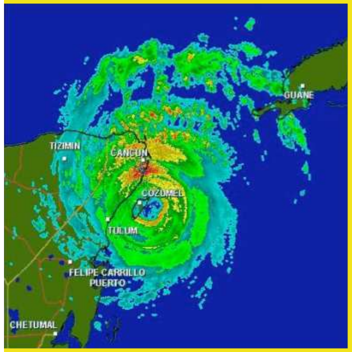
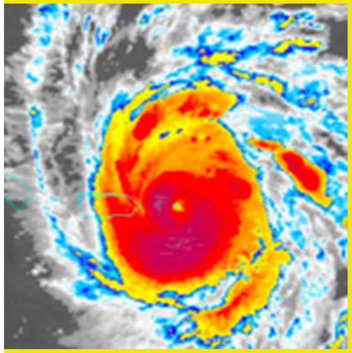
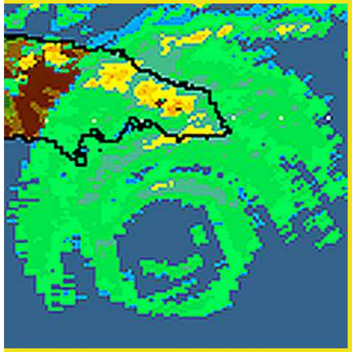
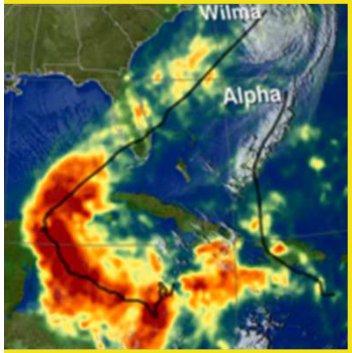


Tropical Cyclone Rainfall

Jessica Schauer

National Hurricane Center
Tropical Analysis and Forecast Branch
Lead Forecaster

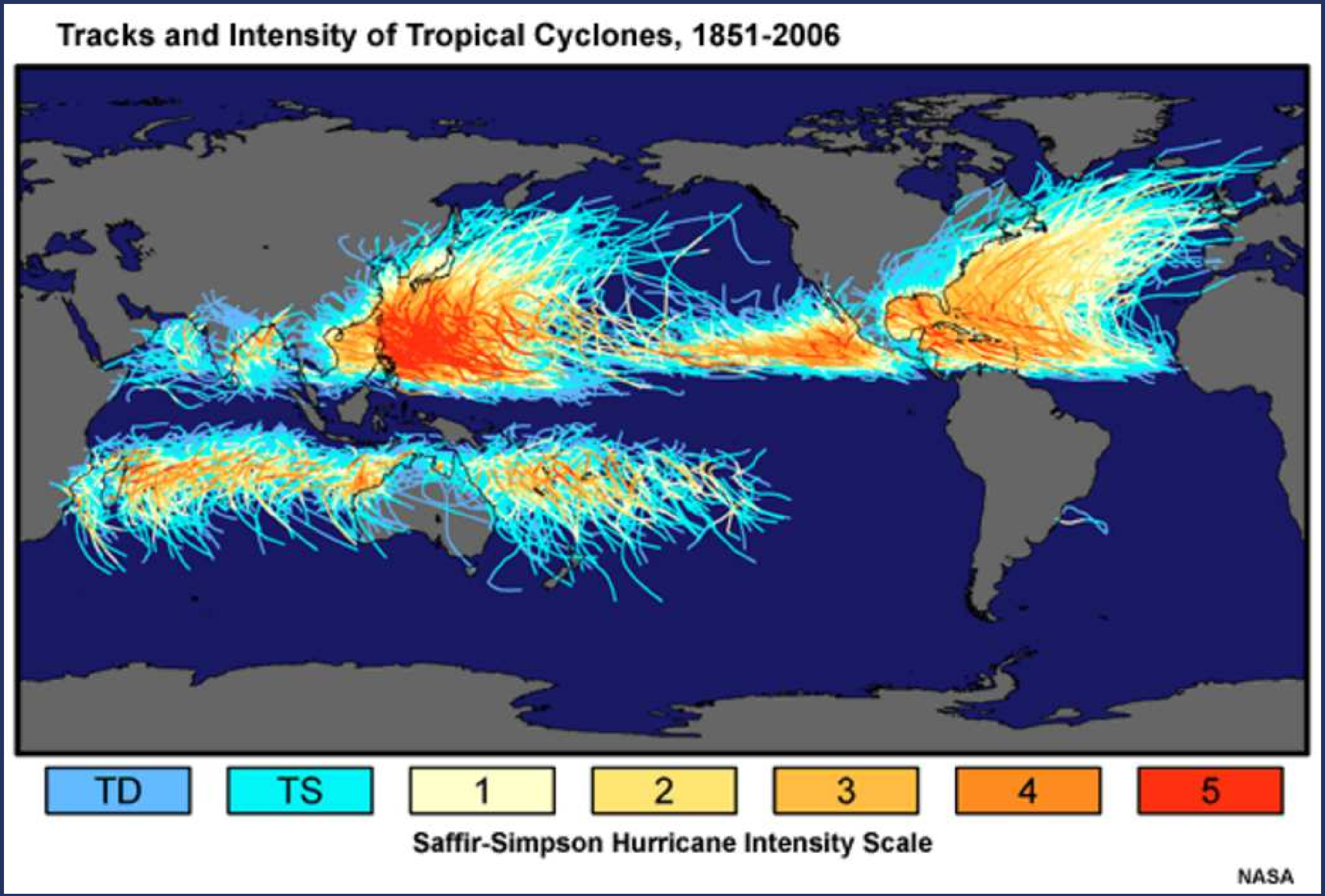
NATIONAL HURRICANE CENTER MIAMI FL

Outline

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

Tropical Cyclone Rainfall Climatology

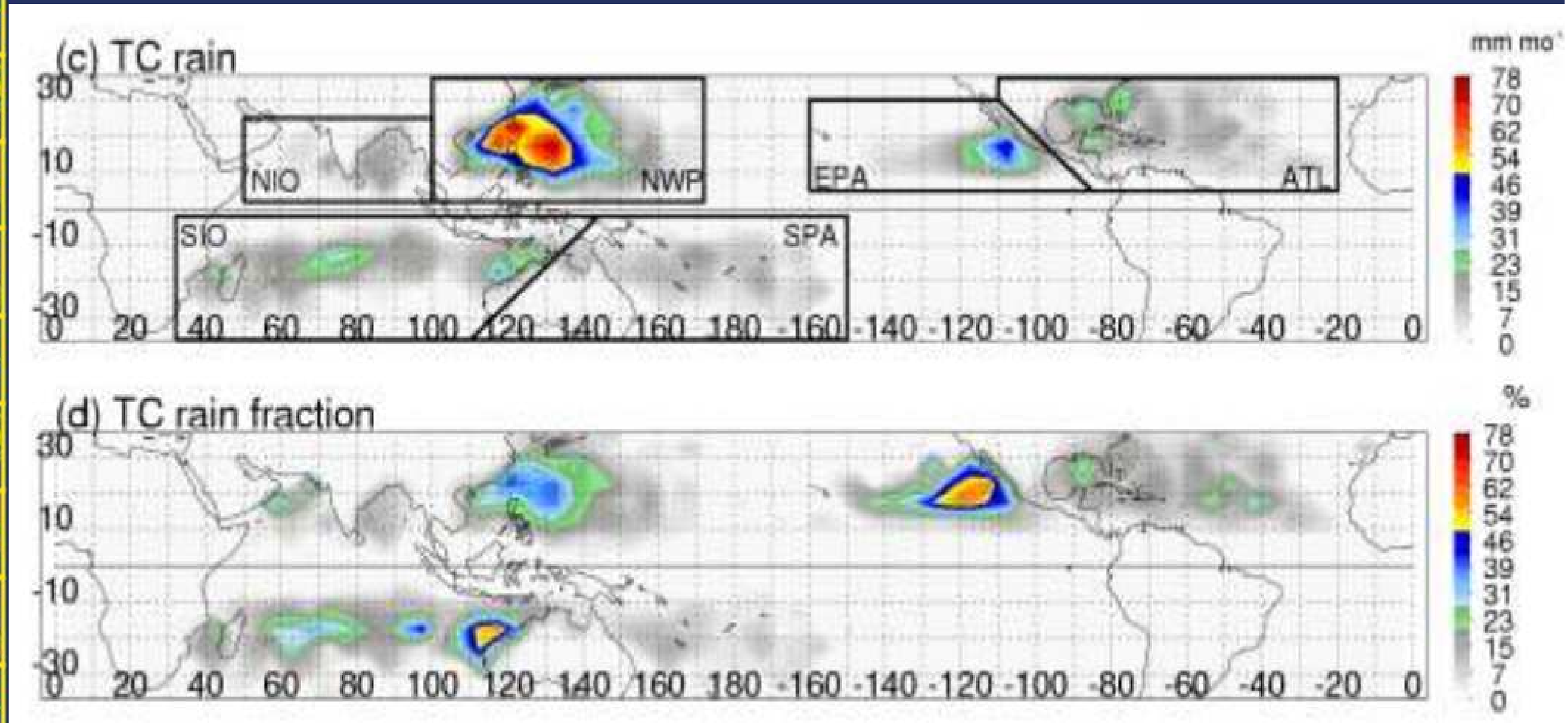
Tropical Cyclone Tracks



COMET (2011)

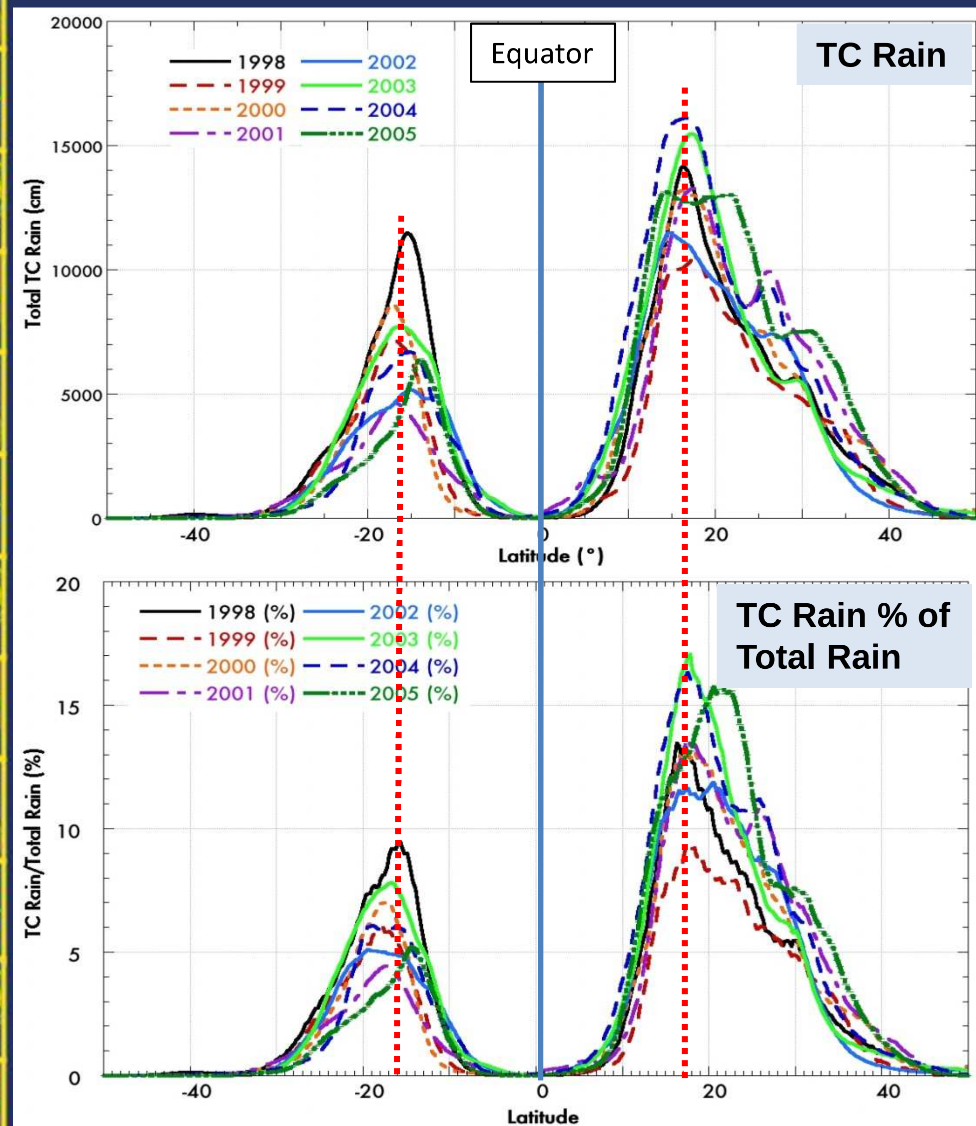
Global Mean Monthly TC Rainfall During the TC Season and Percent of Total Annual Rainfall

Data from TRMM 2A25 Precipitation Radar from 1998-2006



Jiang and Zipser (2010)

Annual TC Rainfall



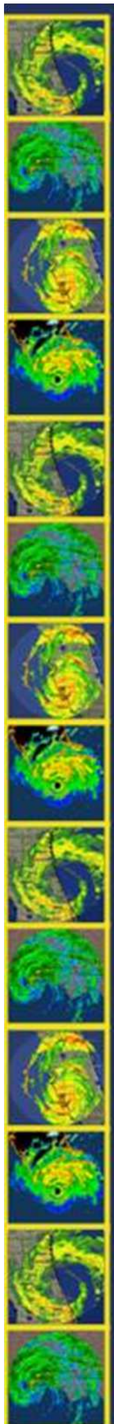
Frank Marks (HRD)

- 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

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)
Costa Rica	920.0 mm	36.22”	Cesar (1996)
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)
El Salvador	406.4 mm	16.00”	Adrian (2005)
Guadeloupe	508.0 mm	20.00”	Marilyn (1995)
Guatemala	600.0 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
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 WPC (2006)



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Original Source: David Roth WPC (2006)

National Hurricane Center Miami FL

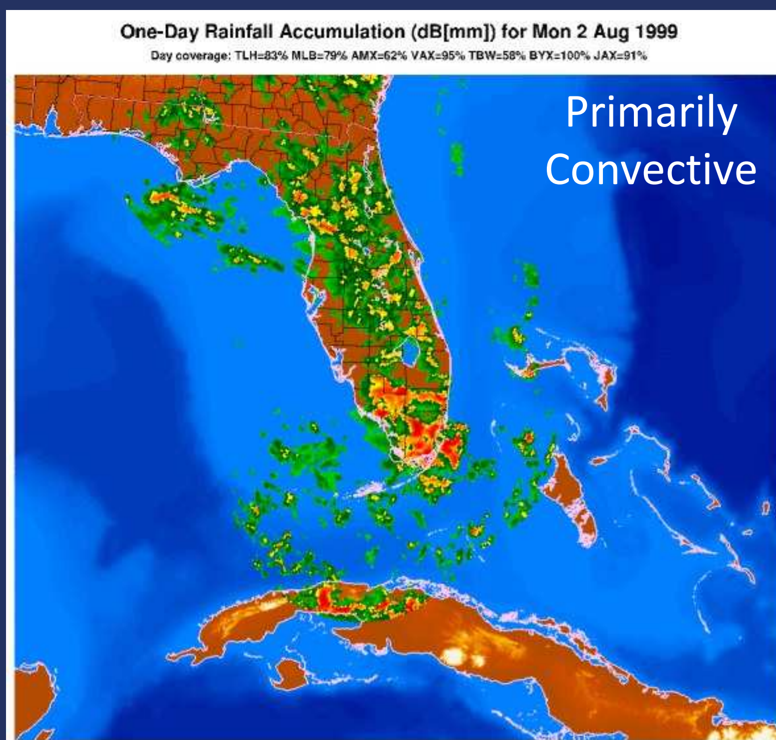
Characteristics of TC Precipitation

Stratiform and Convective Mechanisms

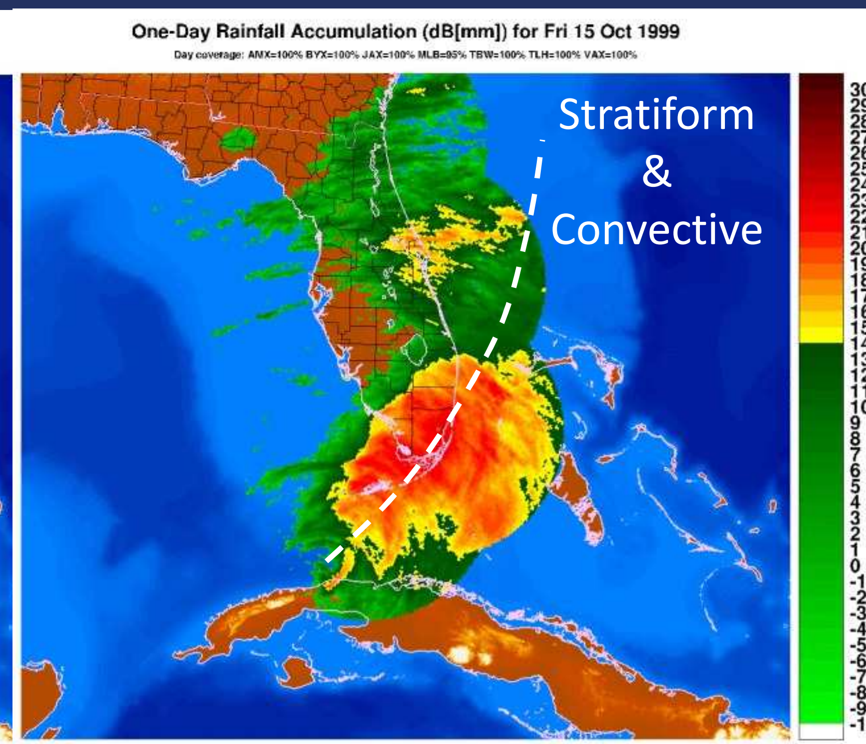
Stratiform Rain ~50% of Total Rain from TC

NOAA/HRD - Daily Radar Rainfall Estimate Study

Typical warm season 1-day total

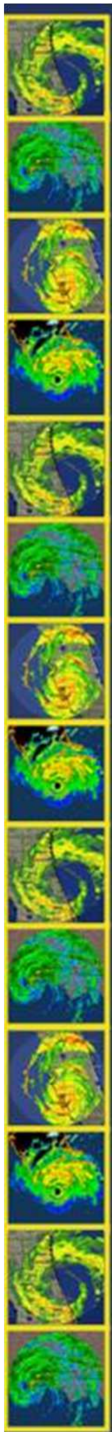


Hurricane Irene 1-day total

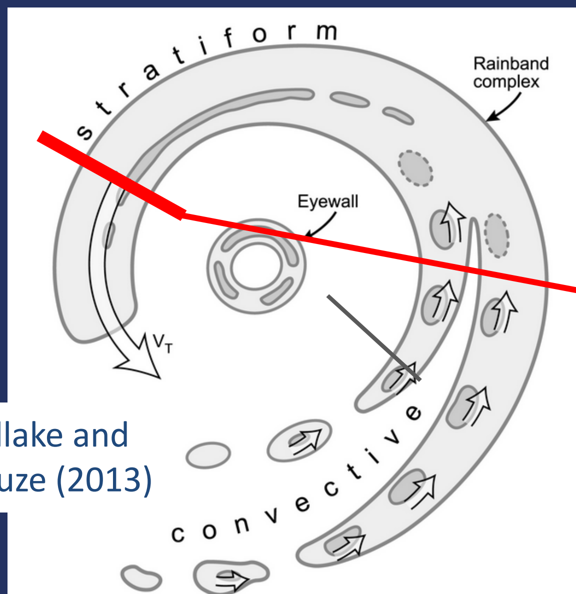


Hurricane Irene (15 October 1999)

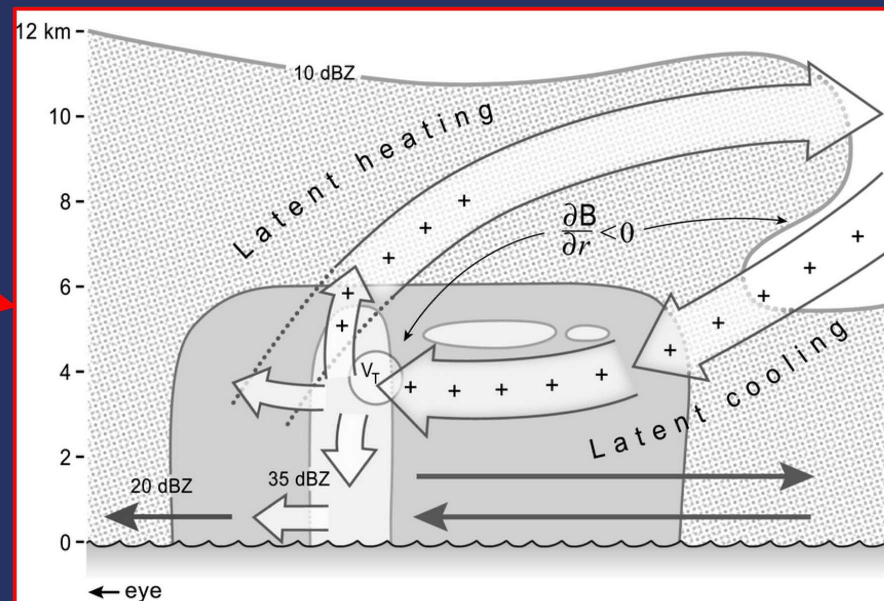
Frank Marks (HRD)



