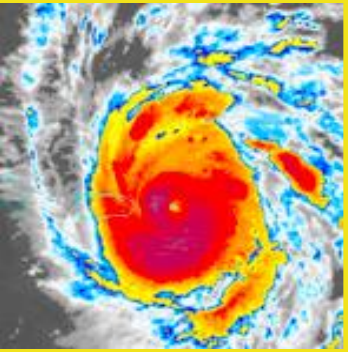
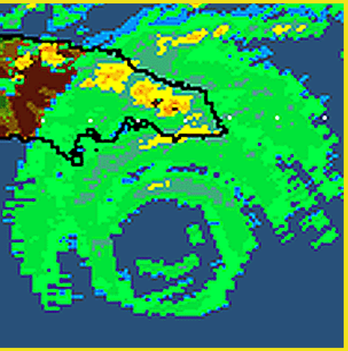




Tropical Cyclone Rainfall

Michael Brennan
National Hurricane Center

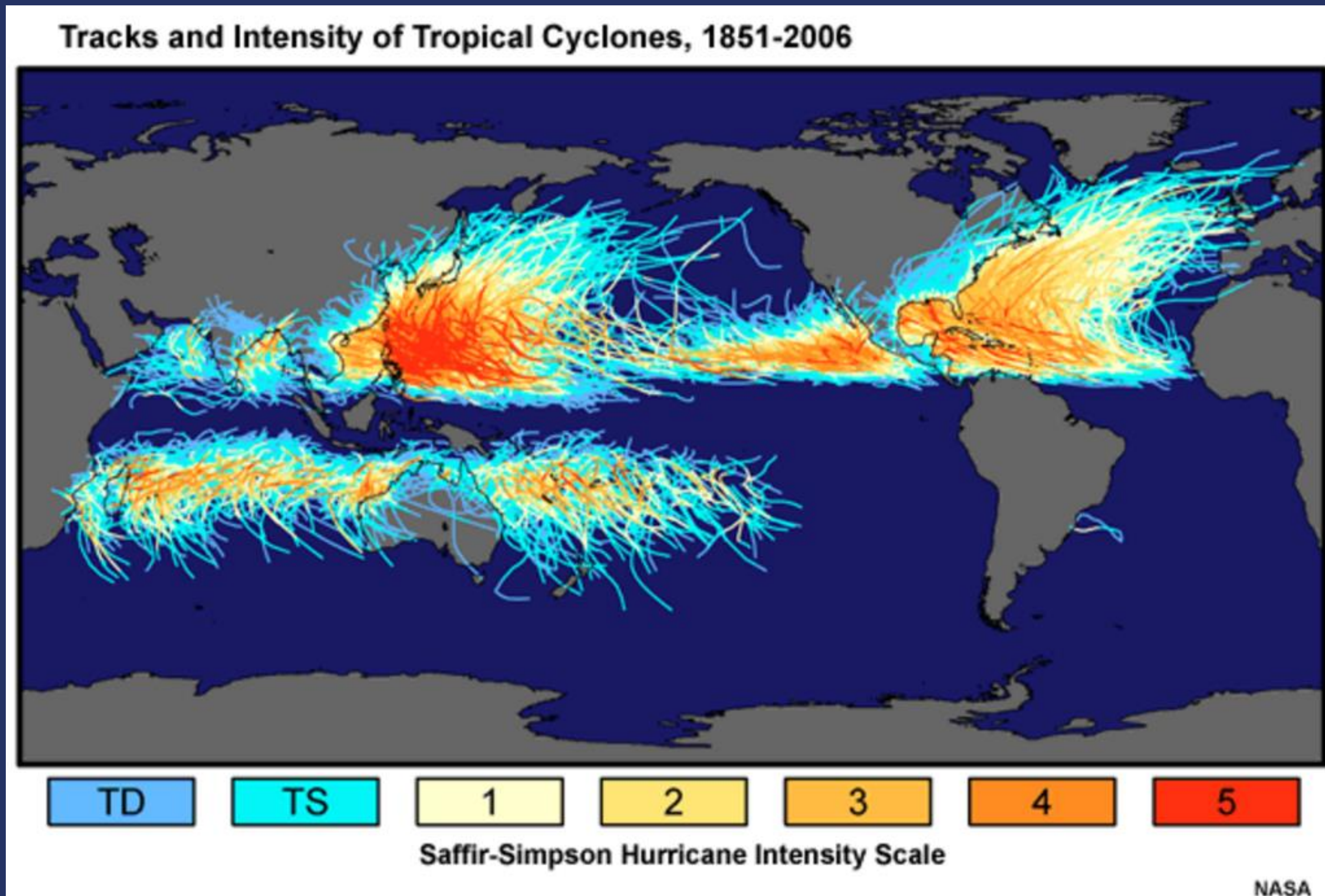
NATIONAL HURRICANE CENTER MIAMI FL

Outline

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

Tropical Cyclone Rainfall Climatology

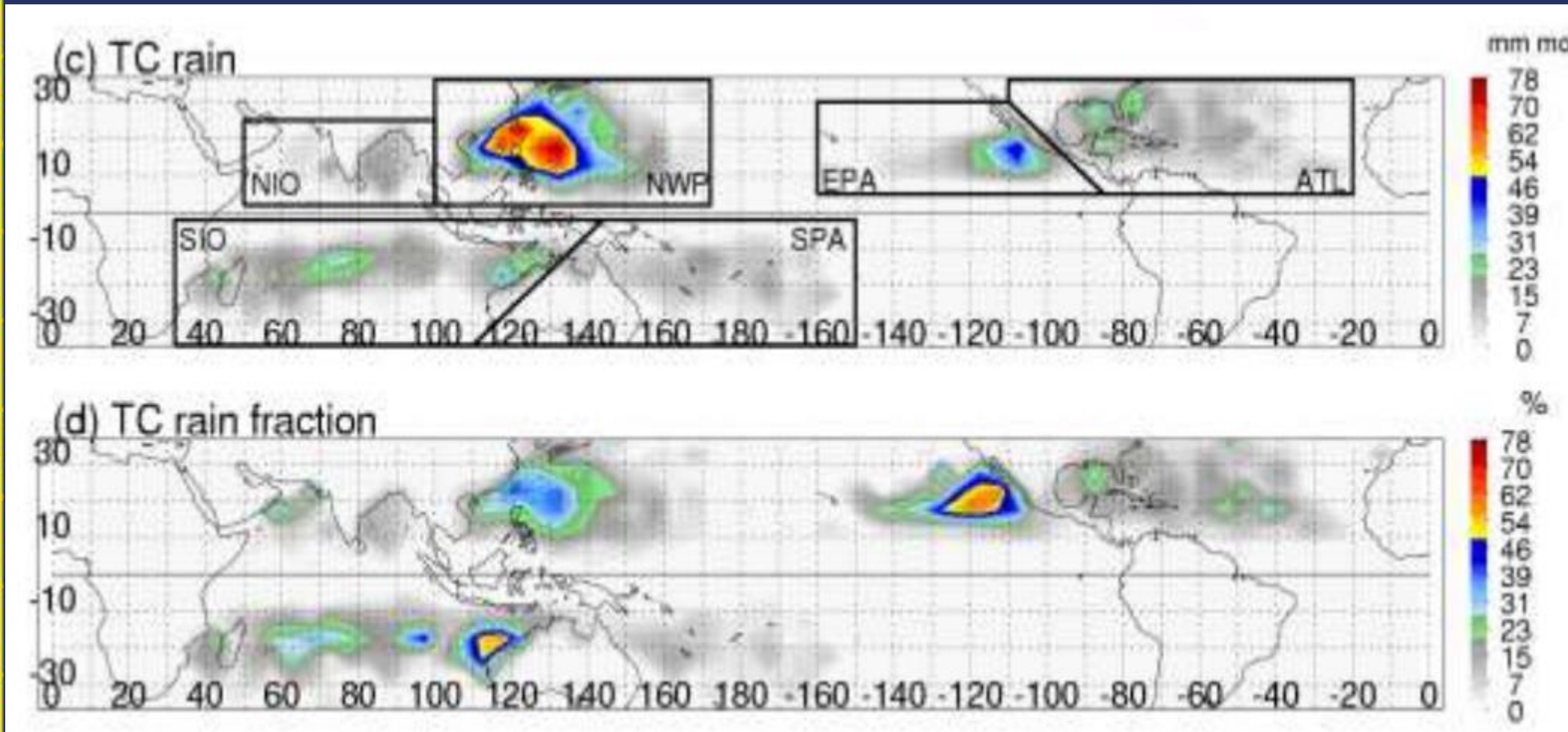
Tropical Cyclone Tracks



