receiving rain
- Calculates a maximum or “core” rainfall amount
- Apportions the rainfall into a distribution where 50% of the total area average rainfall occurs in the coldest 10% of the cloud top area.

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

  DATE/TIME      LOCATION       MOTION
 -----------   ------------     ------
 29/1815 UTC   23.9N  79.7W     315/11


LAST RAINFALL DISTRIBUTION...
```

```
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
```

```
   MAX RAINFALL
  MEAN       LAST
-------    -------
 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
```

```
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)
```

Provides the distribution of rainfall estimates (in inches) based on recent infrared satellite imagery