TC Rainband Complexes: Stratiform Region



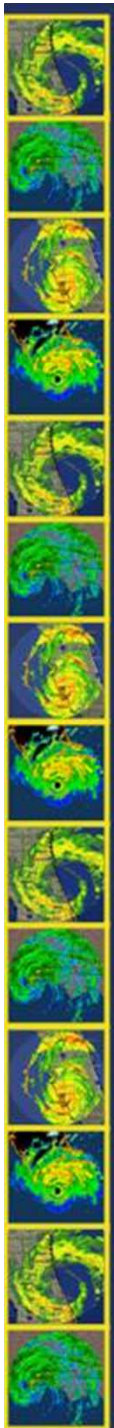
Didlake and Houze (2013)

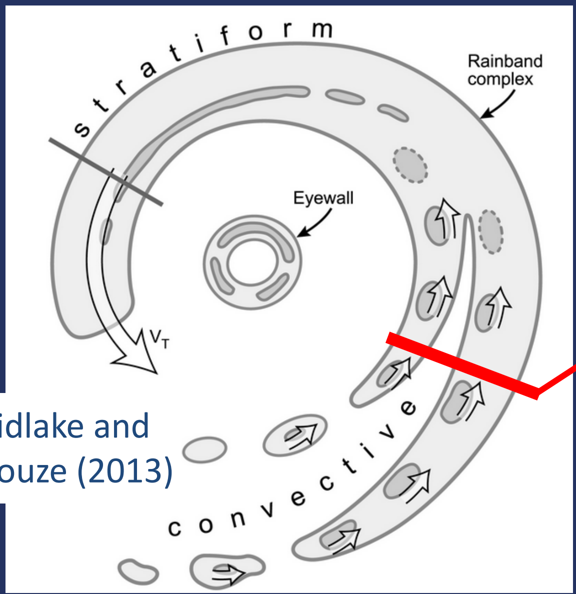


- Broad stratiform band in left-of-shear half of the storm
- Mesoscale ascending outflow & descending inflow driven by latent heating & latent cooling patterns
- Increased rainfall along line where descending inflow halts
- Descending inflow strengthens the outer core of vortex

Marchok (2014)

TC Rainband Complexes: Convective Cells





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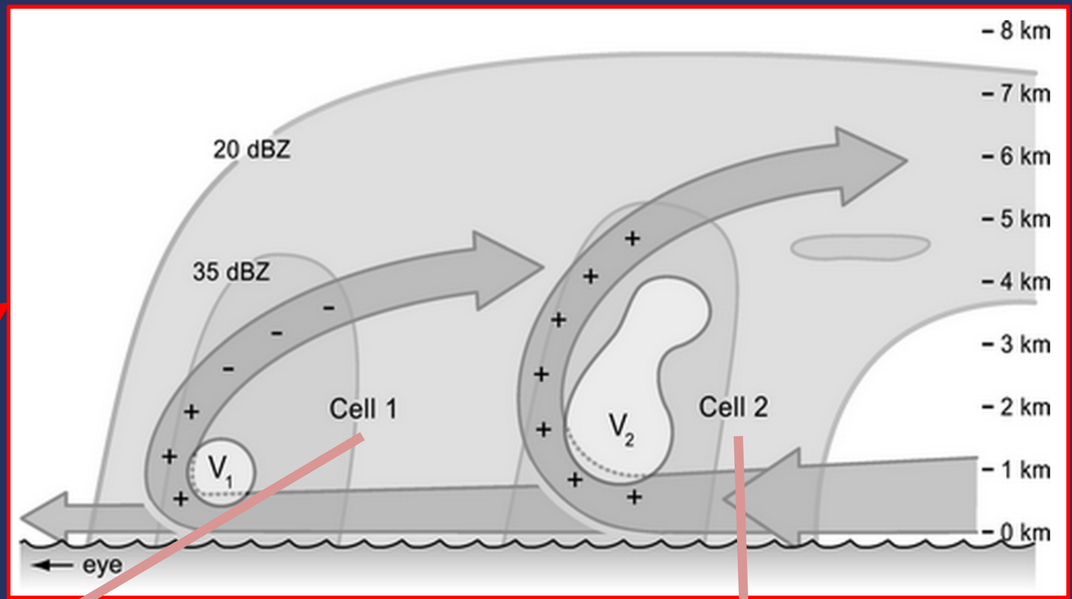


Cell 1

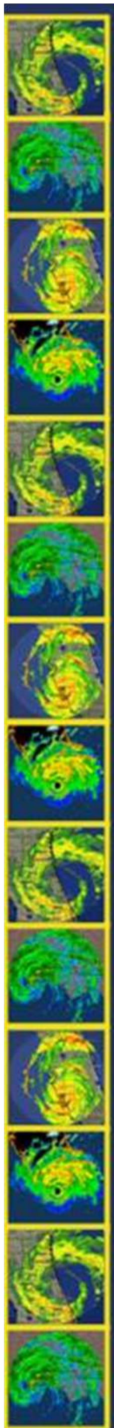
- Weaker, shallower reflectivity core
- Weaker updrafts
- Shallower, but stronger inflow layer
- Tangential jet and outflow confined to lower levels

Cell 2

- More intense reflectivity, heavier rain
- Increased CAPE, more buoyant updrafts
- Deeper inflow layer
- Tangential jet and outflow extend deeper into the troposphere

Marchok (2014)

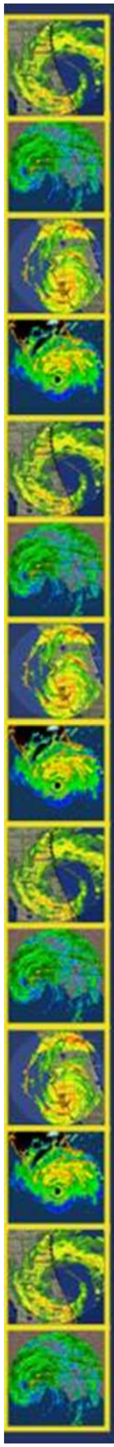
Factors Influencing Tropical Cyclone Rainfall



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

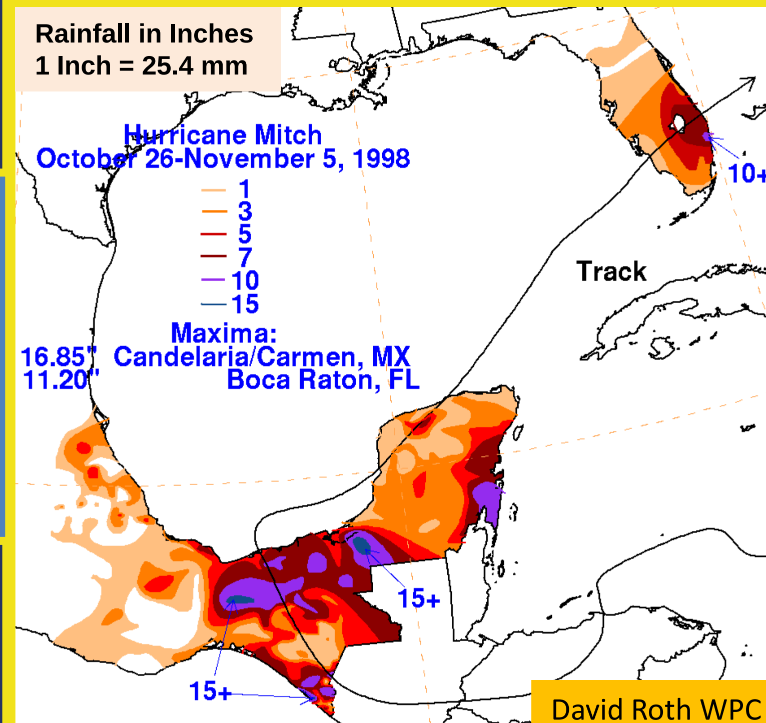


Factors Influencing TC Rainfall

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 WPC

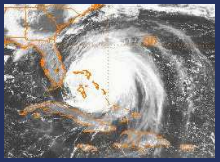

Vulcan Casita, Nicaragua - debris flows


Tegucigalpa, Honduras river flooding

Factors Influencing TC Rainfall

Storm Size

Determined by distance from center to outermost closed isobar

<2 degrees	"Very small/ midget"	Marco (2008) 
2-3 degrees	"Small"	Ida (2009) 
3-6 degrees	"Average"	Frances (2008) 
6-8 degrees	"Large"	Wilma (2008) 
>8 degrees	"Very large"	Sandy (2012) 

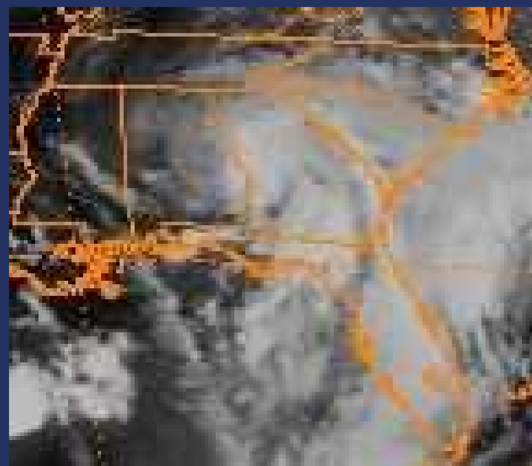
Original Source: Joint Typhoon Warning Center

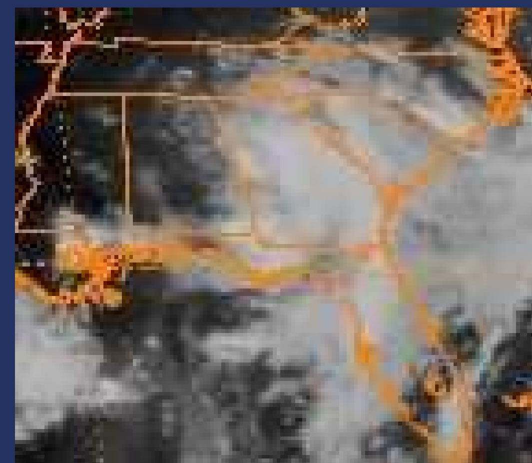
Factors Influencing TC Rainfall

Time of Day

Alberto, July 4-5, 1994

04/18z





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05/06z

12z

18z

Factors Influencing TC Rainfall

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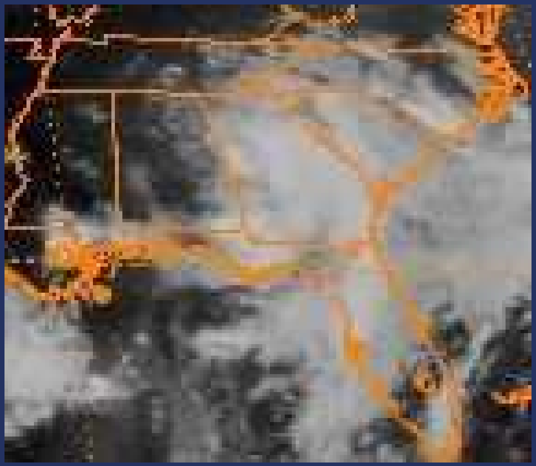

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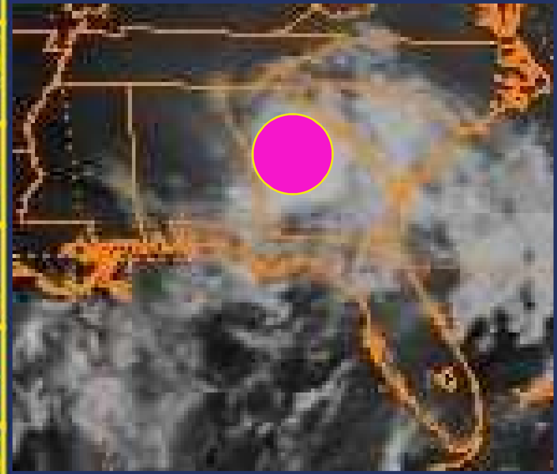

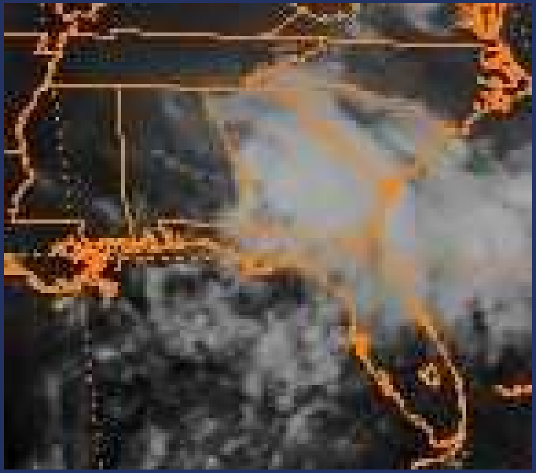

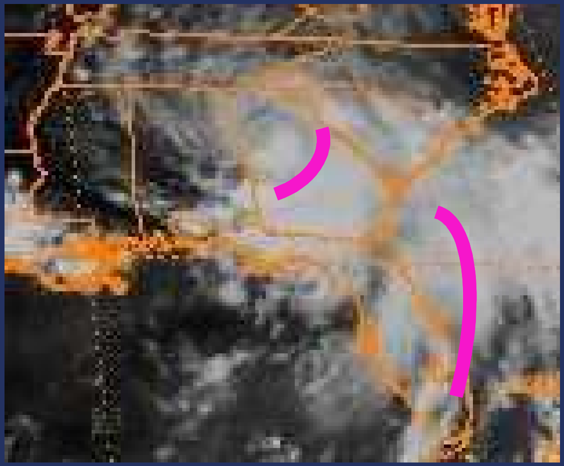

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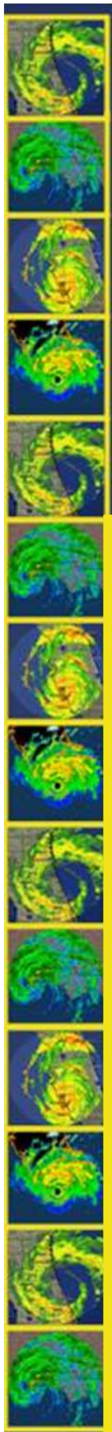
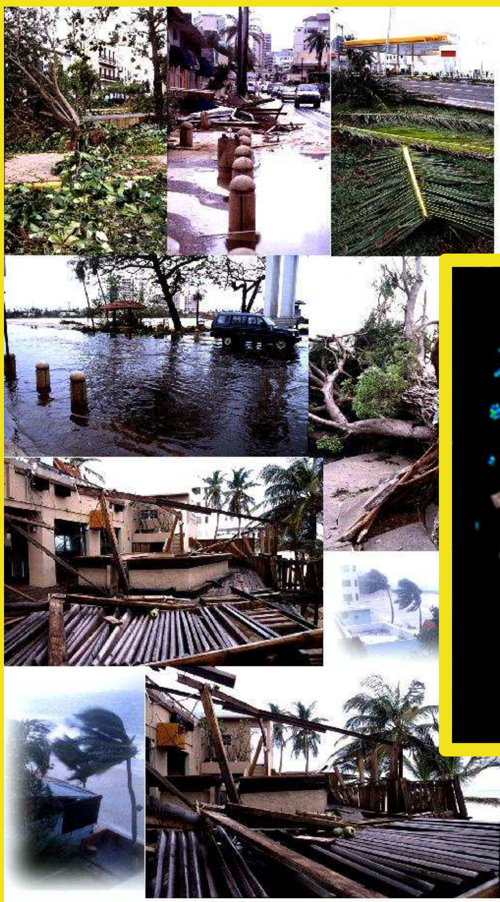
18z

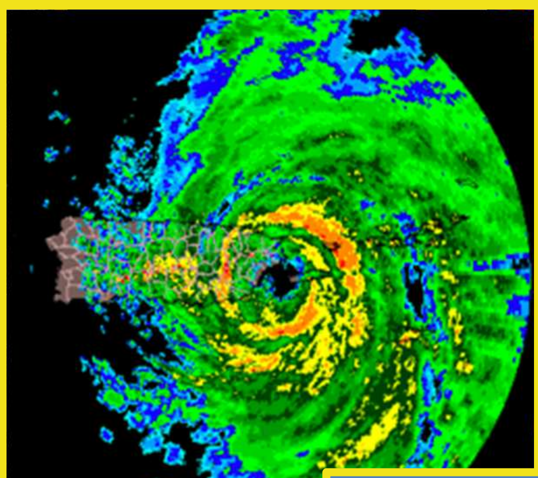
Factors Influencing TC Rainfall

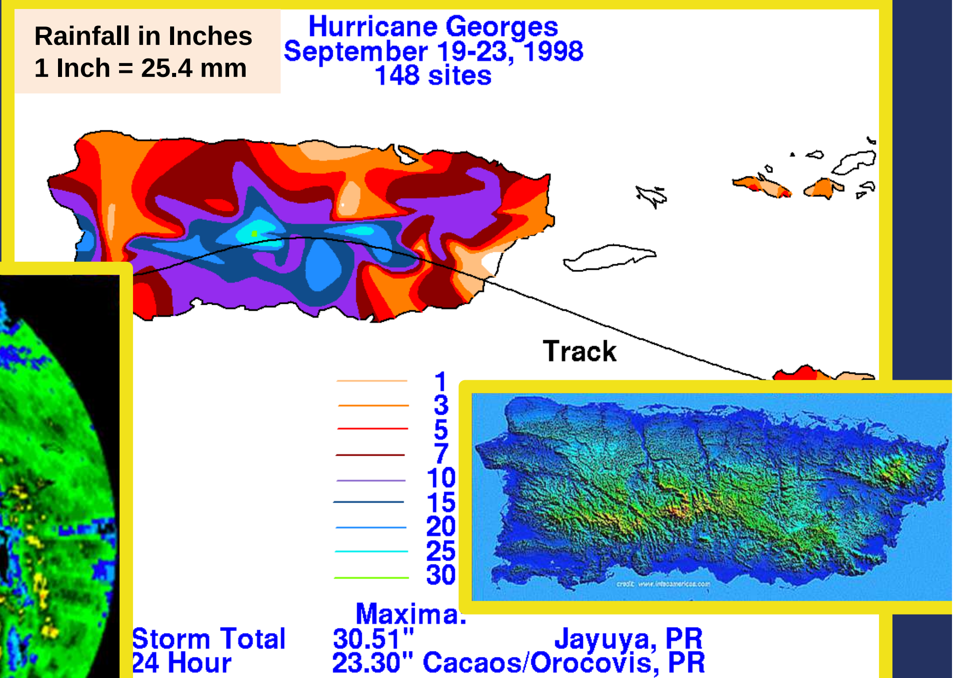
Terrain Impacts

Heaviest rainfall favors mountains perpendicular to the wind







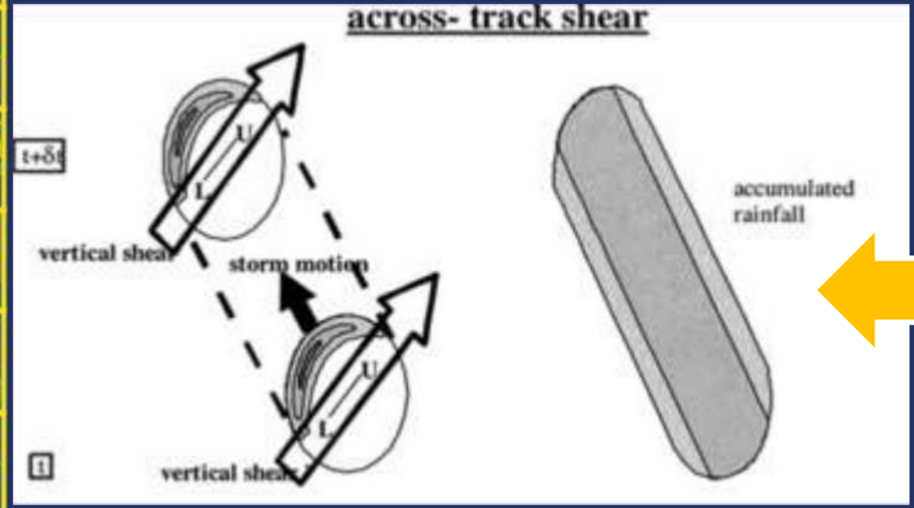


David Roth WPC

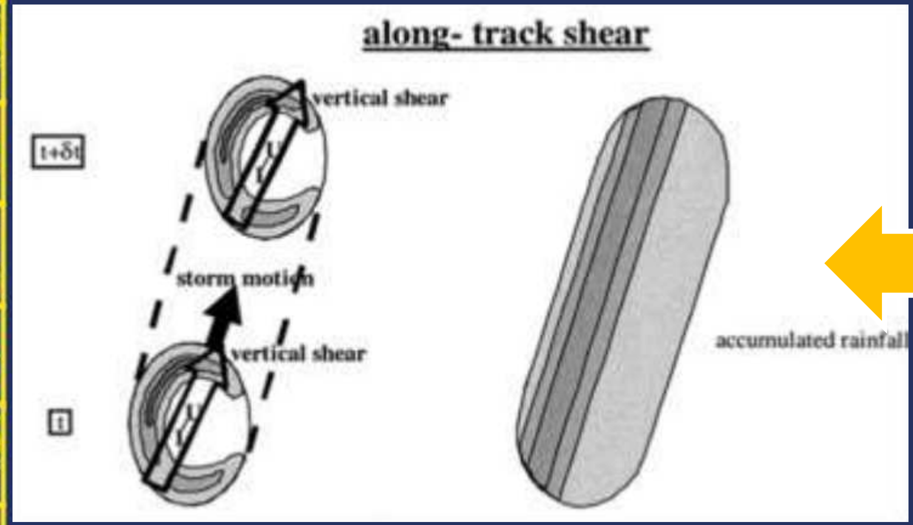
Hurricane Georges in Puerto Rico
$1.75 billion in damage
28,005 homes destroyed

Factors Influencing TC Rainfall

Vertical Wind Shear – Northern Hemisphere



Shear directed across the storm track leads to more uniform distribution of the rainfall