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)

Contribution to Total Rainfall from TCs

- What percentage of average annual rainfall in southern Baja California, Mexico comes from tropical cyclones?

1. 10-20%
2. 20-30%
3. 40-50%
4. 50-60%

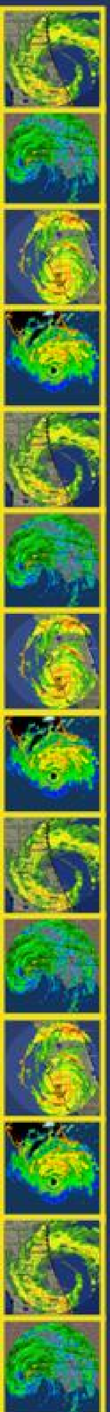
Khouakhi et al. (2017)
J. Climate

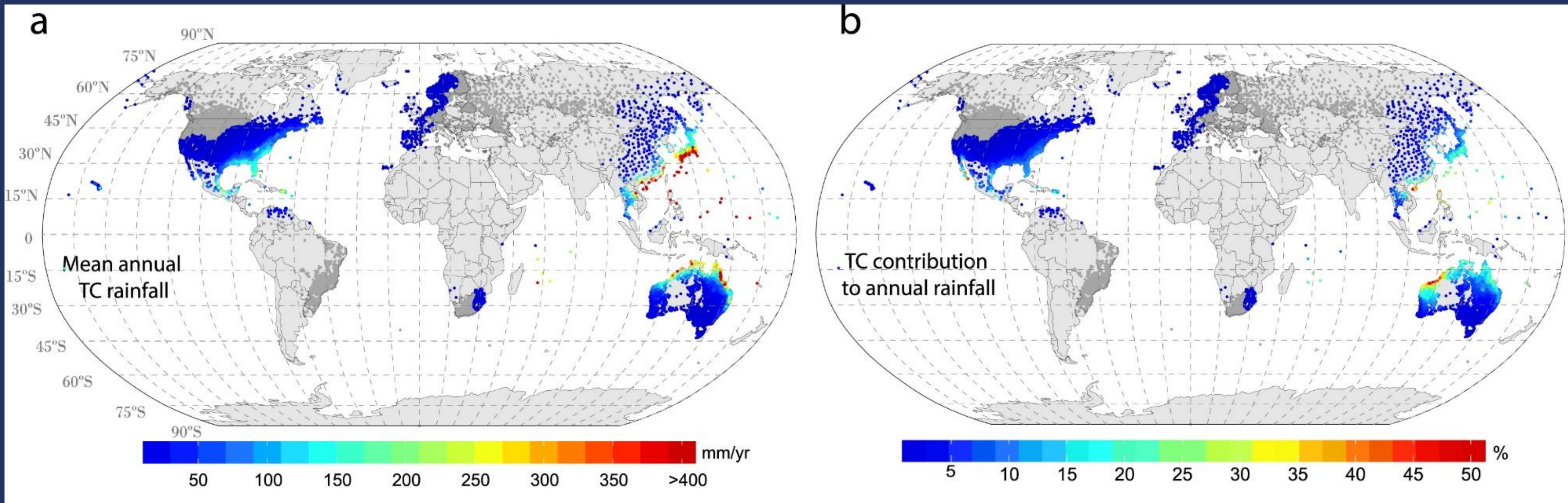
Contribution to Global Rainfall from TCs (1970-2014 rain gauge study)