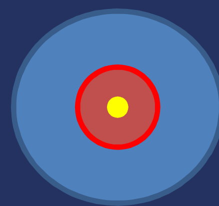
Shear directed parallel to the storm track leads to a distribution of the rainfall asymmetry on the left side of the track

Rogers et al, 2003

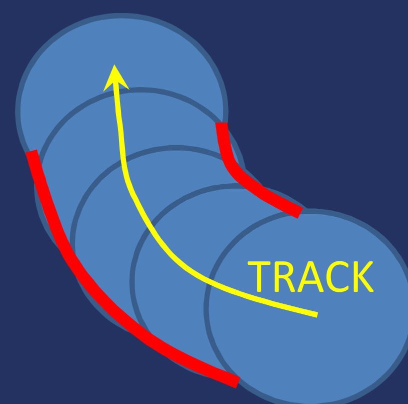
Factors Influencing TC Rainfall

Environmental Steering in Northern Hemisphere

- Very slow moving TCs and symmetrical TCs produce the most rainfall *near the center*
  - Maximum rainfall at night (especially when over land)
  - Weak steering flow



- TCs that move into a break in the subtropical ridge often produce most of the rain *right* of their track



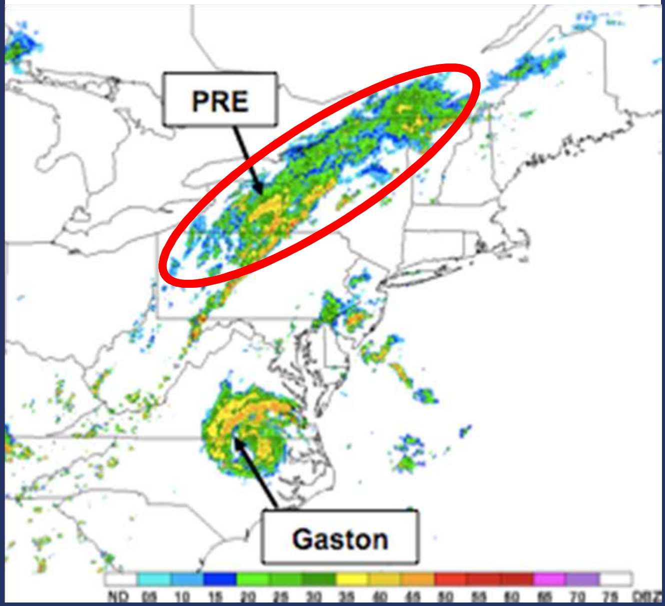
Even rainfall distribution = Rain over smaller area on right side = Higher totals

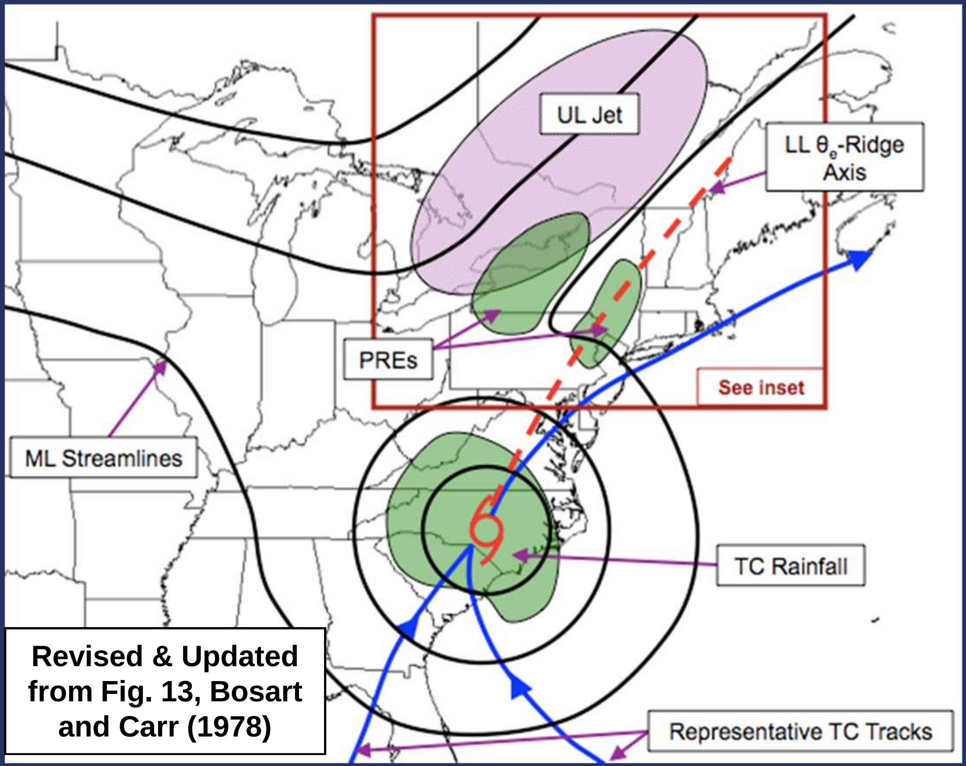
- TCs that recurve due to significant upper troughs in the westerlies often produce most of their rain *left* of their track
  - Rainfall may spread well in advance of the TC due to interaction with the upper jet on the leading edge of the trough

Factors Influencing TC Rainfall

Predecessor Rainfall Events

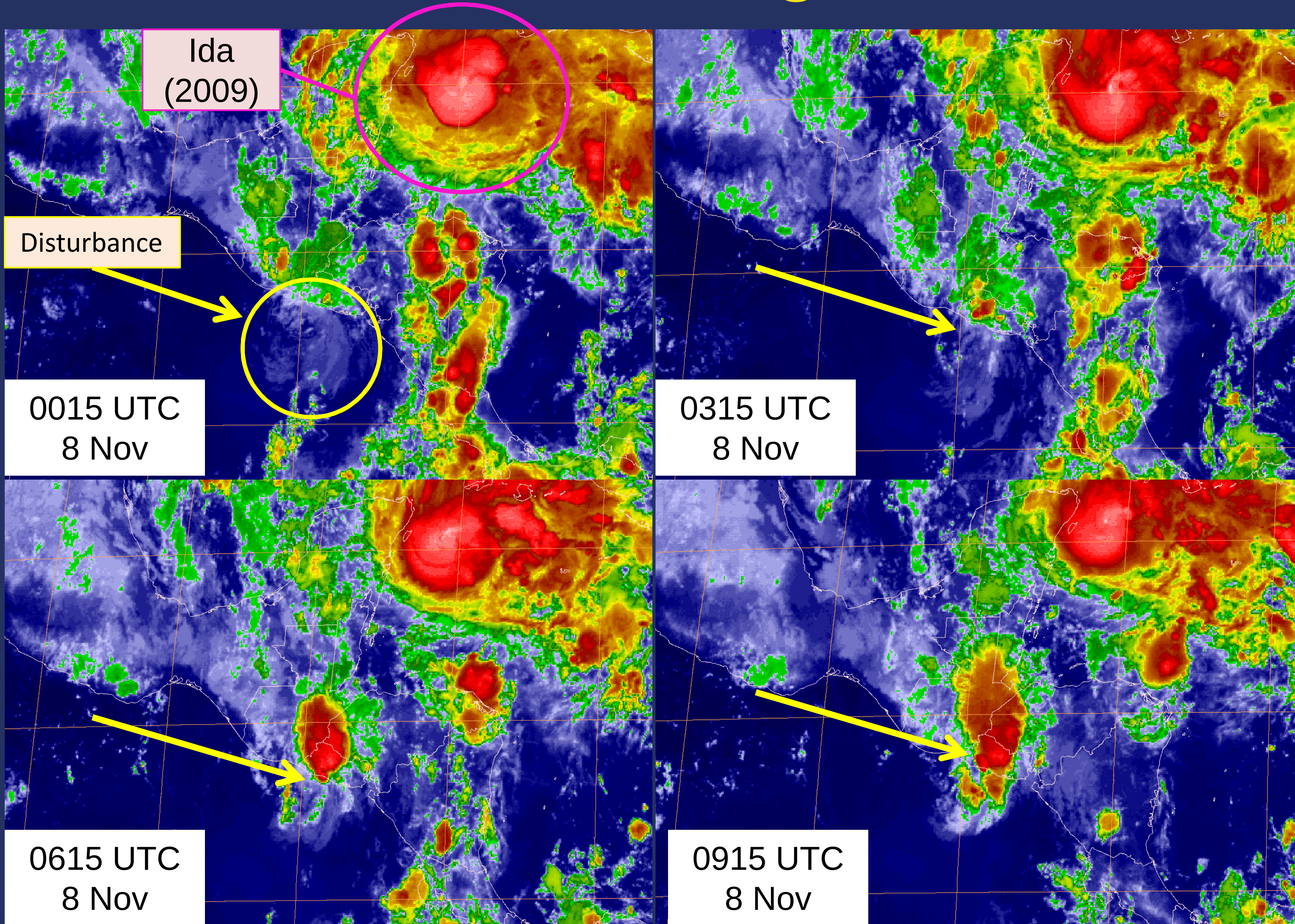
Predecessor Rainfall Event (PRE)
Image from Matt Cote and Lance Bosart – SUNY Albany





- 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?

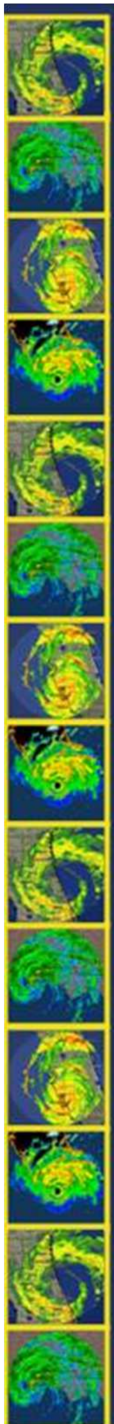
- Areas where the ground is already saturated (low flash flood guidance values)
- Valleys/watersheds
- Areas of orographic enhancement
- Areas with poor drainage or prone to runoff
- Areas with directed drainage that can be overwhelmed

Costa Rica stream flooding

Clear Cut Areas in Haiti

TC Rainfall Forecasting Tools

NHC Satellite Tropical Disturbance Rainfall Estimates



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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

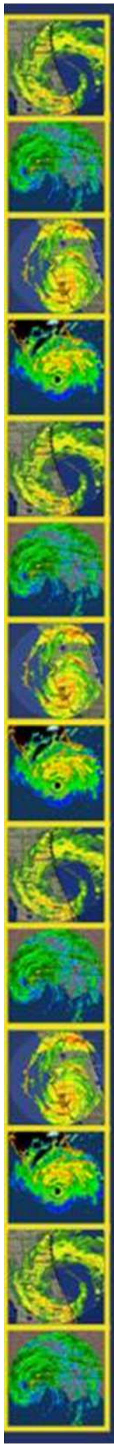
MEAN MAXIMUM RAINFALL... THE 24-HOUR MEAN MAXIMUM ACCUMULATION OF
                         RAINFALL FOR THE SYSTEM IN INCHES BASED
                         ON FOUR SATELLITE IMAGES SIX HOURS APART

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 ... tellite Tropical Disturbance Rainfa... stimates

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TCCA22 KNHC
STDCCA

SATELLITE TROPICAL                    MATES
NWS TPC/NATIONAL HUR
1815 UTC TUE AUG 29 20


SYSTEM NAME/IDENTIFIER...T.S.


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


LAST RAINFALL DISTRIBUTION...

    DISTANCE          LEFT OF C
  -------------     ----------
  0 TO 1 DEGREE      2.5 TO  9
  1 TO 2 DEGREE      0.5 TO  2
  2 TO 3 DEGREE      0.1 TO  0
  3 TO 4 DEGREE      0.0 TO  0


                         ...LEGEN

SYSTEM NAME/IDENTIFIER...NAME OR
                         (E.G. T
                         DISTURB

DATE/TIME...             DAY OF MONTH AND TIME IN UNIV
                         COORDINATES (UTC) IN A DY/H

LOCATION...              ESTIMATED CENTER OF SYS
                         POSITION FOR TROPICAL
                         OF DEGREES OF LATIT

MOTION...                ESTIMATED DIRE
                         IN DEGREES A

MEAN MAXIMUM RAINFALL... THE 24-H                 TION OF
                         RAINFA                 ES BASED
                         ON F                 HOURS APART

LAST MAXIMUM RAINFALL...                 OF RAINFALL FOR
                                        SED ON THE MOST
                                     GE

RAINFALL DISTRIB                   OF RAINFALL WITHIN FOUR
                                 ) LEFT AND RIGHT OF THE
                              R IN ONE DEGREE (60NM)
                             ...LOOKING DOWNSTREAM
                            25.4 MM)
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TCCA ... cts

- Estimate ... s for tropical cyclon... the cloud top temp... a acquired using inf... lite imagery (Griffith-
- ... agery to ... f the area
- ... um or “core” ... mount
- A... the rainfall into a dis... here 50% of the total area a... fall occurs in the coldest ... cloud top area.

Product Replaced in 2013

Changes to NHC Rainfall Product

Limitation of old product:

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

Improvements:

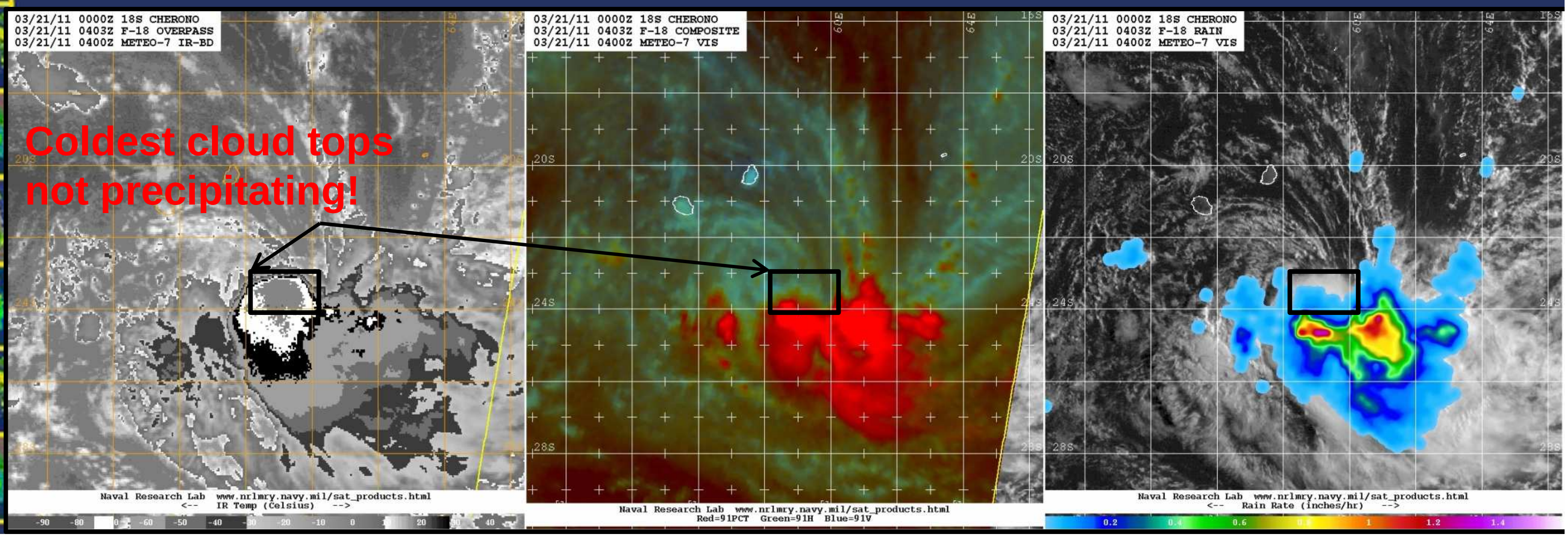
Incorporate microwave (MW) satellite data (rainfall rates)

- 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:

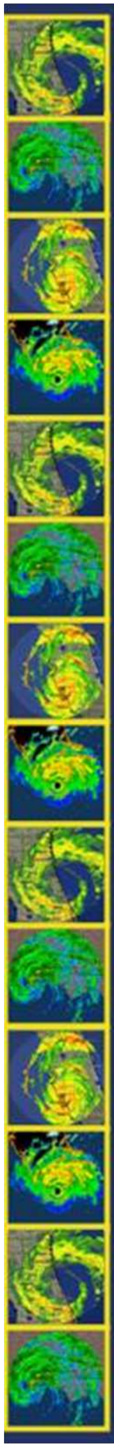
    http://www.nrlmry.navy.mil/training-bin/training.cgi
- As a third product, NHC uses the last applicable GFS forecast
  - A model forecast has the advantage of dynamics, topography, moisture, etc.

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
- Quantitative precipitation estimate (QPE) products leverage each method's strength…

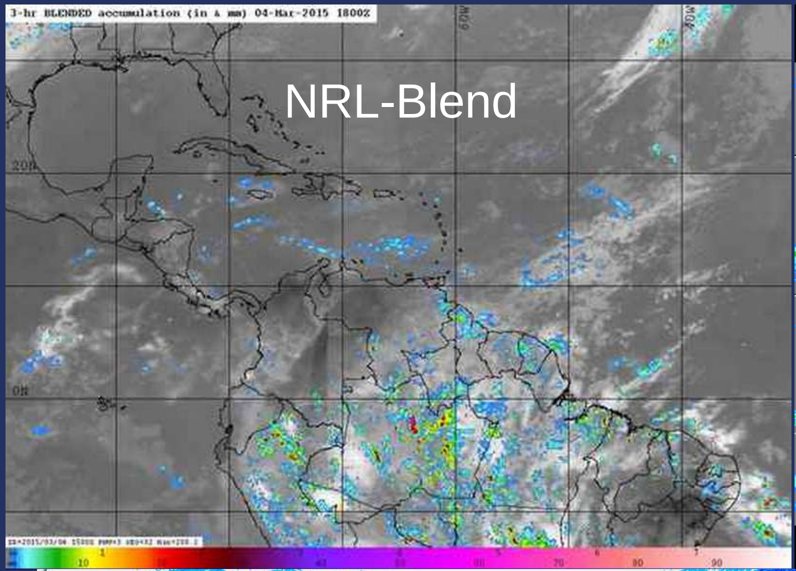


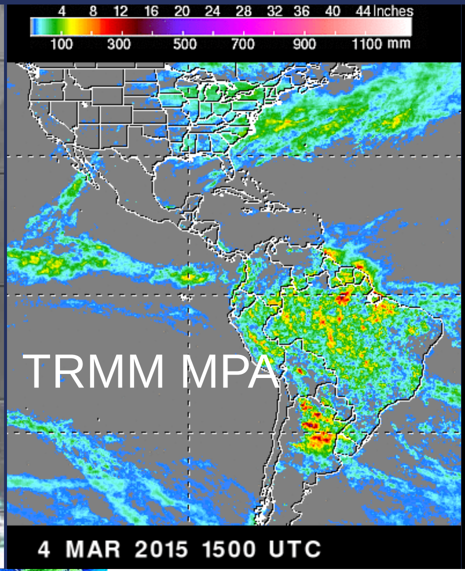
Satellite Rainfall Estimates

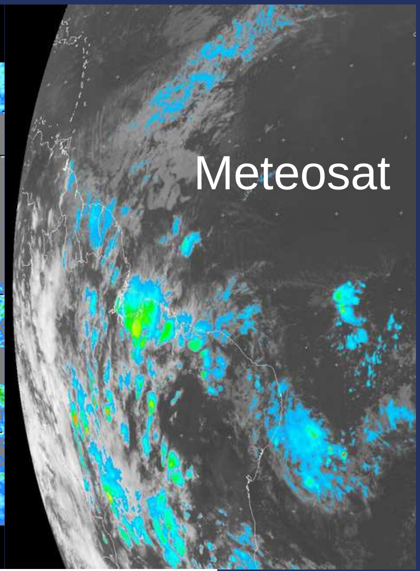


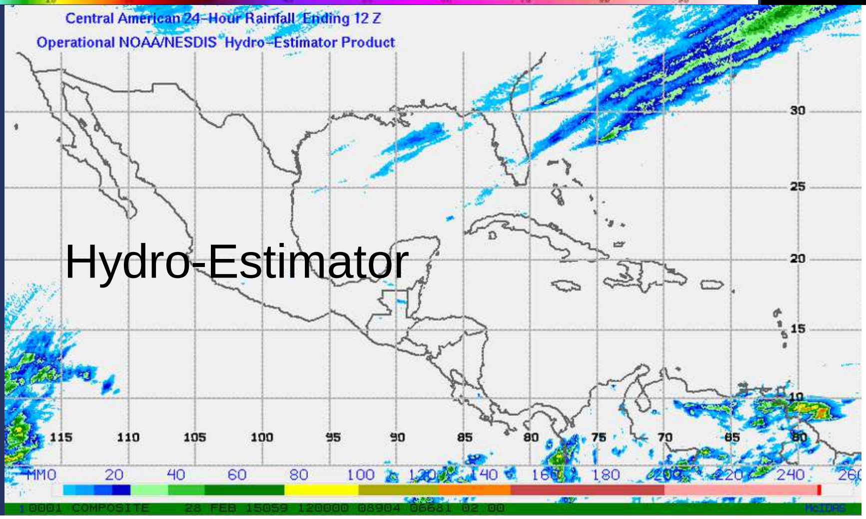
International Precipitation Working Group (IPWG) has an exhaustive list of data sources for precipitation information, some of it in real time.

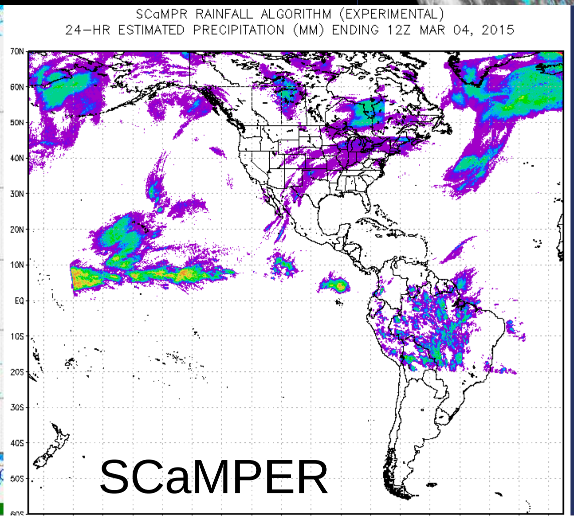
http://www.isac.cnr.it/~ipwg/data/datasets.html

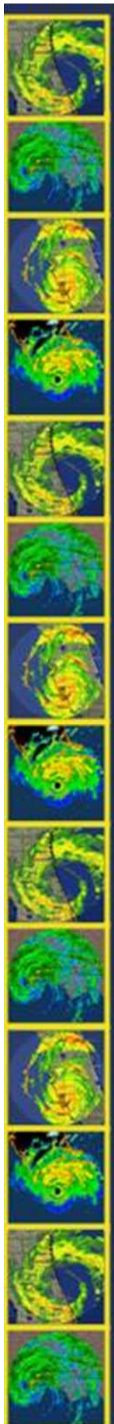








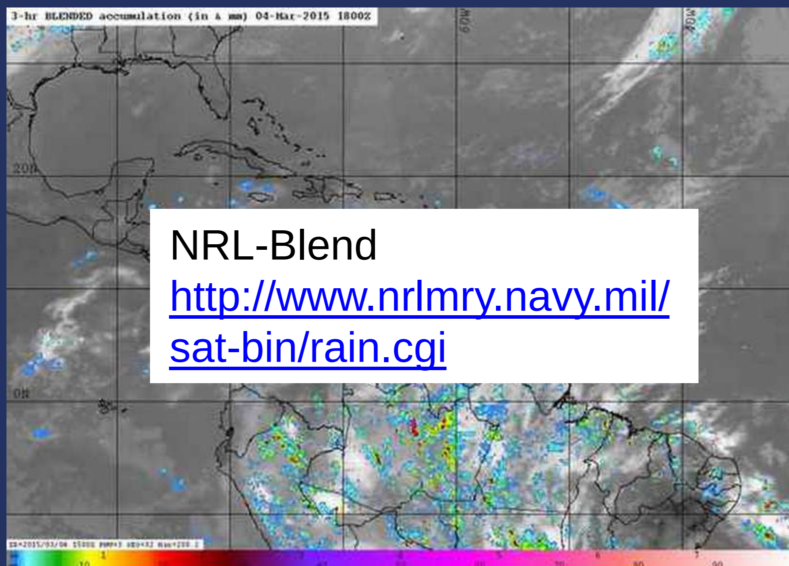




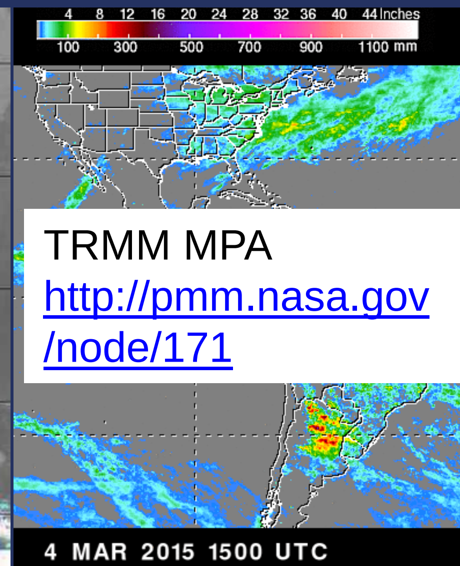
Satellite Rainfall Estimates

International Precipitation Working Group (IPWG) has an exhaustive list of data sources for precipitation information, some of it in real time.

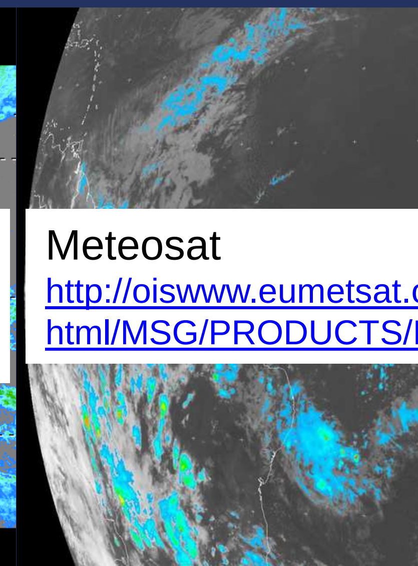
http://www.isac.cnr.it/~ipwg/data/datasets.html



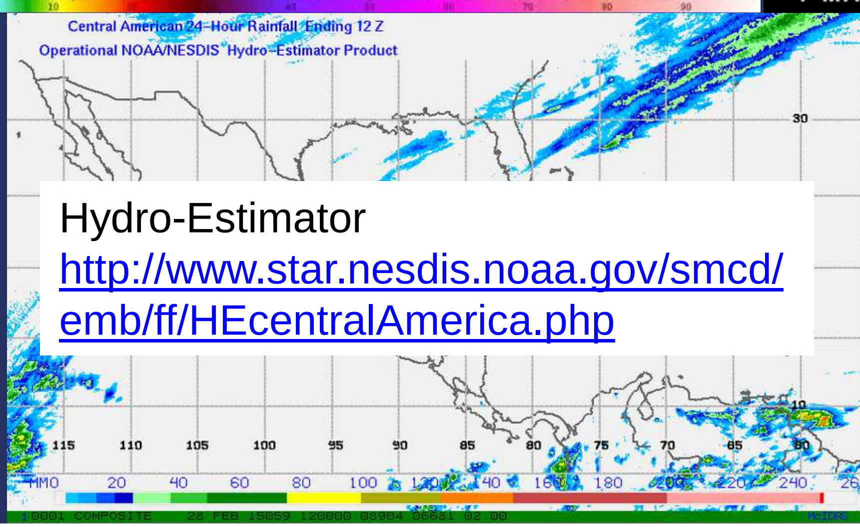
NRL-Blend
http://www.nrlmry.navy.mil/sat-bin/rain.cgi



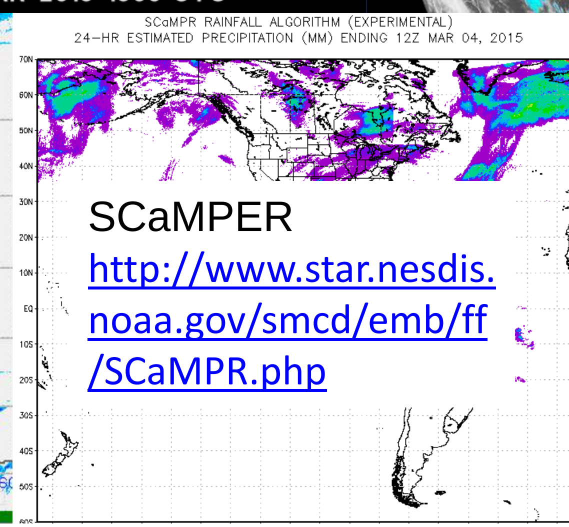
TRMM MPA
http://pmm.nasa.gov/node/171



Meteosat
http://oiswww.eumetsat.org/IPPS/html/MSG/PRODUCTS/MPE/

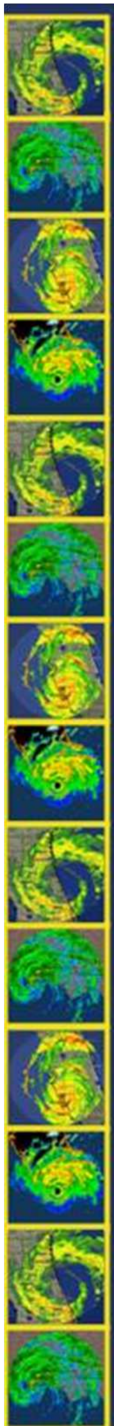


Hydro-Estimator
http://www.star.nesdis.noaa.gov/smcd/emb/ff/HEcentralAmerica.php



SCaMPER
http://www.star.nesdis.noaa.gov/smcd/emb/ff/SCaMPR.php

New 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
```

Created for every "invest" system

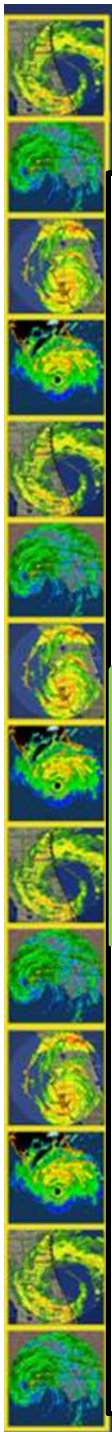
Can be created for any disturbance

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")

NATIONAL HURRICANE CENTER MIAMI FL



New NHC Rainfall Product: Text

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TCCA22 KNHC 291843
STDWCA

SATELLITE T..PIC.. DI
NWS NAT..ONA.. H.... C..N
2115 UTC TU.. 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
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RAINFALL MAY BE UNDERESTIMATED ON THE WINDWARD SIDE OF TERRAIN

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FORECASTER NELSON
```

```
RAINFALL ESTIMATED BY SATELLITE VIA NRL-BLEND...
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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
-----------------------------------------------------------------
```
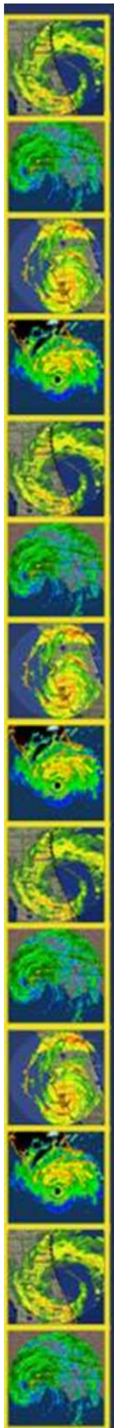
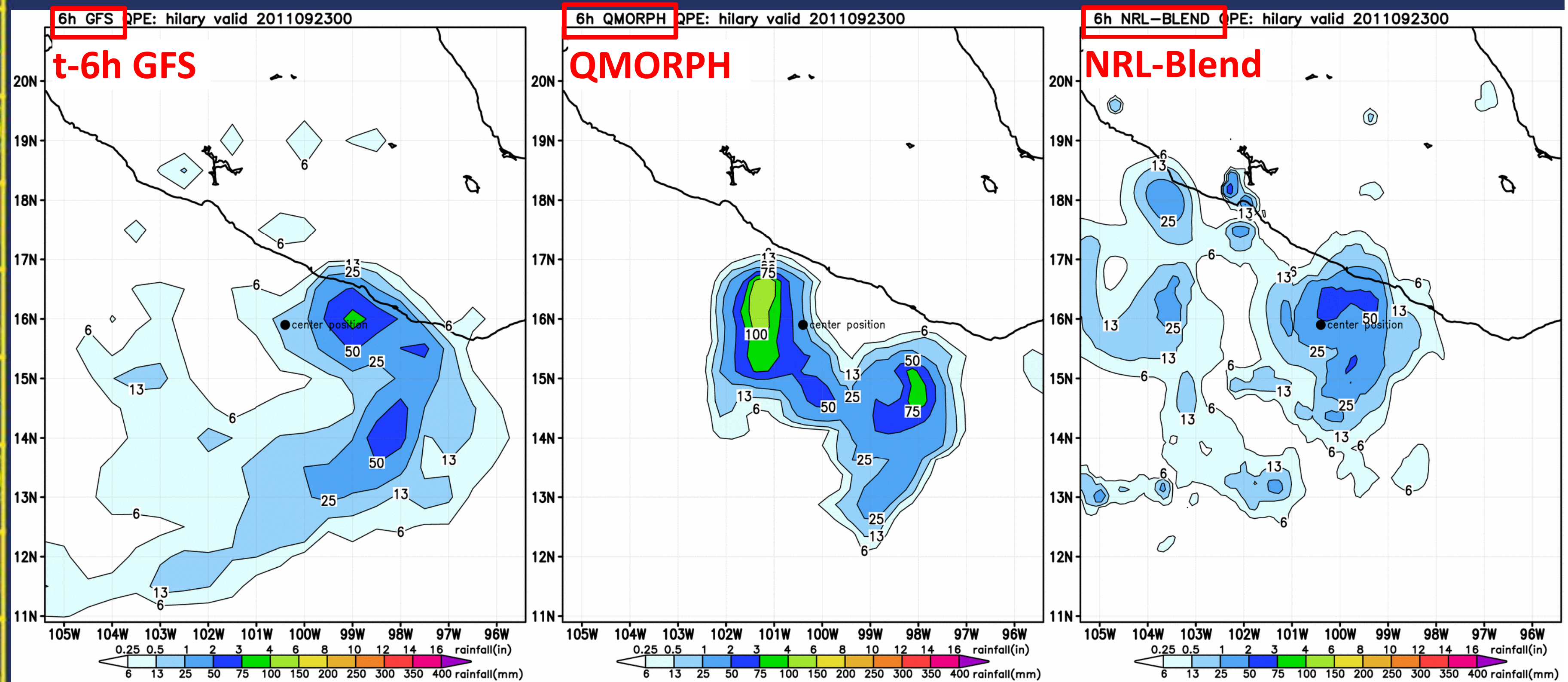

- Lat-lon grid of rainfall accumulation
- 6-h accumulation ranges (in mm)
- Differences in the 3 rainfall estimates reveal uncertainty



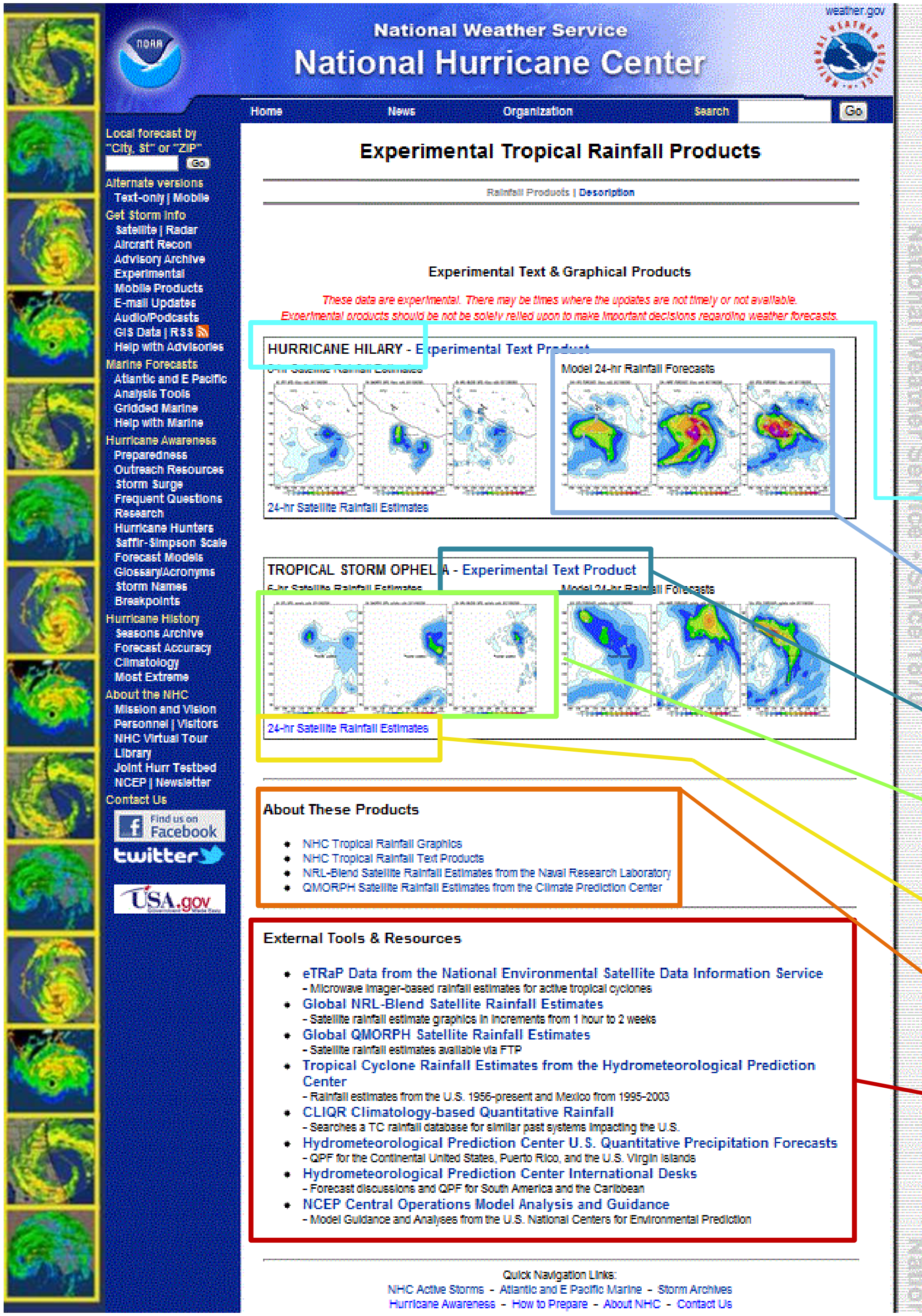
Experimental NHC Rainfall Product: QPE Graphics

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/marine/rainfall/

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

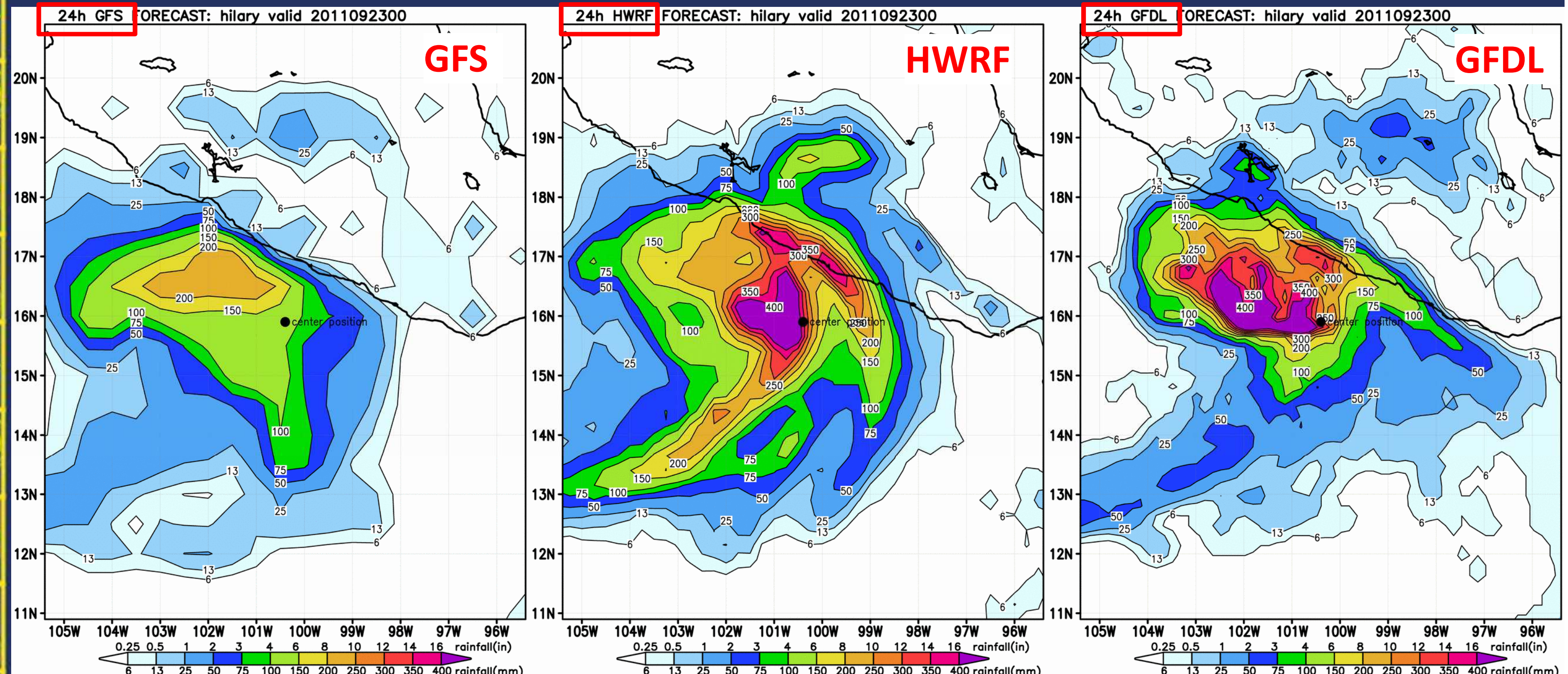
Link to 24-hour QPE graphics

Product descriptions

Other tropical rainfall tools and resources

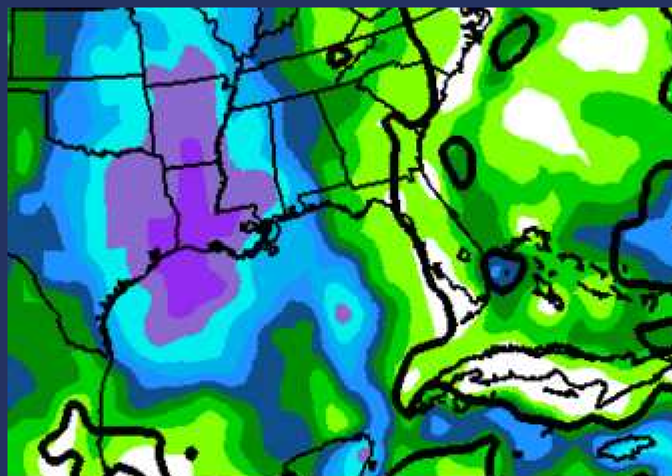
Experimental NHC Rainfall Product: QPF Graphic