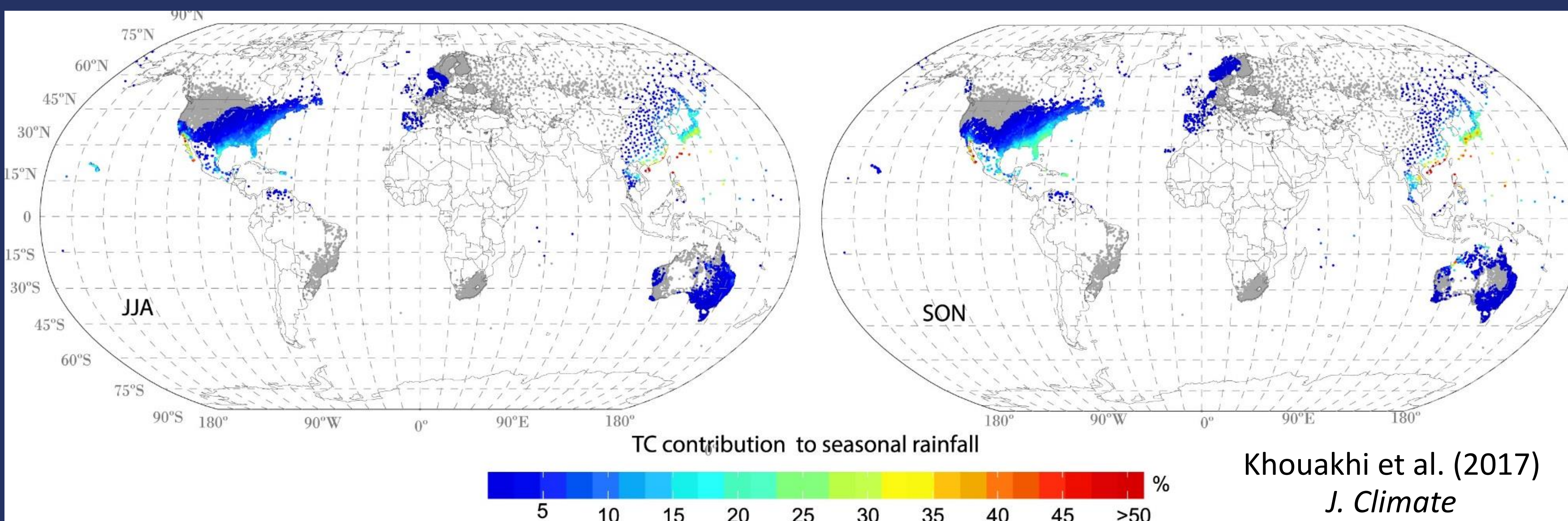
- Globally, highest TC rainfall totals are in eastern Asia, northeastern Australia, and the southeastern United States
- Percentage of annual rainfall contributed by TCs:
  - 35-50%: NW Australia, SE China, northern Philippines, Baja California
  - 40-50%: Western coast of Australia, south Indian Ocean islands, East Asia, Mexico

Khouakhi et al. (2017)
J. Climate

Contribution to Global Rainfall from TCs (1970-2014 rain gauge study)

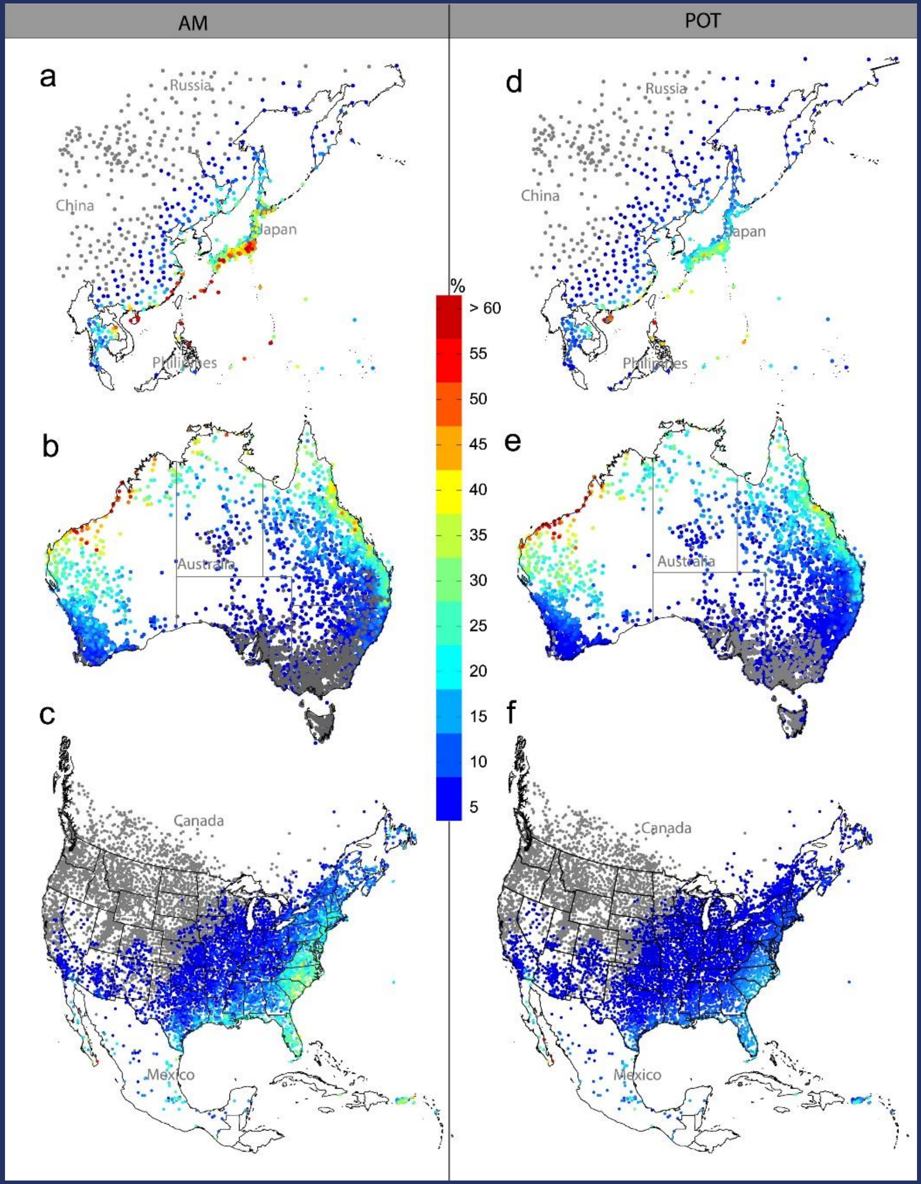






Khouakhi et al. (2017)
J. Climate

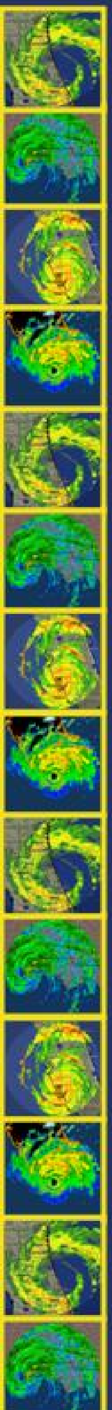
Contribution to Global Rainfall from TCs (1970-2014 rain gauge study)

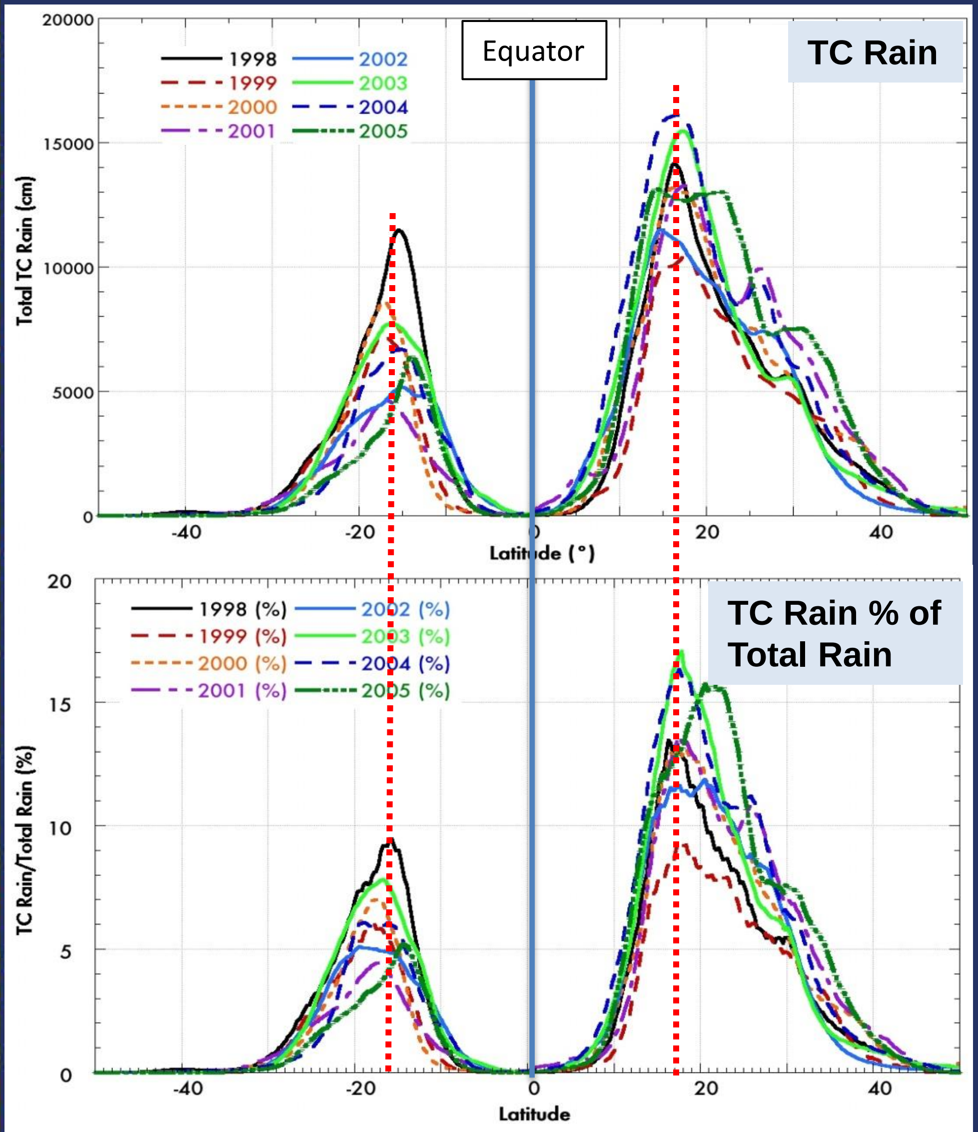


- Relative contribution of TCs to extreme rainfall
- Gray circles indicate locations at which TCs have no contribution to extreme rainfall

Khouakhi et al. (2017)
J. Climate

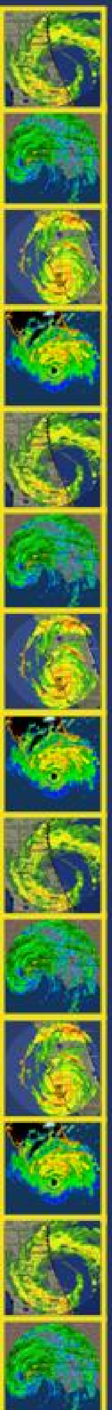
Annual TC Rainfall





Frank Marks (HRD)

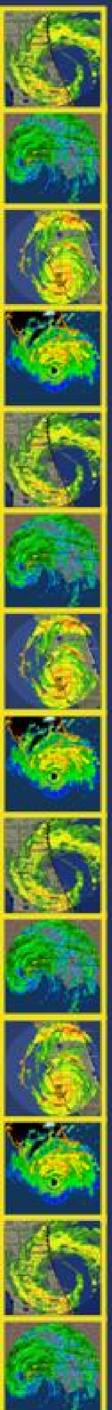
- TC rainfall makes up a larger percentage of total rainfall during years when global rainfall is low
- Asymmetric - generally more TC rainfall in the Northern Hemisphere
  - TCs produce 10-17% of global rain from 15-25°N
  - TCs produce 5-10% of global rain from 15-25°S