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

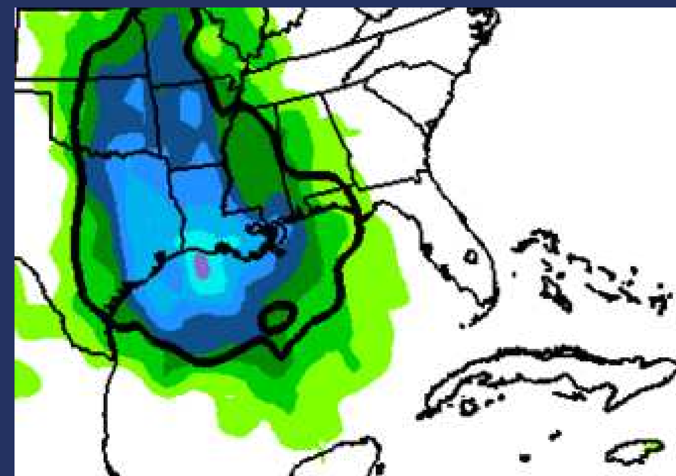


GEFS Probabilities of Exceedance

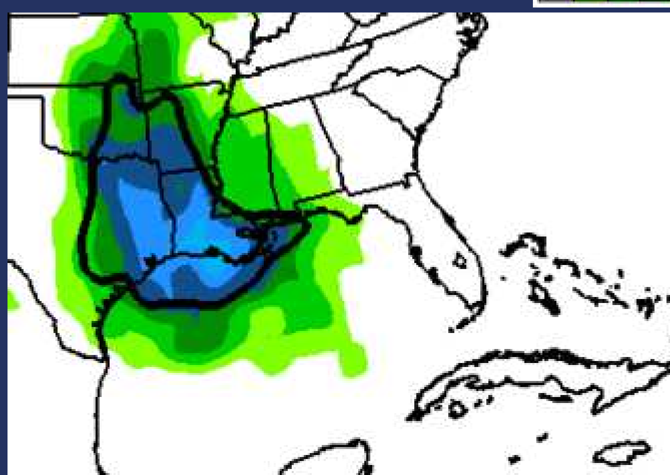
Potential Addition to NHC Rainfall Webpage



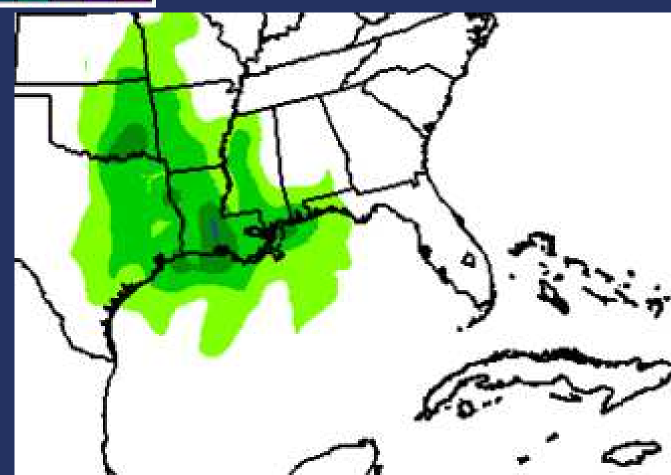
Probability of measurable precipitation



Probability of exceeding 10 mm



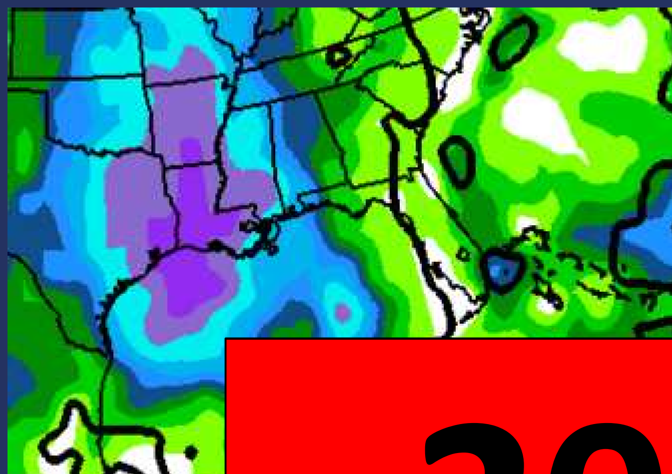
Probability of exceeding 25 mm



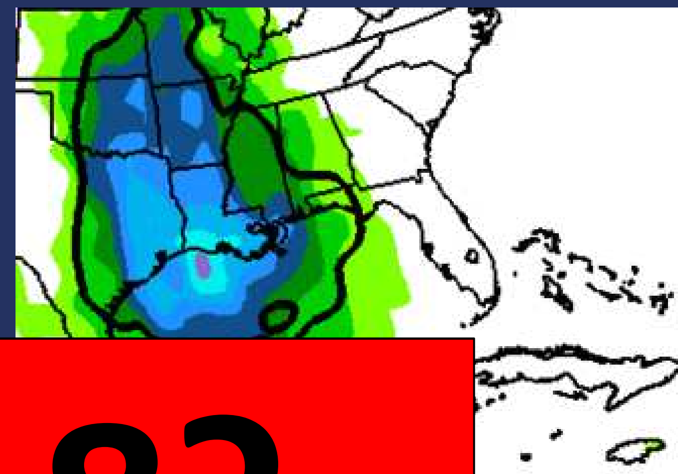
Probability of exceeding 50 mm

GEFS Probabilities of Exceedance

Potential Addition to NHC Rainfall Webpage

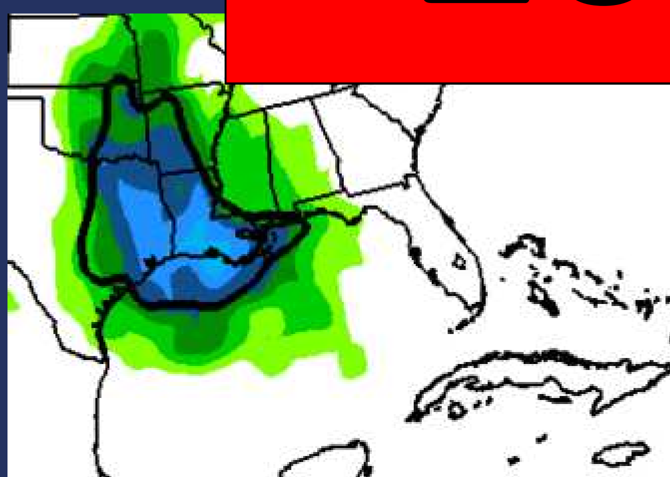


Probability o

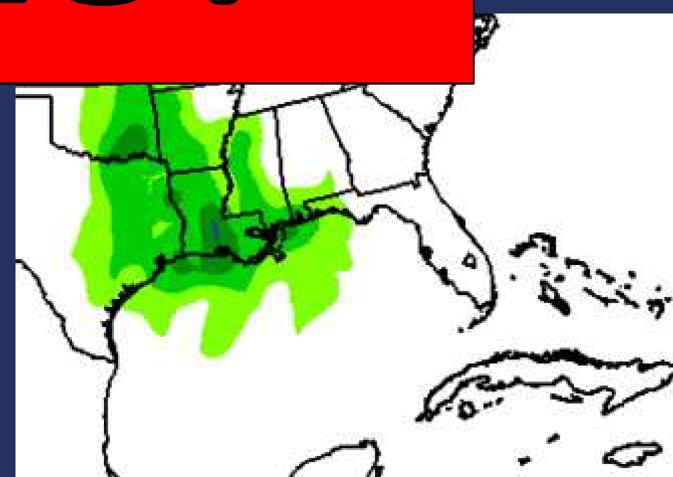


g 10 mm

2018?

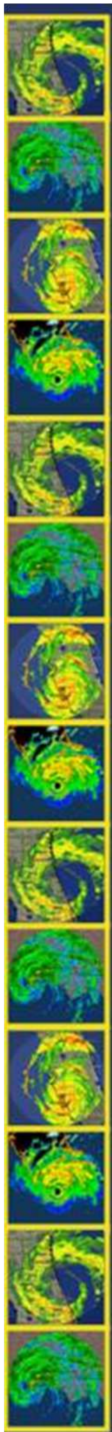


Probability of exceeding 25 mm



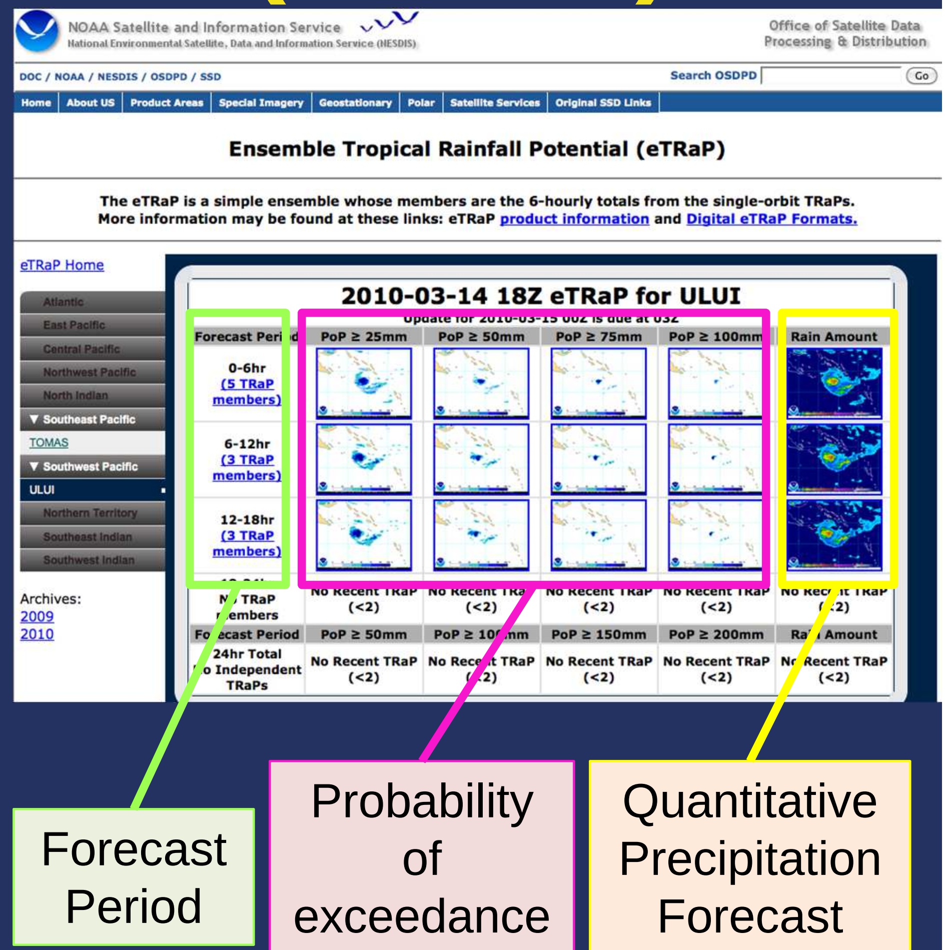
Probability of exceeding 50 mm

Ensemble Tropical Rainfall Potential Product (eTRaP)



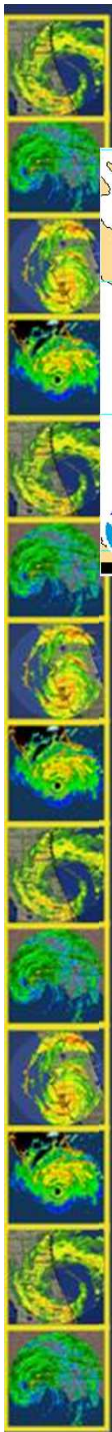
- 6-hourly Day 1 forecasts: Extrapolates polar orbiting satellite rain rate along TC forecast tracks

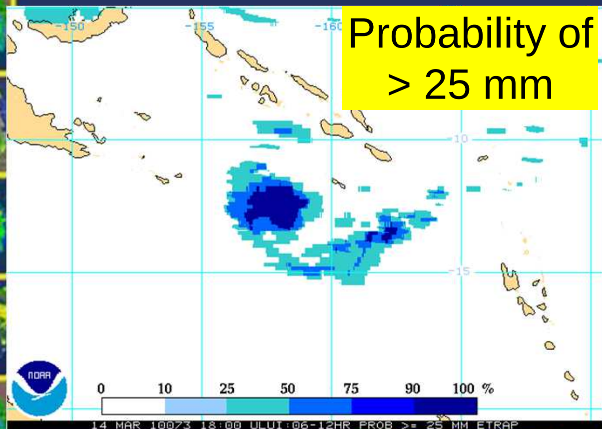
  (AMSU, SSMI, & AMSRE)
- A satellite “member” is included when its path passes over the TC
- “Members” are weighted according to age of pass and past performance of sensor
- Official forecast of TC track & at least 2 members needed to create a forecast
- Updated daily at 0315, 0915, 1515, and 2115 UTC

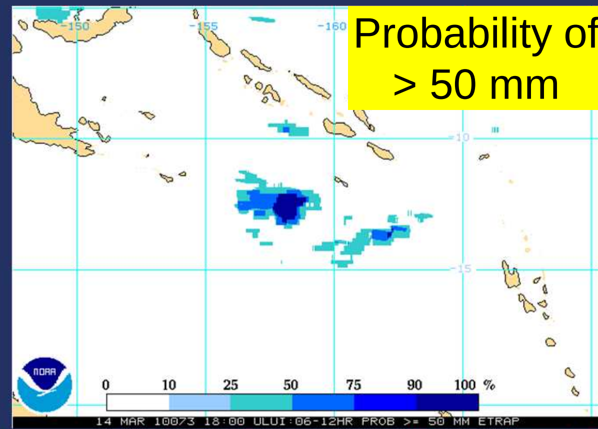


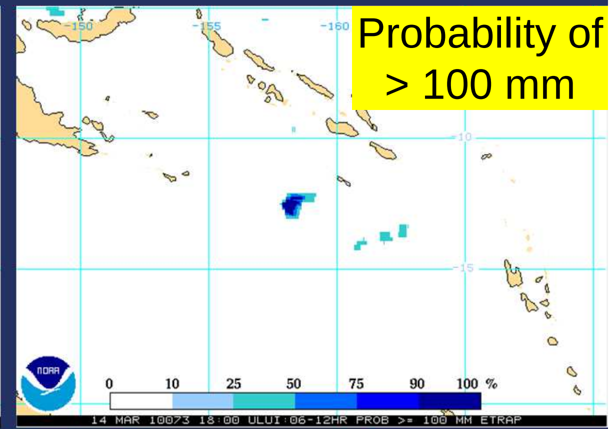
http://www.ssd.noaa.gov/PS/TROP/etrap.html

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

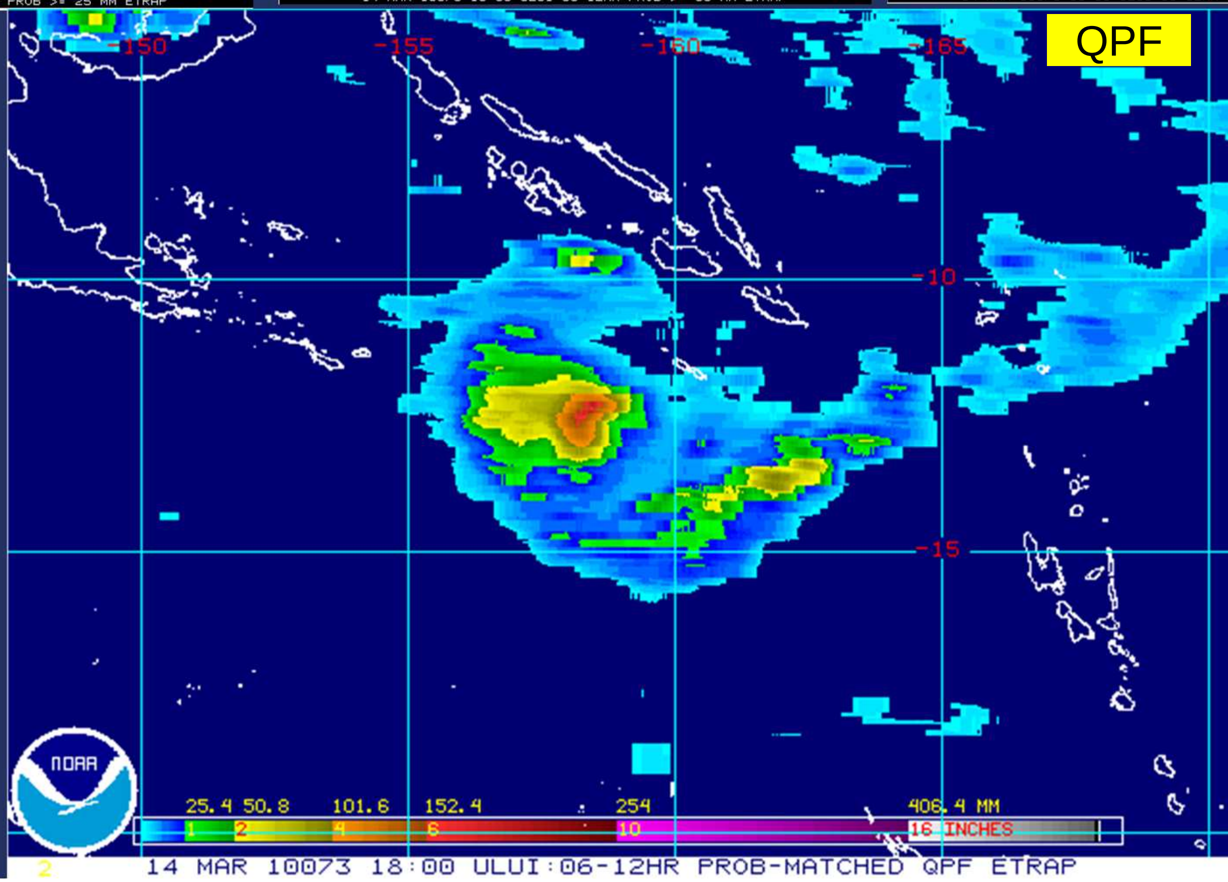


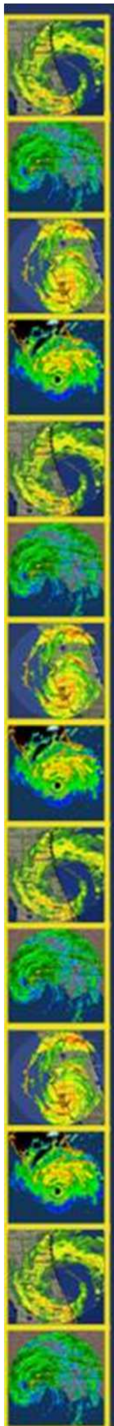






Typhoon Ului
06-12 hr
eTRaP
forecast





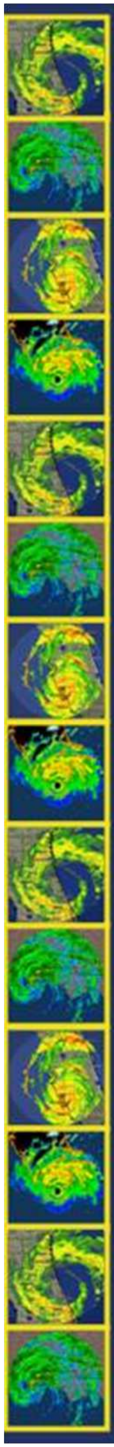
CLIQR: Picking an Analog for a TC Rainfall Event

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

Looks 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 examines 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.

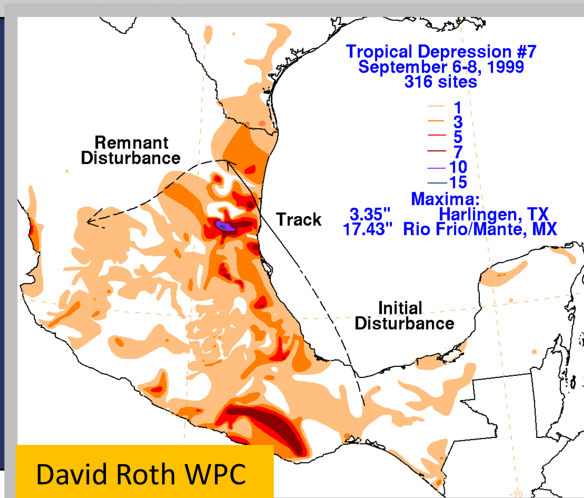
Select Storm By Name	Rainfall analogs to current tropical cyclones	Select Storm By Year
Select Storm By Region Of Impact	Select Storm By Point Of Entry	Tropical Cyclone Maxima Per U. S. State
Tropical Cyclone Maxima Per Mexican State	Point Maxima for Tropical Cyclones	Tropical Cyclone Averages and Maxima 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

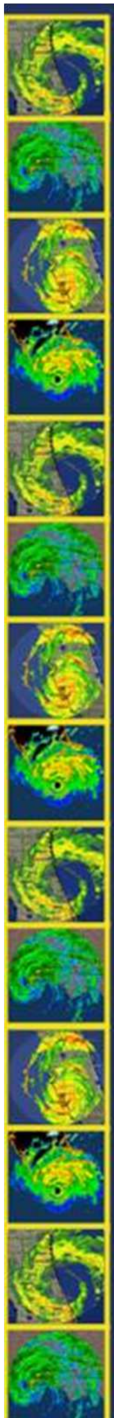
CLIQR Matching TC List
(Rainfall Matches Accessible via Hyperlink)

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



GOES-R Products

Scheduled for Launch in Late 2016

Rainfall Rate Algorithm

Rainfall Potential Algorithm

Probability of Rainfall Algorithm

GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITE-R SERIES

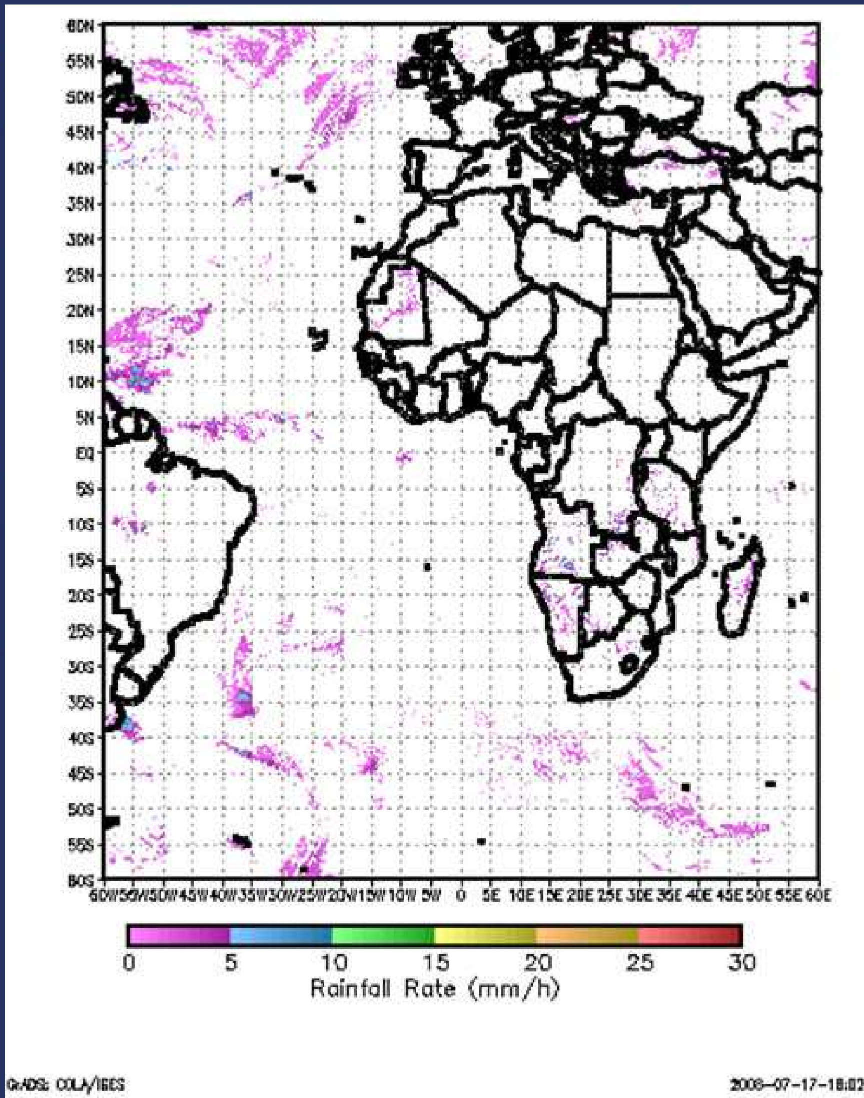
GOES-R

NOAA ~ NASA

NATIONAL HURRICANE CENTER

GOES-R Products

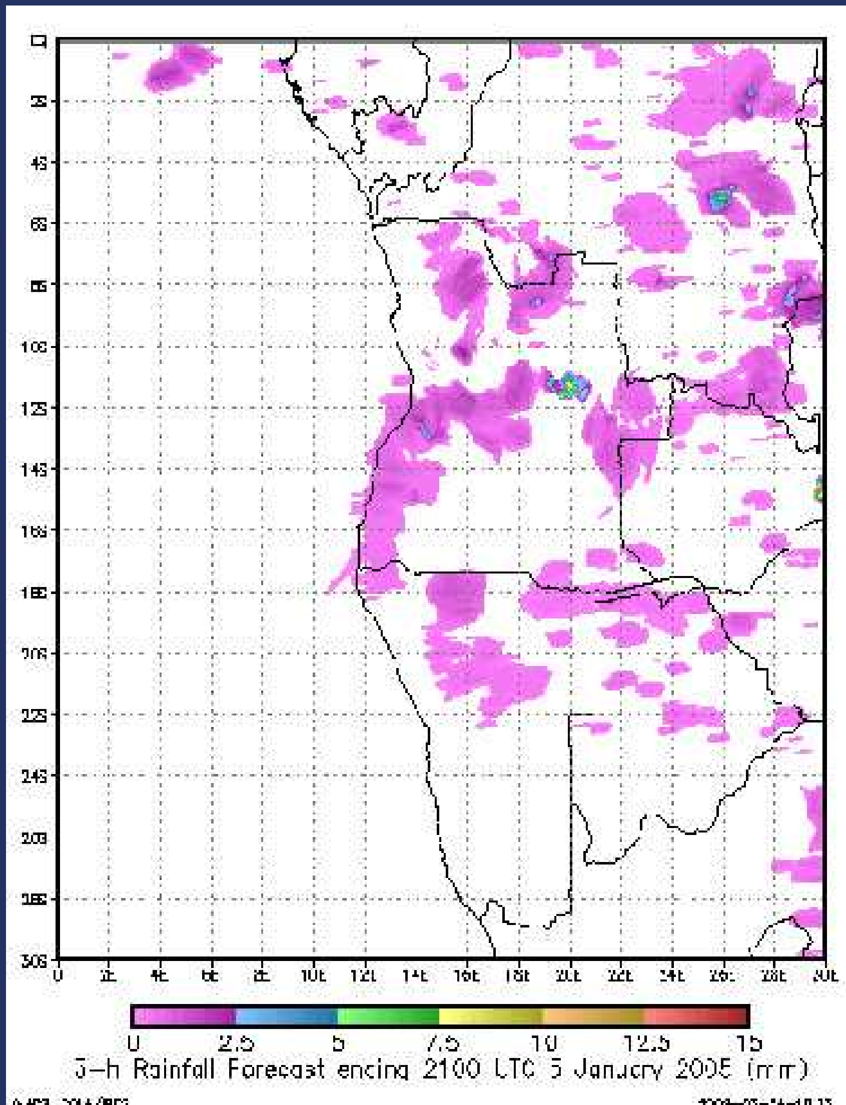
Rainfall Rate



- The algorithm generates estimates of the instantaneous rainfall rate at each IR pixel
- Uses IR brightness temperatures and is calibrated in real time against microwave-derived rain rates to enhance accuracy
- The higher spatial and temporal resolution available from GOES-R will be able to automatically resolve rainfall rates on a finer scale

GOES-R Products

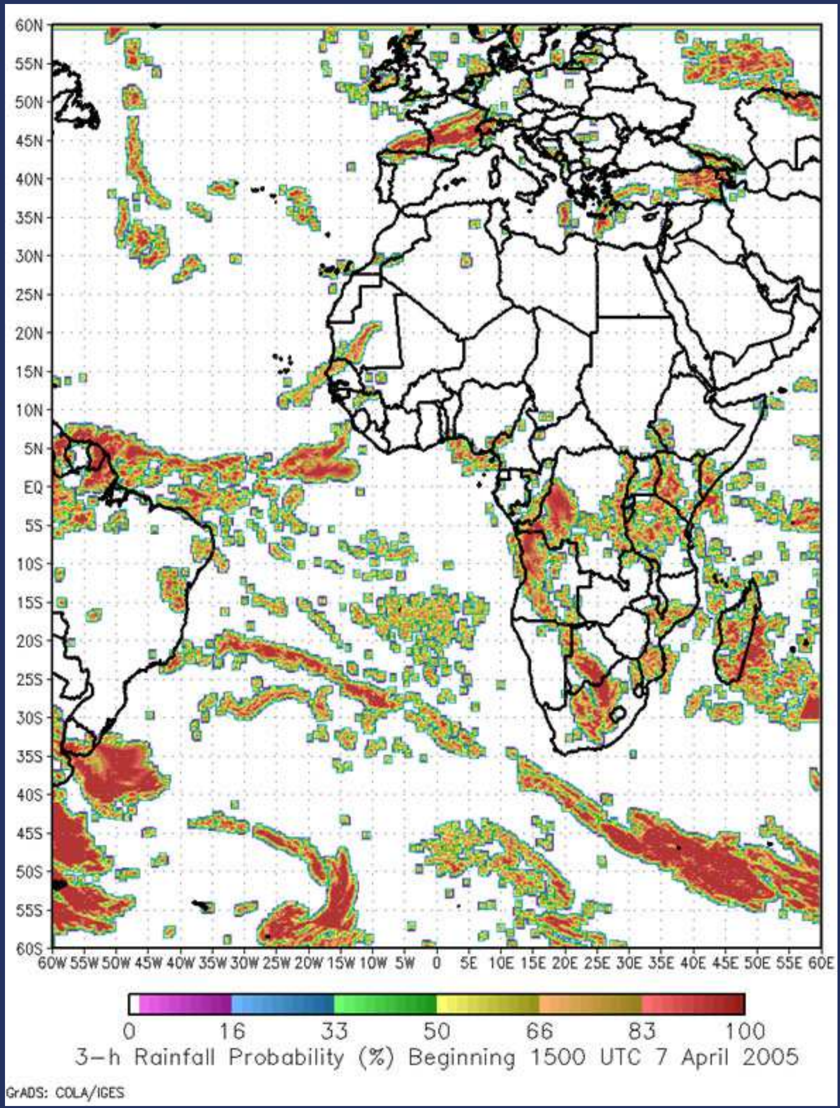
Rainfall Potential



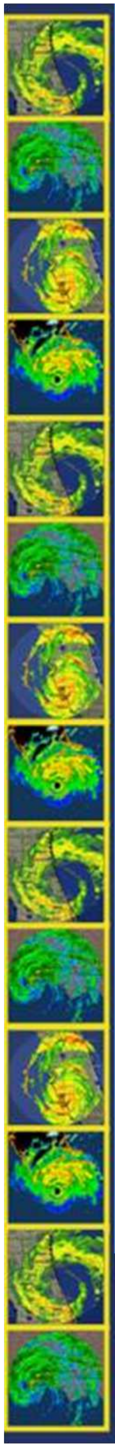
- Predicted rainfall accumulation for the next 3 hours at the satellite pixel scale
- Extrapolation from current and previous rainfall rates from the GOES-R Rainfall Rate Algorithm

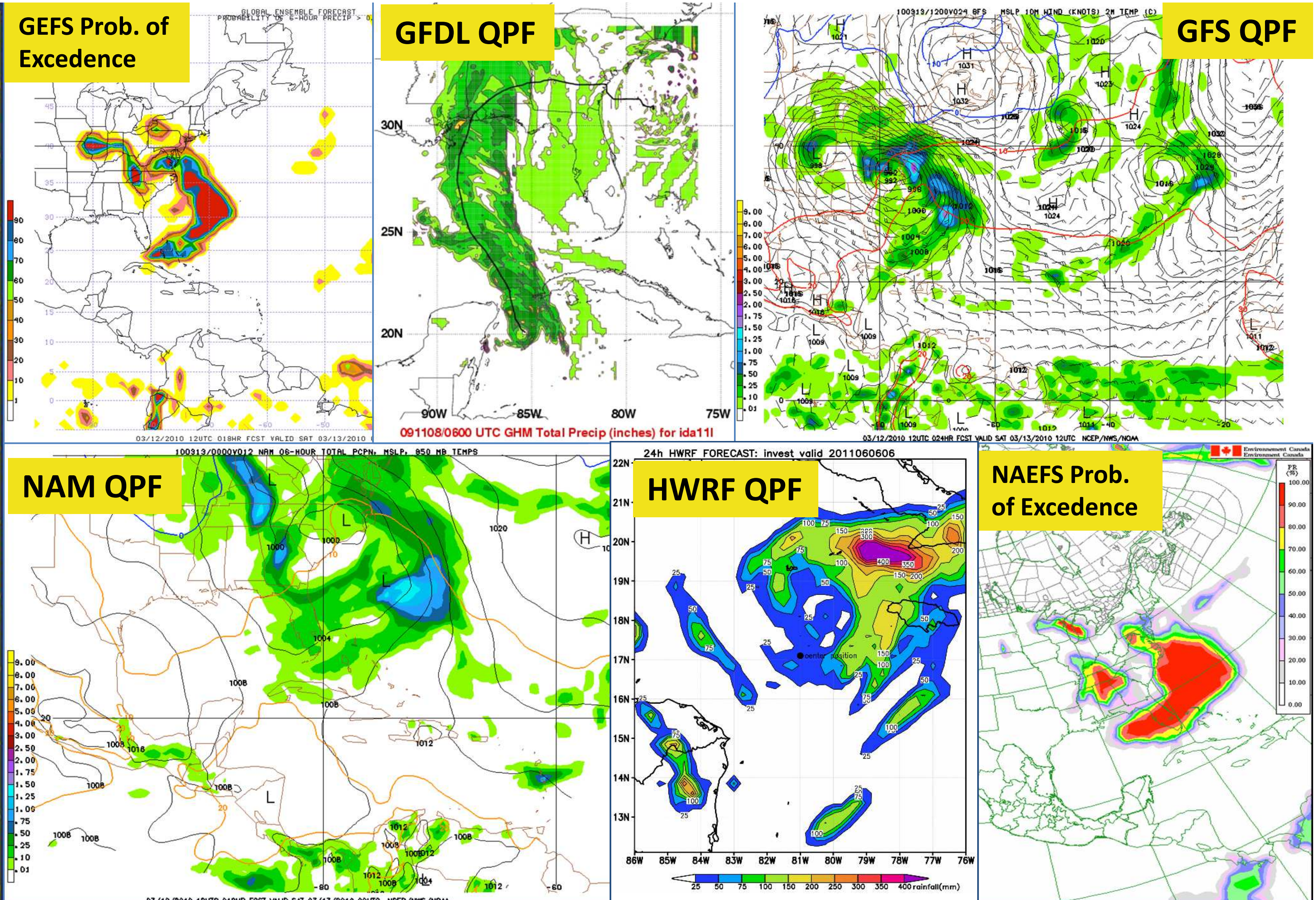
GOES-R Products

Probability of Rainfall



- Generates a gridded probability of at least 1 mm of rainfall during the next 3 hours at the satellite pixel scale
- Uses intermediate rainfall rate forecasts from the Rainfall Potential Algorithm as input to a statistical model calibrated against estimates from the Rainfall Rate Algorithm

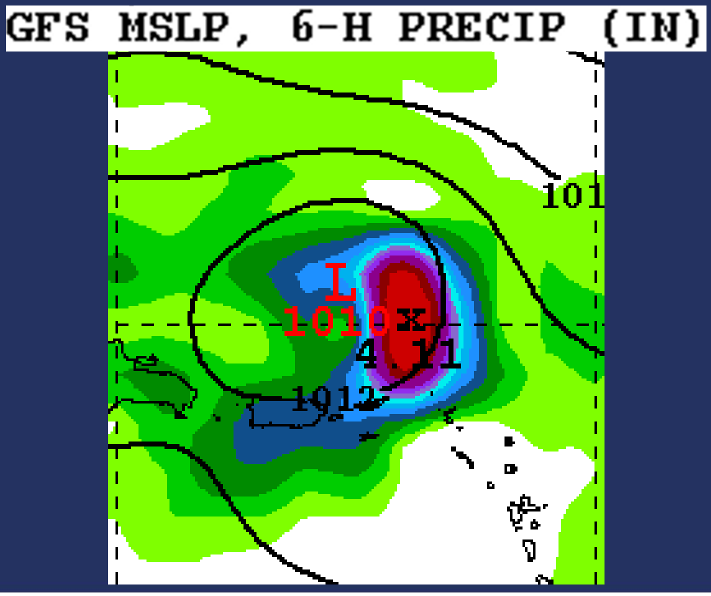


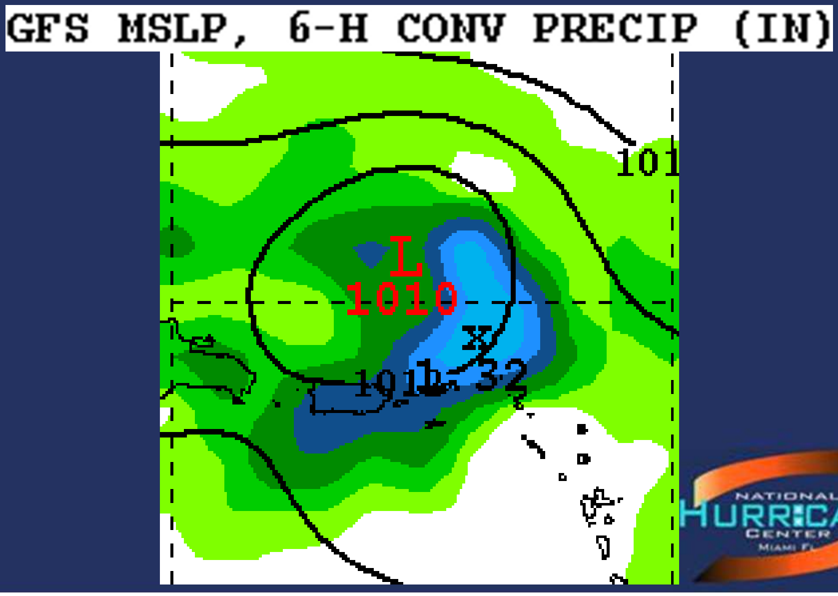


Model Forecasts

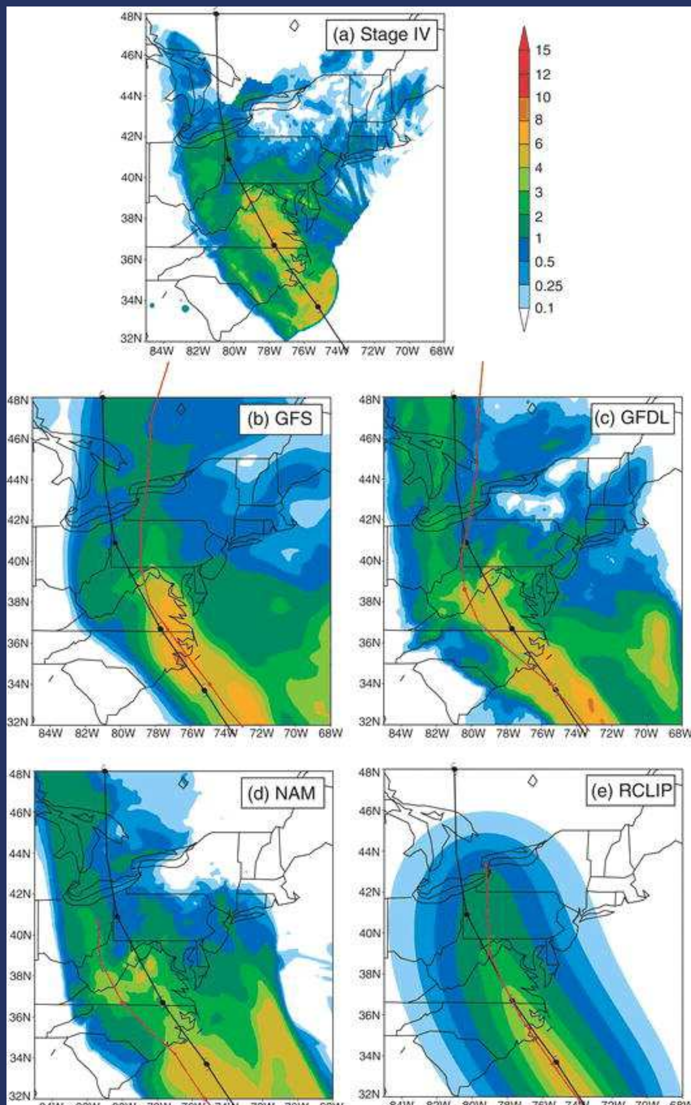
NCEP Model QPF Biases

- **NCEP models are updated frequently which makes it difficult to isolate distinct biases**
- Run-to-run consistency increases confidence of occurrence
- Convective 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)





Model TC QPF Skill
Marchok et al, 2007



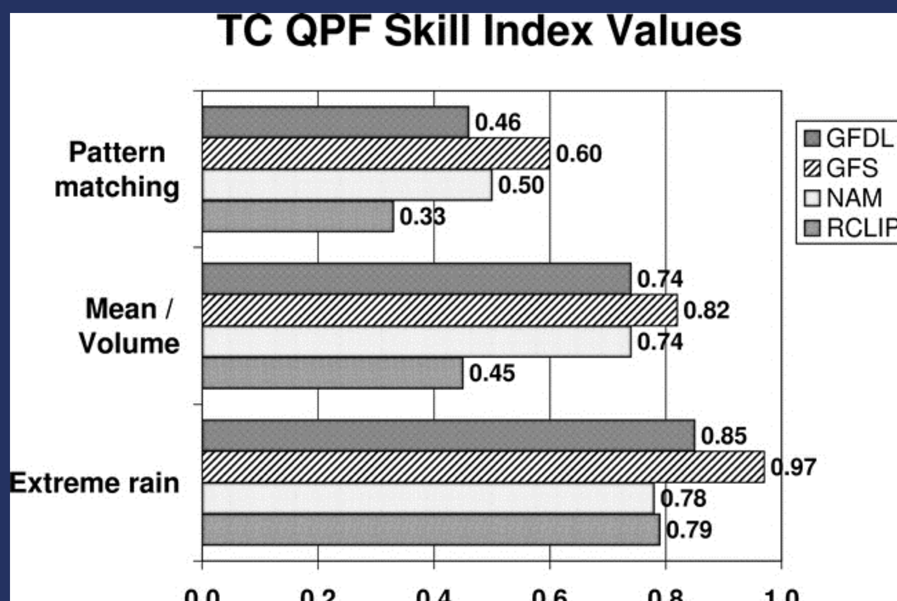
1998-2004 U.S. landfalling TC QPFs from the GFS, GFDL hurricane model, the NAM, and the R-CLIPER (Rainfall Climatology and Persistence)

Three elements of TC rainfall forecasts used as a basis for comparing models:

- model ability to match the large-scale rainfall pattern,
- model ability to match the mean rainfall and the distribution of rain volume, and
- model ability to produce the extreme amounts often observed in TCs

Model TC QPF Skill
Marchok et al, 2007

- Compared to R-CLIPER, all of the numerical models showed comparable or greater skill for all of the attributes
- The GFS performed the best of all of the models for each of the categories
- The GFDL had a bias of predicting too much heavy rain, especially in the core of the tropical cyclones
- the NAM predicted too little of the heavy rain.
- The R-CLIPER performed well near the track of the core, but it predicted much too little rain at large distances from the track.