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)



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)

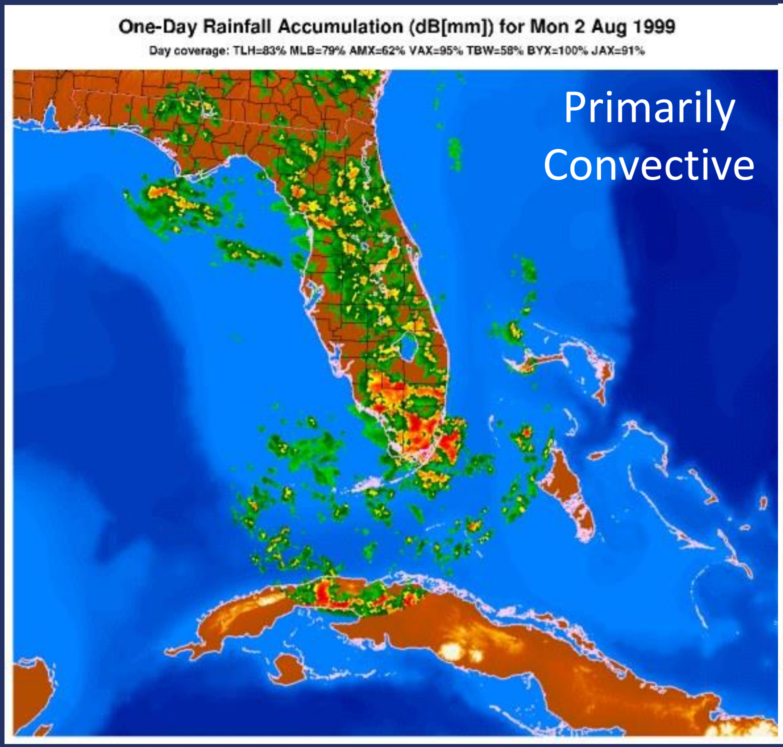
Characteristics of TC Precipitation

Stratiform and Convective Mechanisms

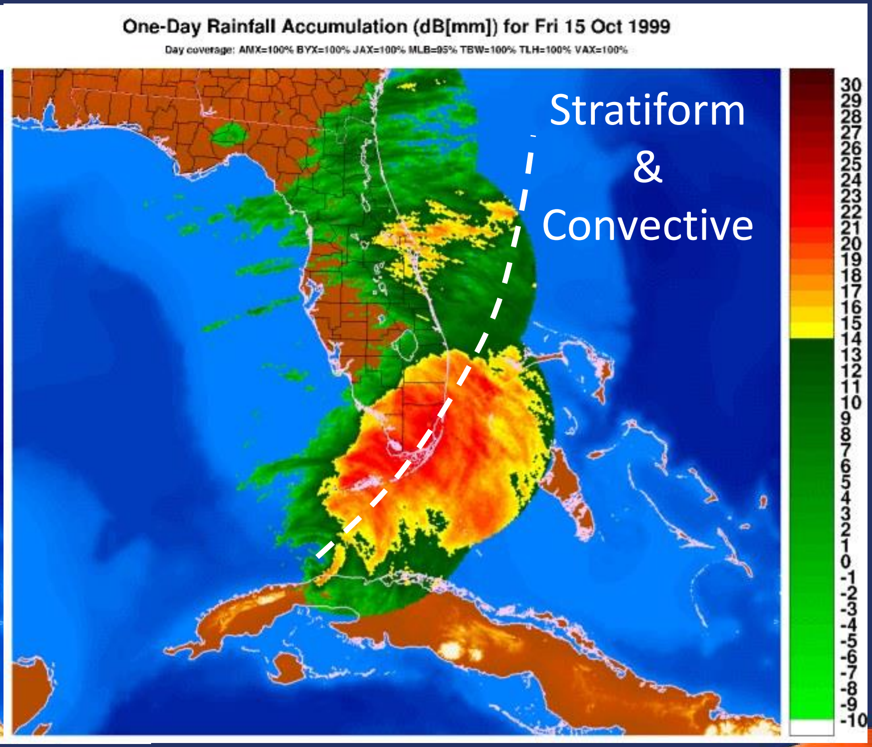
Stratiform Rain ~50% of Total Rain from TC