Model TC QPF Skill
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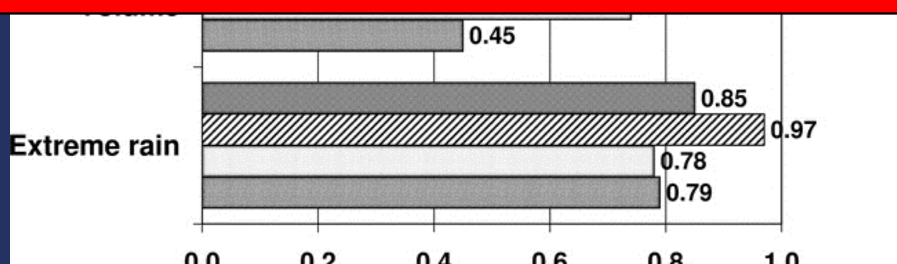
- Compared t parable or greater skill
- The GFS p ategories
- The GFDL I y in the core of the tropic
- the NAM pr
- The R-CLIF edicted much too lit

Track forecast error was a primary determinant of tropical cyclone QPF error



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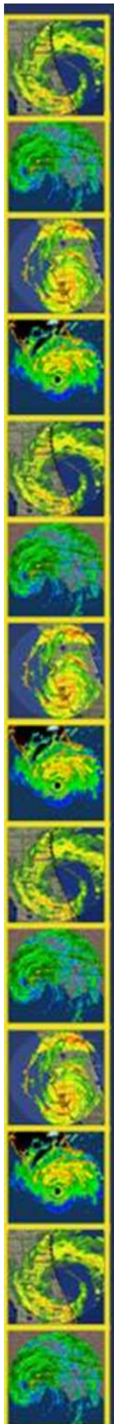


Where to Find Model QPFs

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

http://www.nhc.noaa.gov/marine/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**

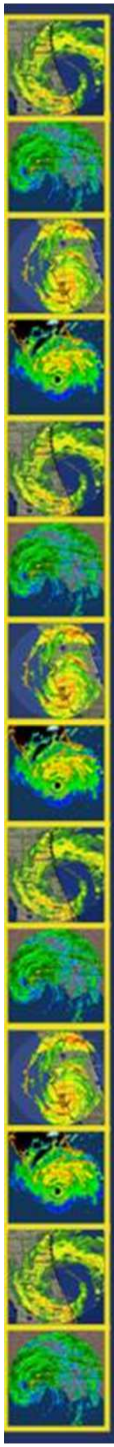
http://schumacher.atmos.colostate.edu/weather/ecmwf.php

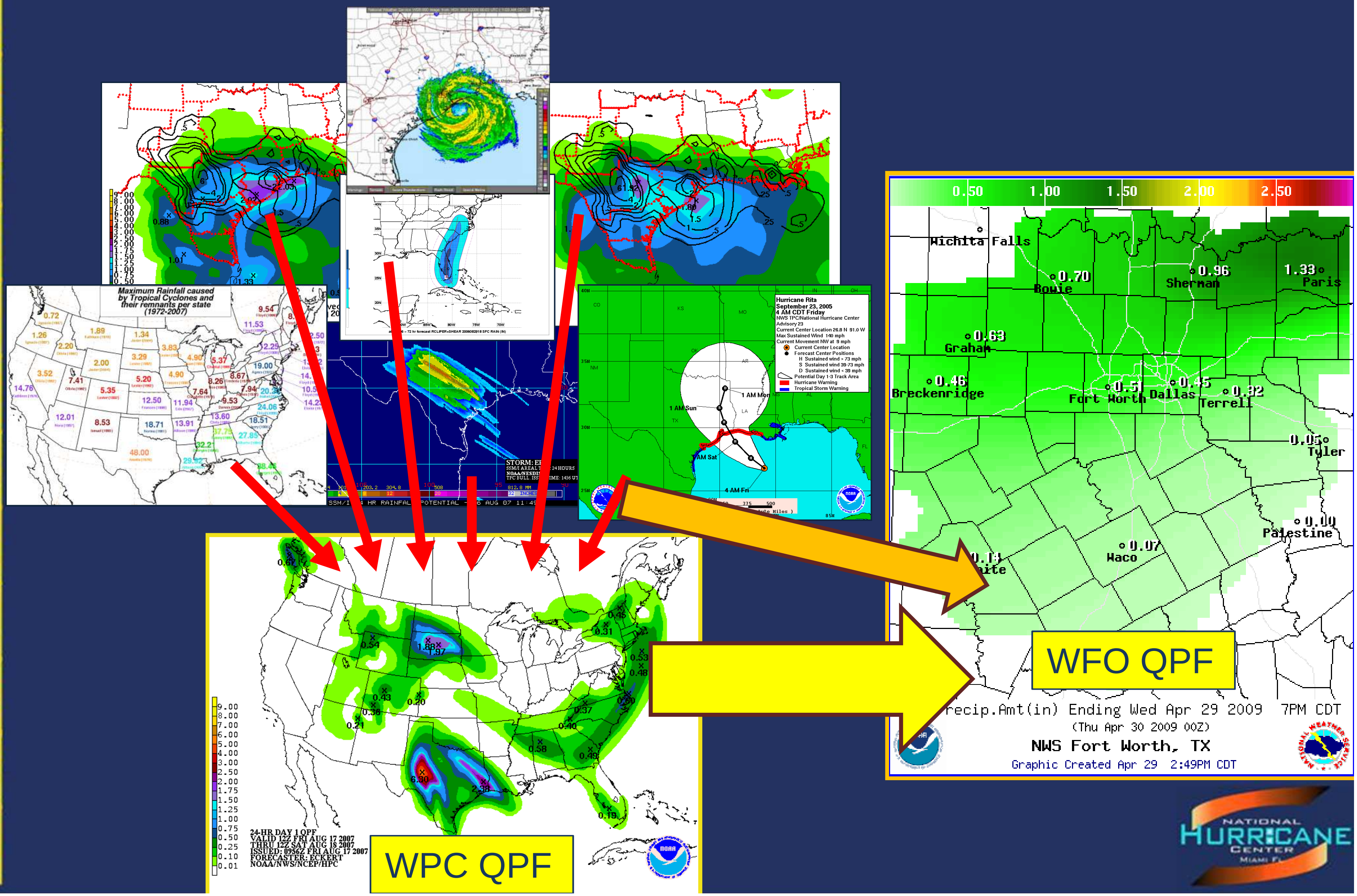
- **Penn State Tropical Atlantic E-Wall**

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

TC QPF Forecast Process

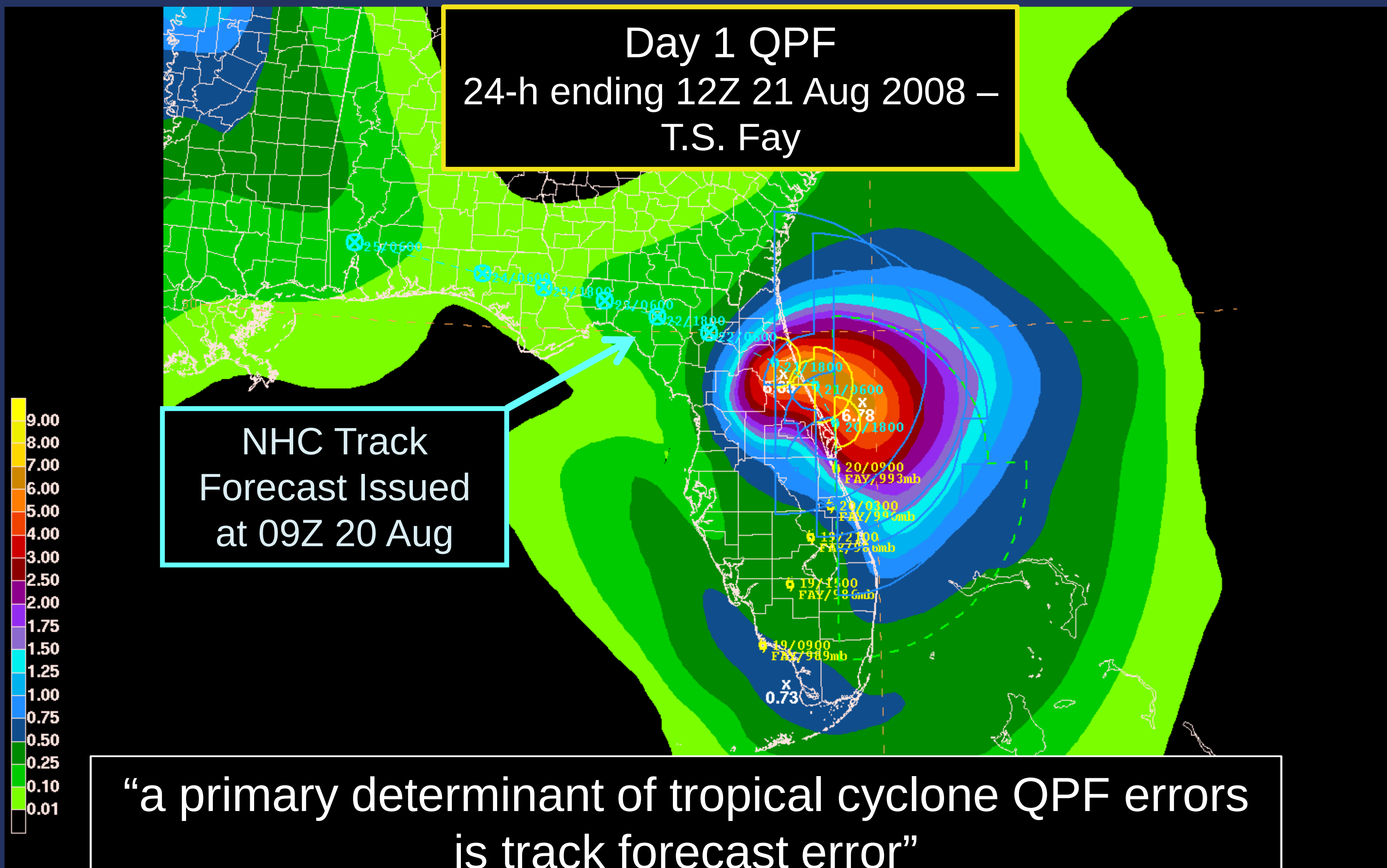
NWS Tropical Cyclone Quantitative Precipitation Forecasts (QPF)





Production of Tropical Cyclone Quantitative Precipitation Forecasts

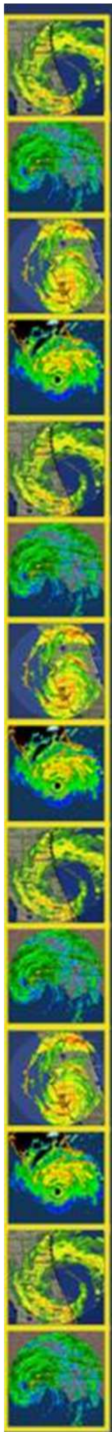
A good place to start is the model closest to the NHC track forecast

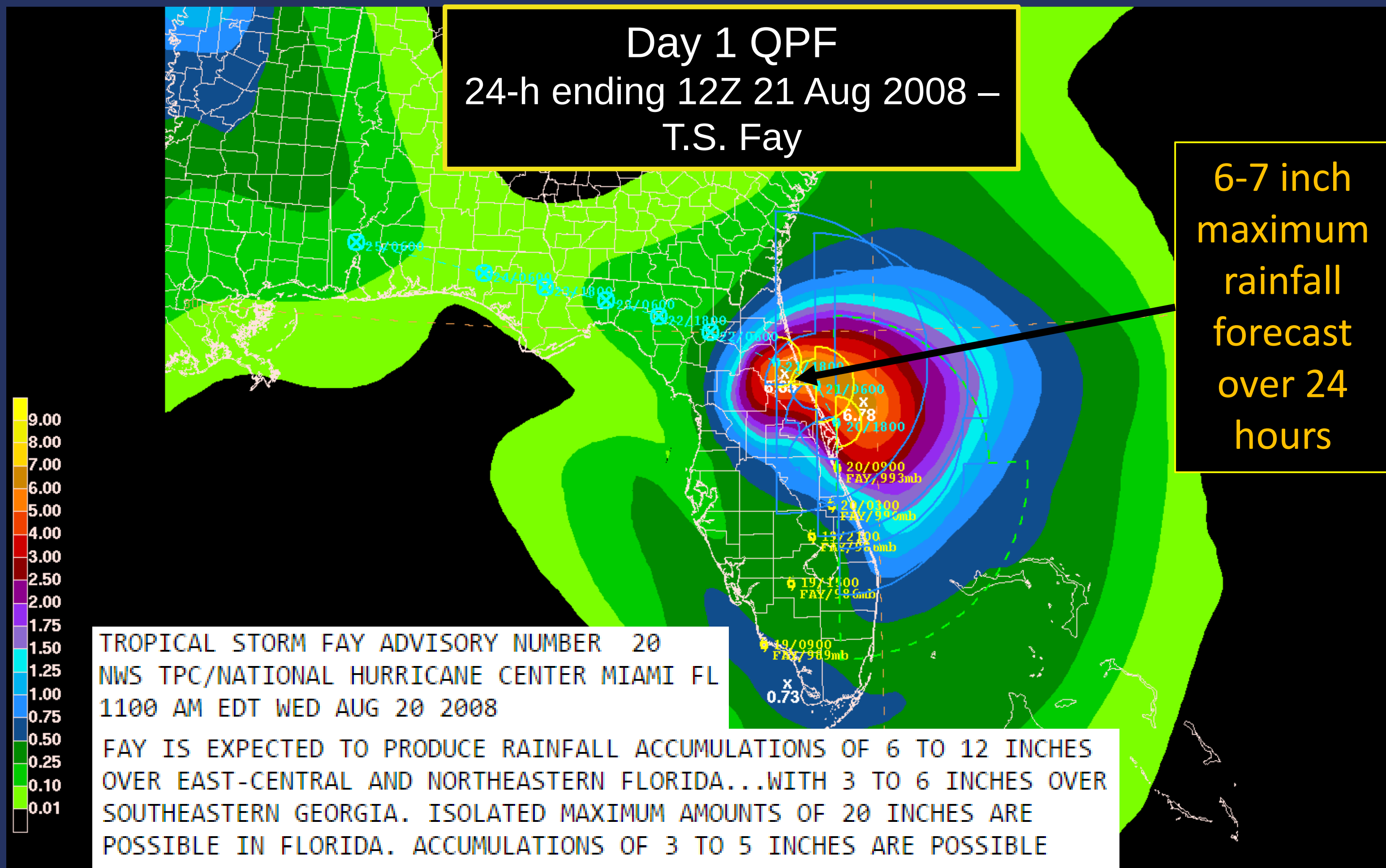


“a primary determinant of tropical cyclone QPF errors is track forecast error”
– Marchok et al 2007

Production of Tropical Cyclone Quantitative Precipitation Forecasts

How well do the models match the NHC rainfall statement?



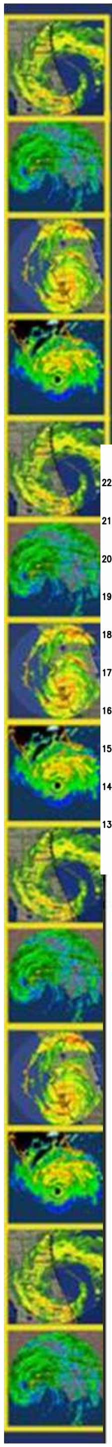


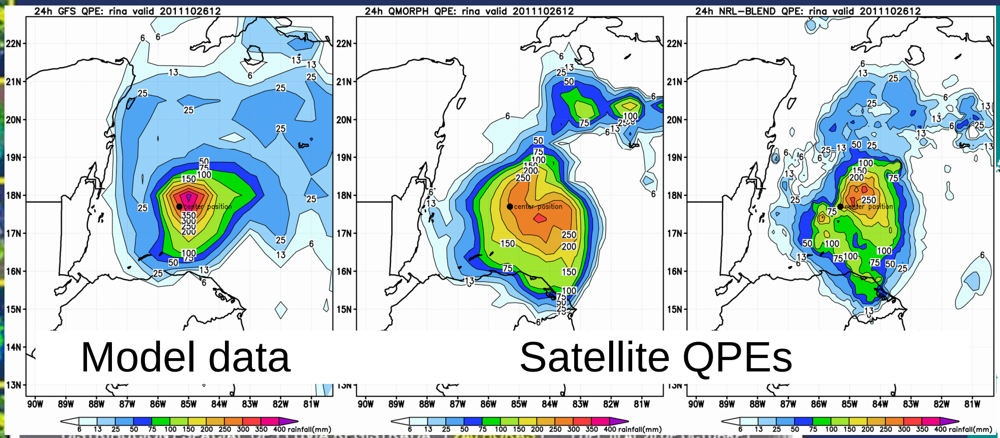
TROPICAL STORM FAY ADVISORY NUMBER 20
NWS TPC/NATIONAL HURRICANE CENTER MIAMI FL
1100 AM EDT WED AUG 20 2008

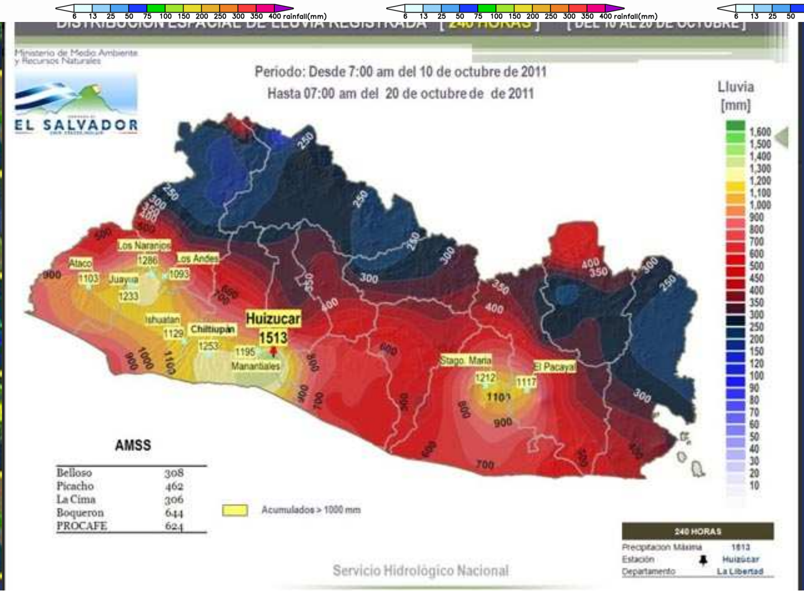
FAY IS EXPECTED TO PRODUCE RAINFALL ACCUMULATIONS OF 6 TO 12 INCHES OVER EAST-CENTRAL AND NORTHEASTERN FLORIDA...WITH 3 TO 6 INCHES OVER SOUTHEASTERN GEORGIA. ISOLATED MAXIMUM AMOUNTS OF 20 INCHES ARE POSSIBLE IN FLORIDA. ACCUMULATIONS OF 3 TO 5 INCHES ARE POSSIBLE IN THE NORTHWESTERN BAHAMAS. AN UNOFFICIAL REPORT OF NEAR 16 INCHES OF RAIN WAS MEASURED AT SATELLITE BEACH JUST TO THE NORTHEAST OF MELBOURNE FLORIDA.