NOAA/HRD - Daily Radar Rainfall Estimate Study

Typical warm season 1-day total



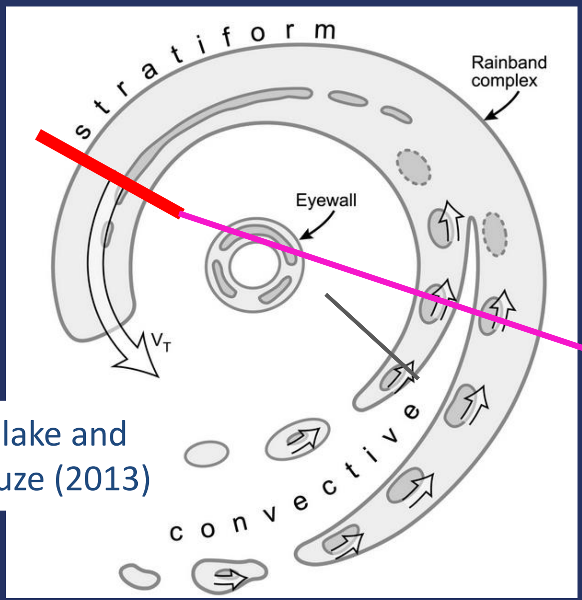
Hurricane Irene (1999) 1-day total



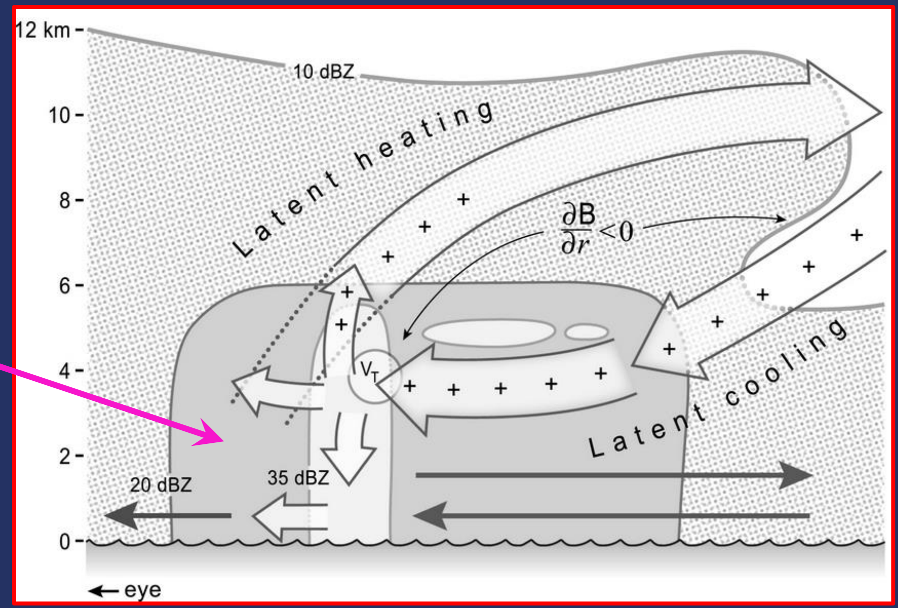
Hurricane Irene (15 October 1999)

Frank Marks (HRD)

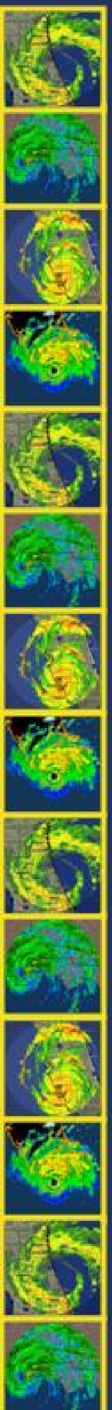
TC Rainband Complexes: Stratiform Region



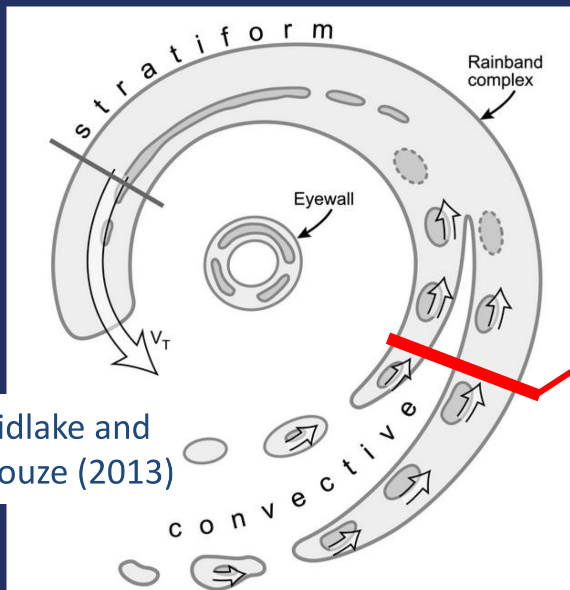
Didlake and Houze (2013)



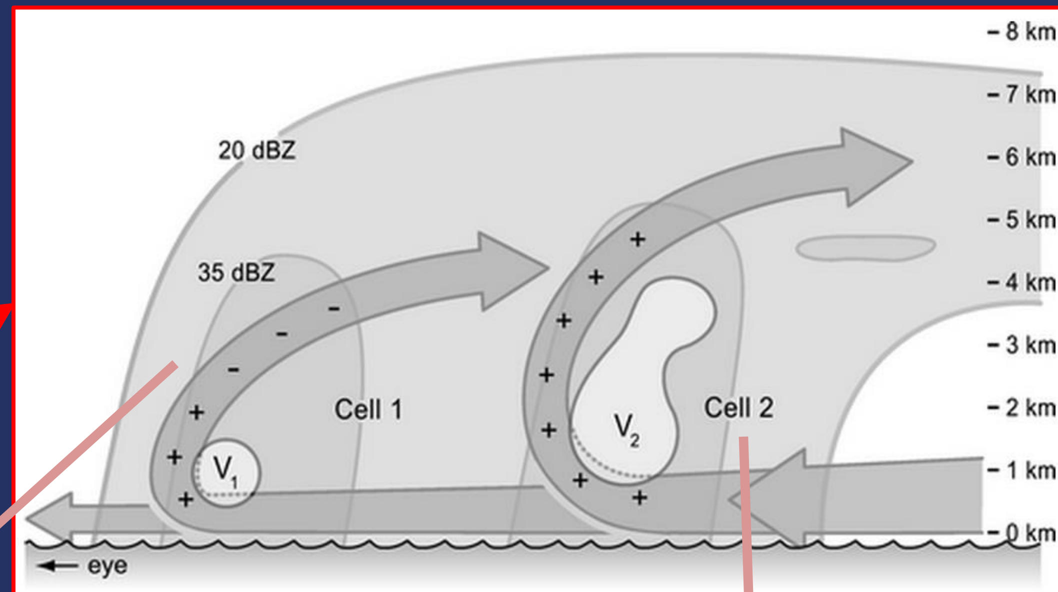
- Broad stratiform band in left-of-shear half of the storm
- Mesoscale ascending outflow & descending inflow driven by latent heating & latent cooling patterns
- Increased rainfall along line where descending inflow halts
- Descending inflow strengthens the outer core of vortex



TC Rainband Complexes: Convective Cells



Didlake and Houze (2013)



Cell 1

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

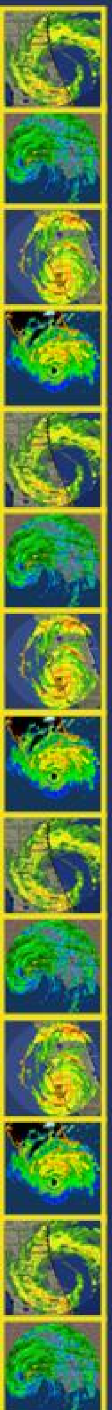
Cell 2

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

Factors Influencing Tropical Cyclone Rainfall

What Factors Influence Rainfall from Tropical Cyclones?

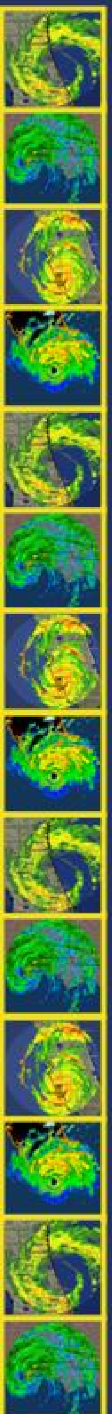
- Which of the following is NOT a primary factor in determining rainfall from tropical cyclones?
  1. TC Track
  2. TC Size
  3. TC Intensity
  4. Topography



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 – determines 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

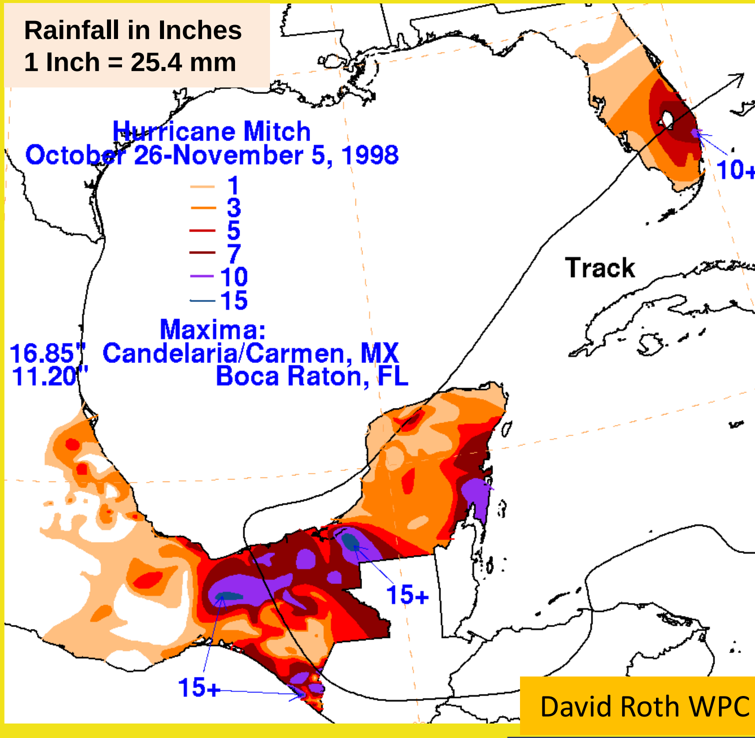
Factors Influencing TC Rainfall



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



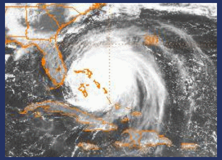

Vulcan Casita, Nicaragua - debris flows


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

00z

05/06z

12z

18z