Production of Tropical Cyclone Quantitative Precipitation Forecasts

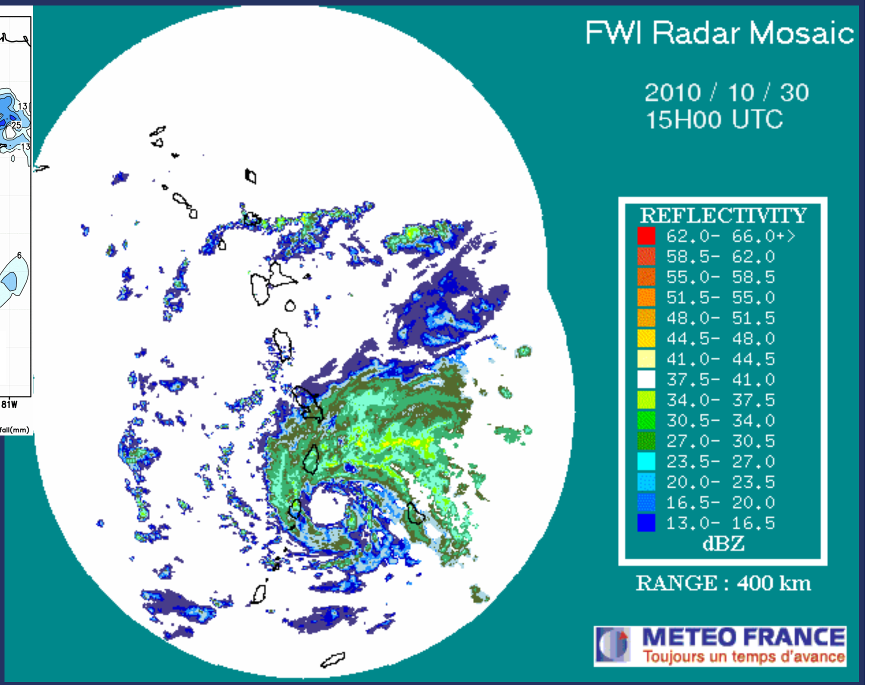
Use observations and recent model data to determine the current structure/rainfall rates







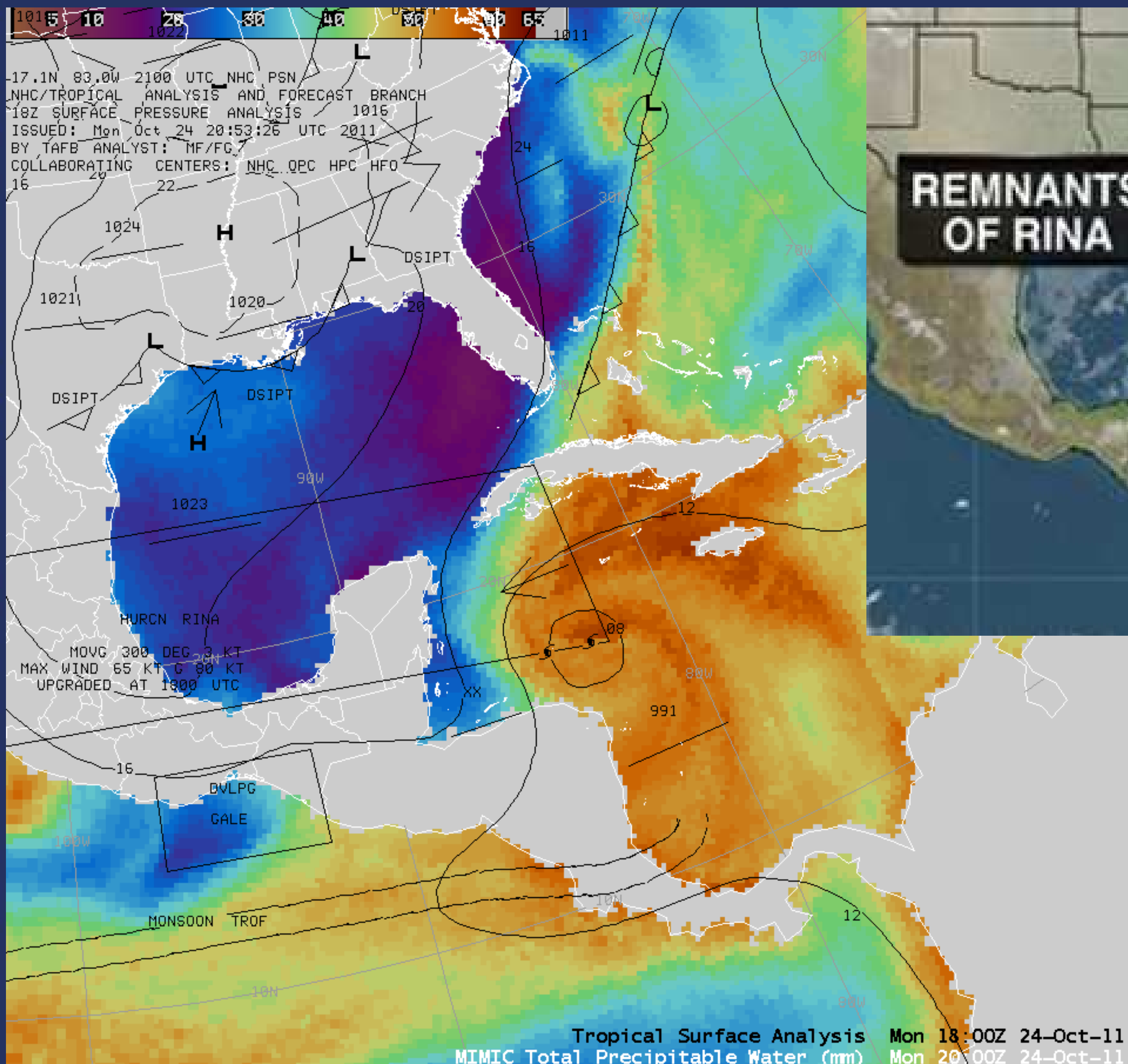
Gauge data



Radar

Production of Tropical Cyclone Quantitative Precipitation Forecasts

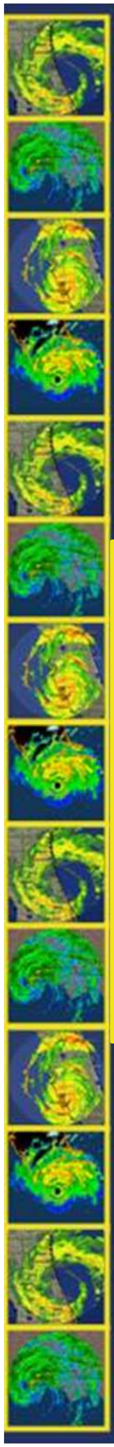
Locate relevant synoptic scale and meso-scale boundaries

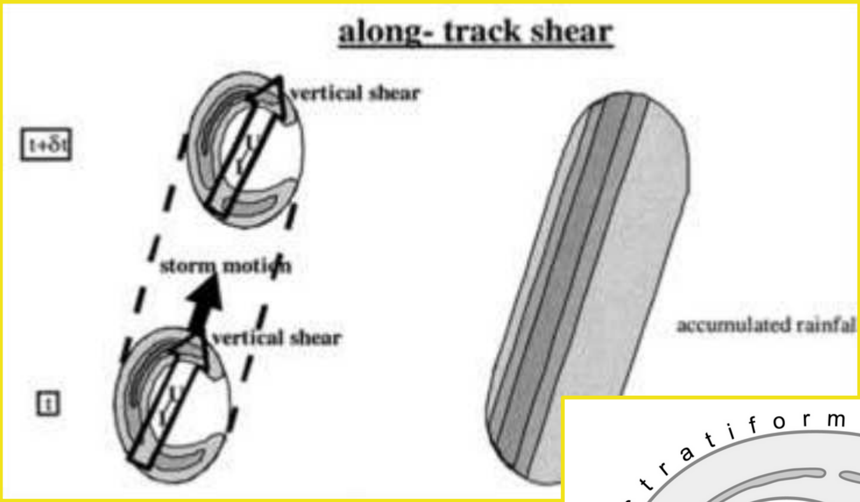


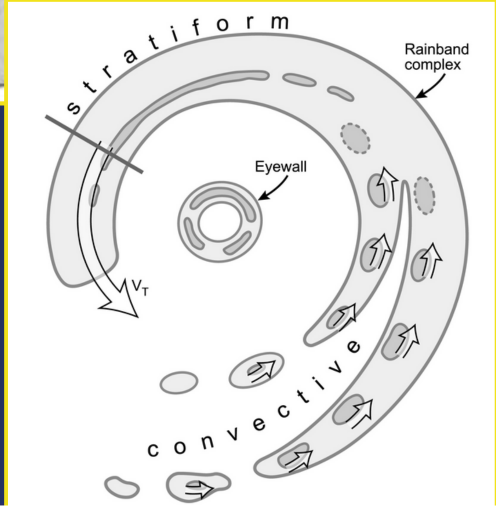
Hurricane Rina (2011)

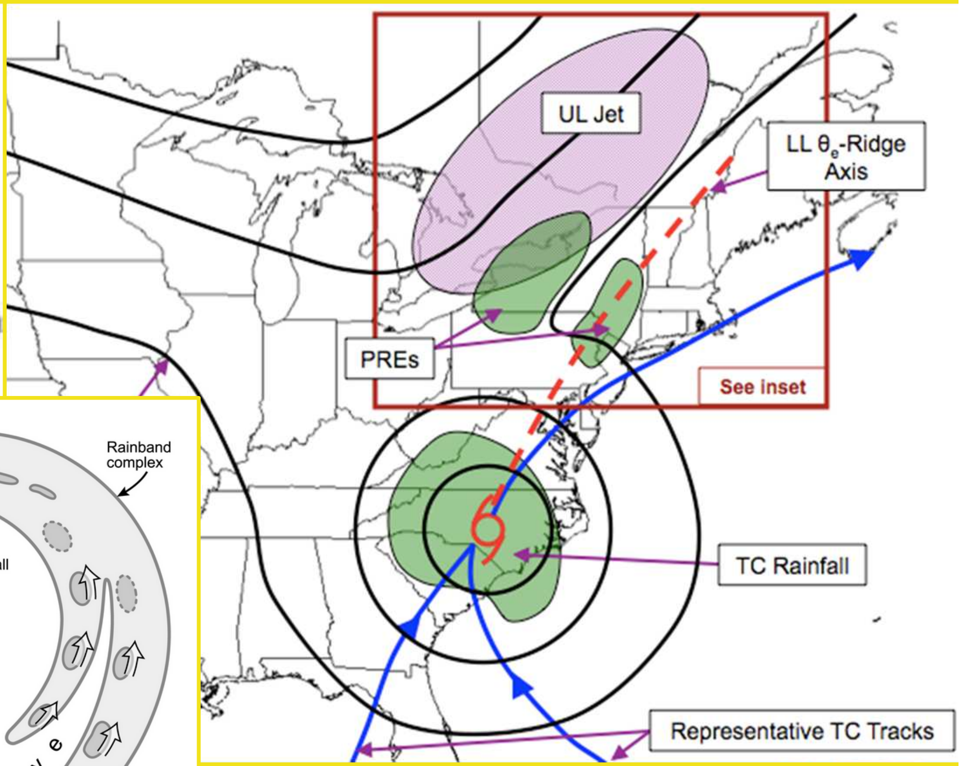
Production of Tropical Cyclone Quantitative Precipitation Forecasts

Use conceptual models and pattern recognition as well as the forecast upper level winds to further adjust QPF









Production of Tropical Cyclone Quantitative Precipitation Forecasts

Identify areas of orographic enhancement

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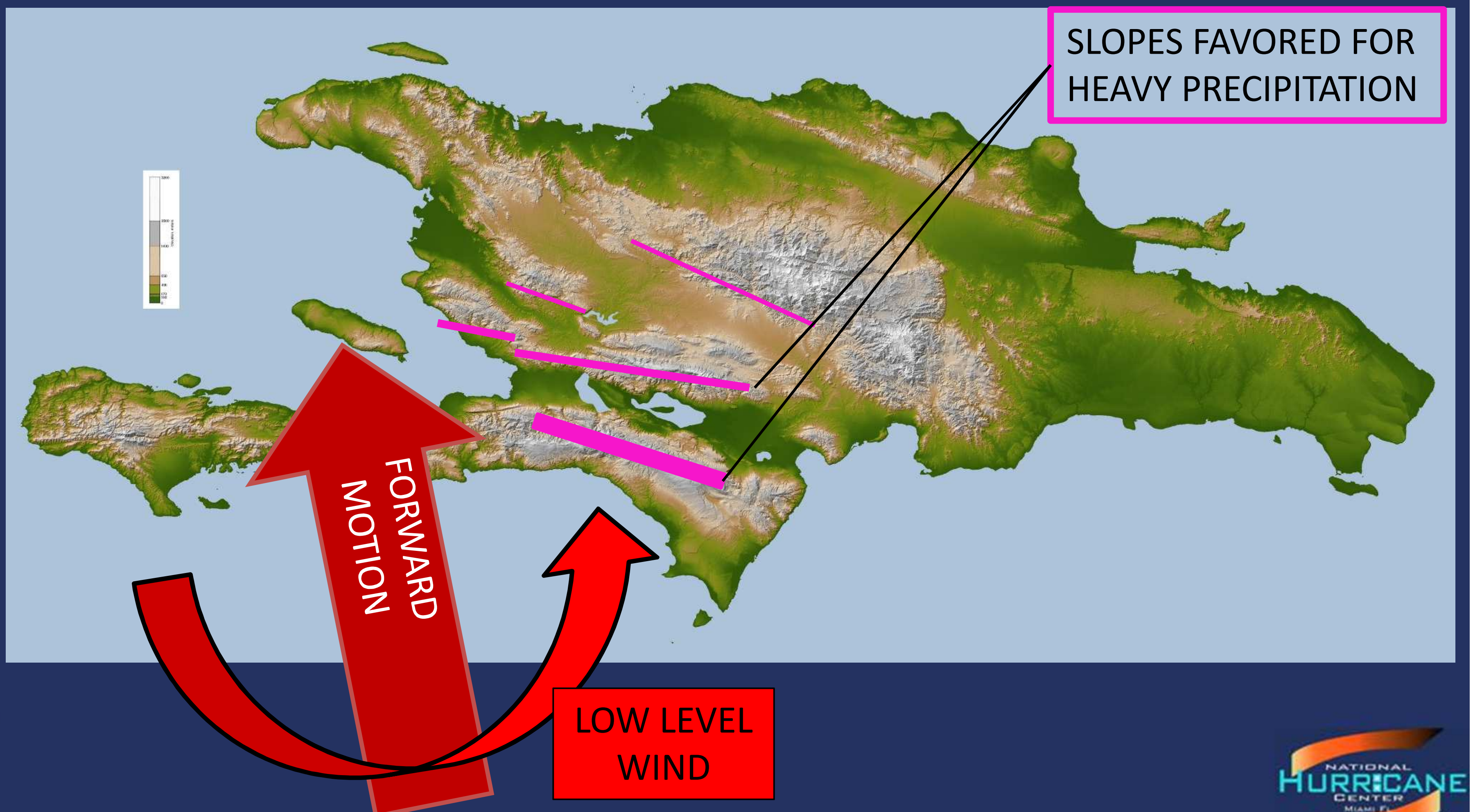

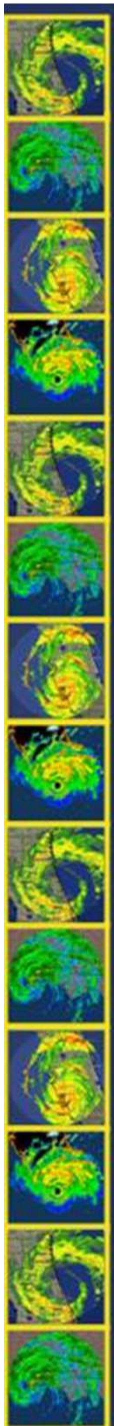

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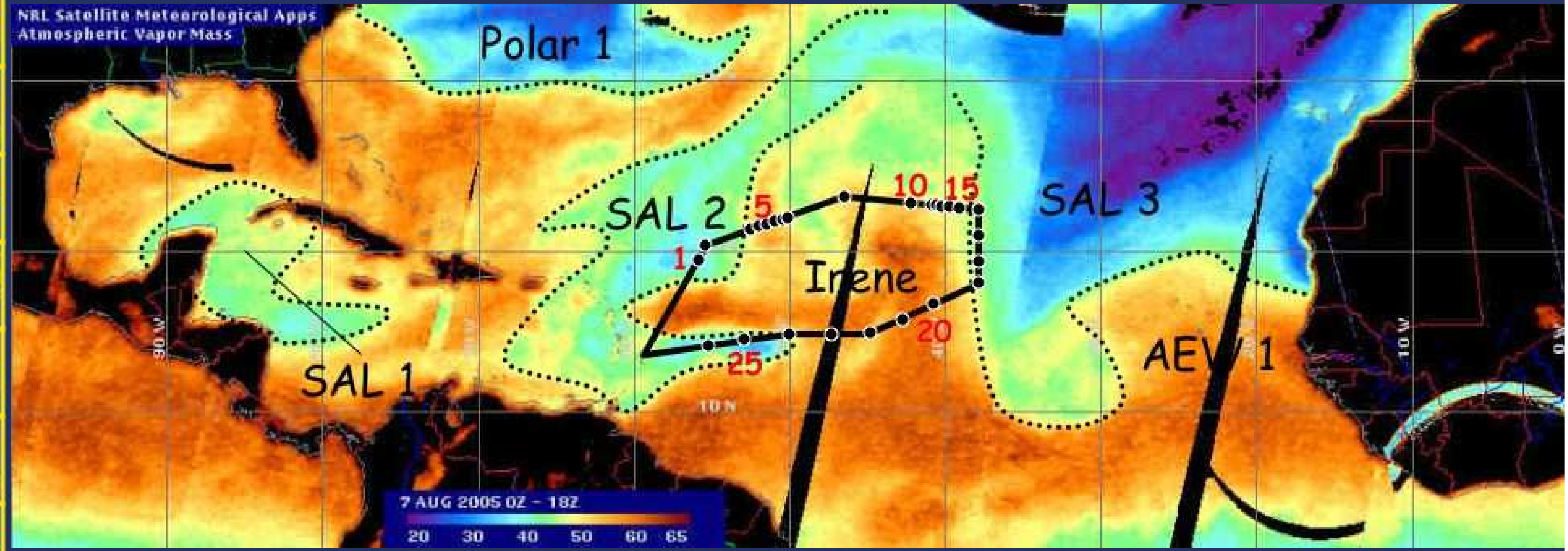
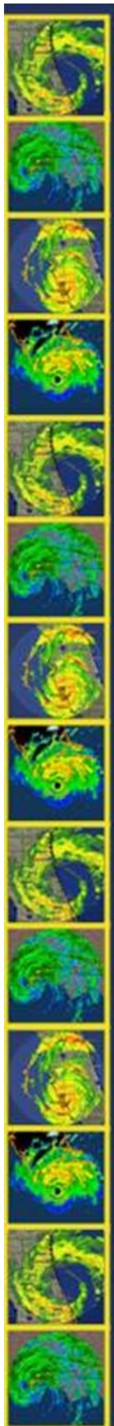
Production of Tropical Cyclone Related QPF

Determine how a change in available moisture could increase, decrease, or redistribute rainfall

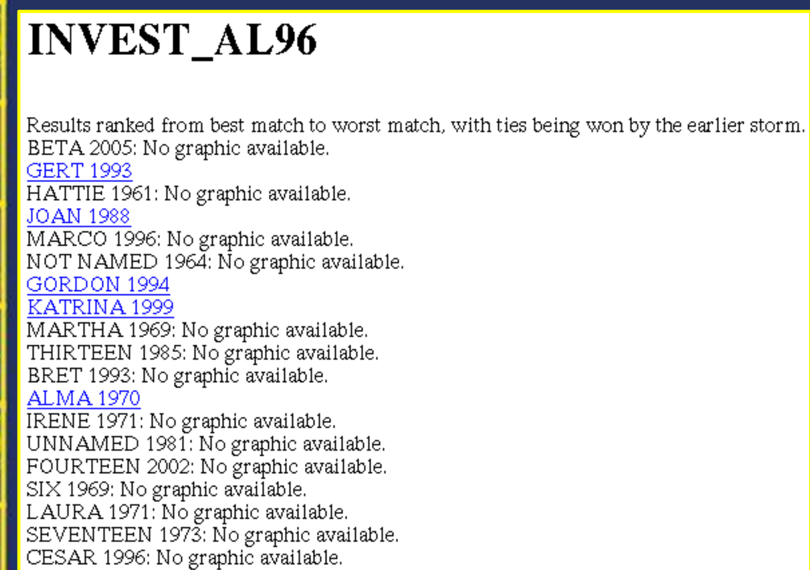




Production of Tropical Cyclone Related QPF

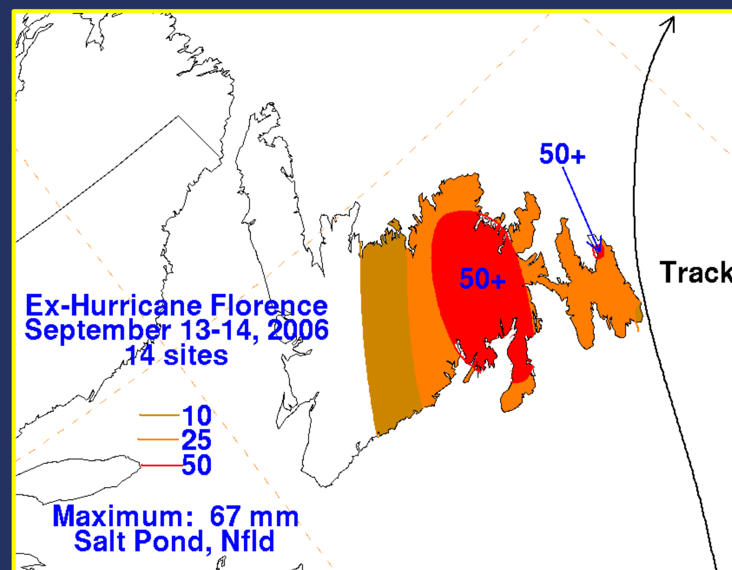
Use climatology (CLIQR, R-CLIPER, TC Rainfall Climatology) and data from past storms to:

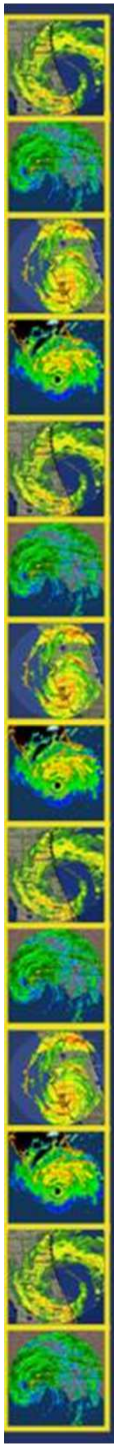
- Increase/decrease amounts
- Adjust numerical guidance biases
- Reality check
- Highlight areas significantly impacted by terrain effects



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.





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?