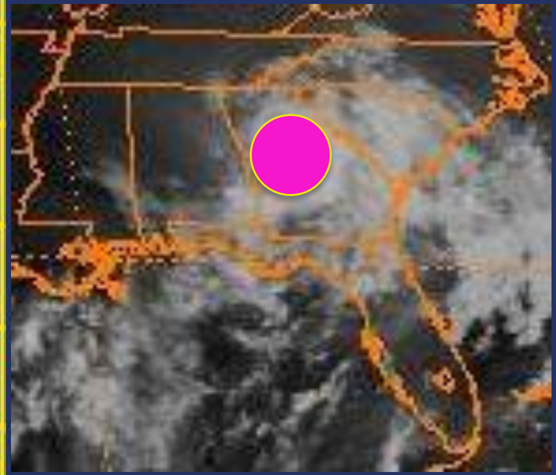
Factors Influencing TC Rainfall

Time of Day

Alberto, July 4-5, 1994

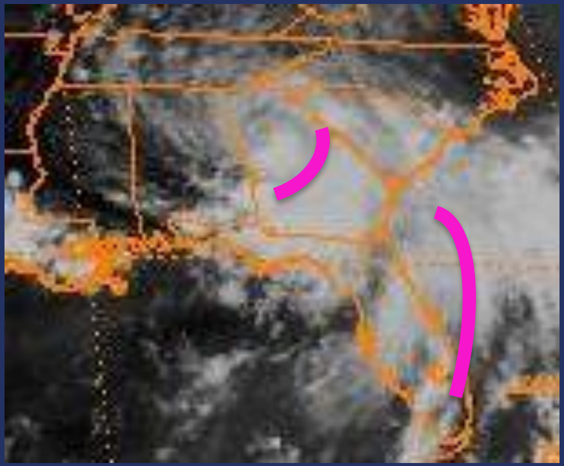
04/18z

00z



05/06z

12z

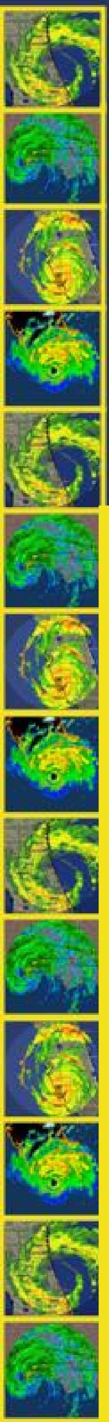


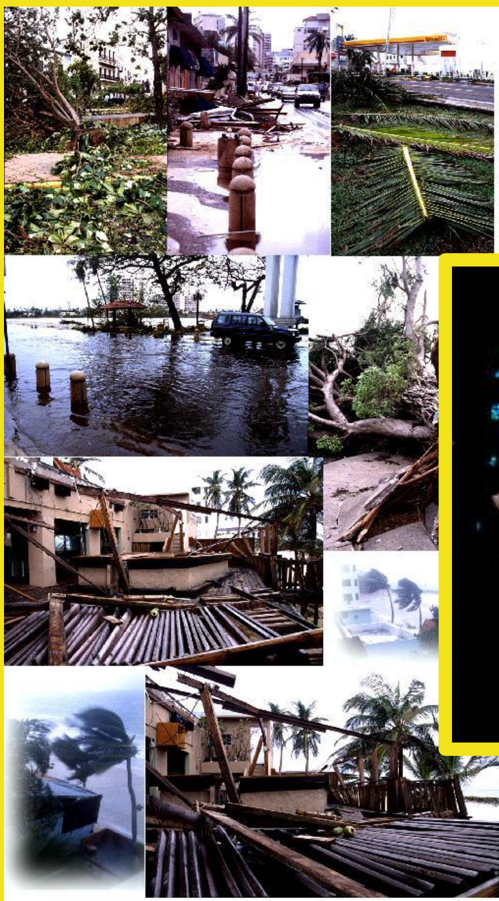
18z

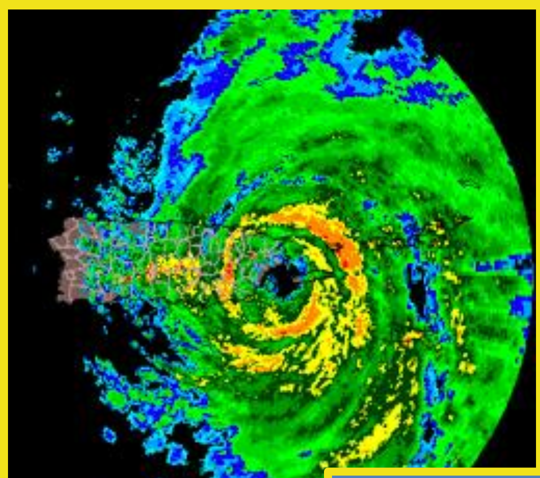
Factors Influencing TC Rainfall

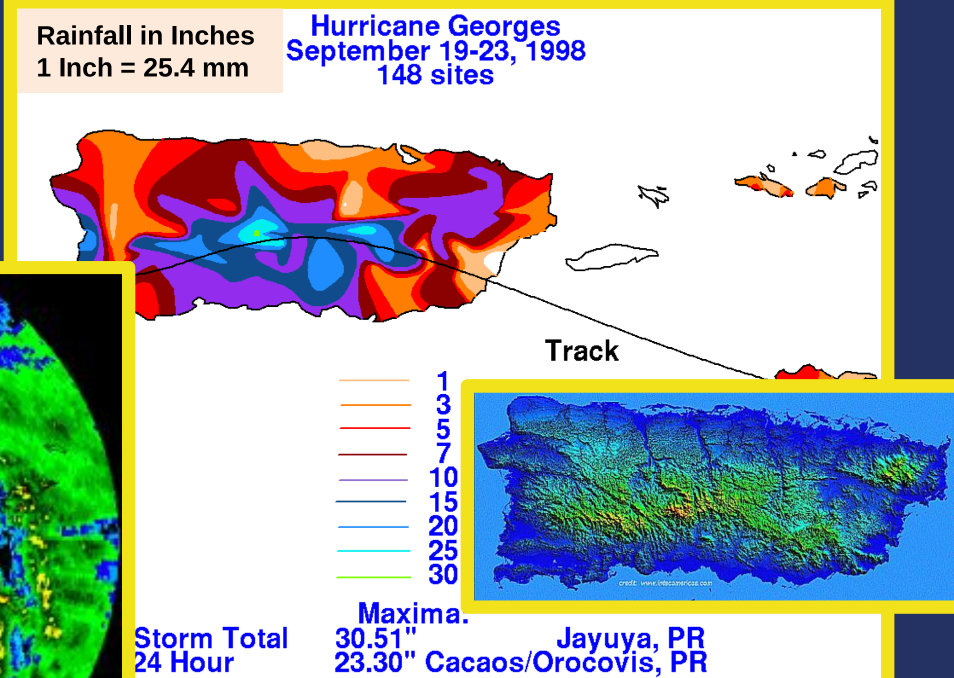
Terrain Impacts

Heaviest rainfall favors mountains perpendicular to the wind







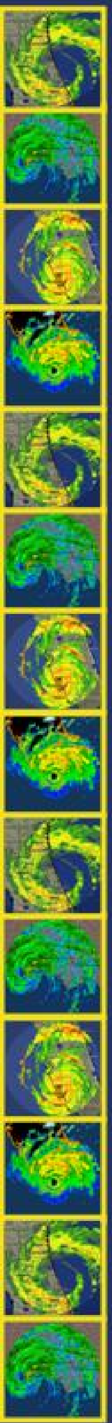


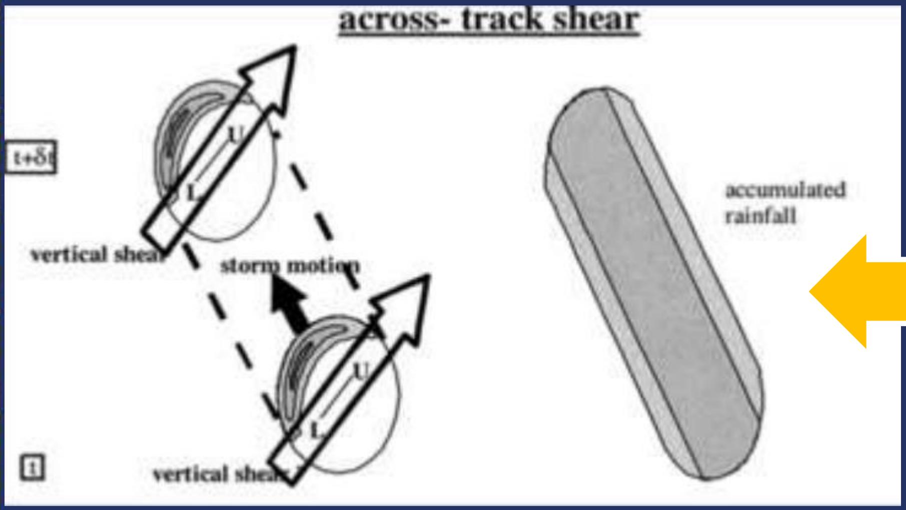
David Roth WPC

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

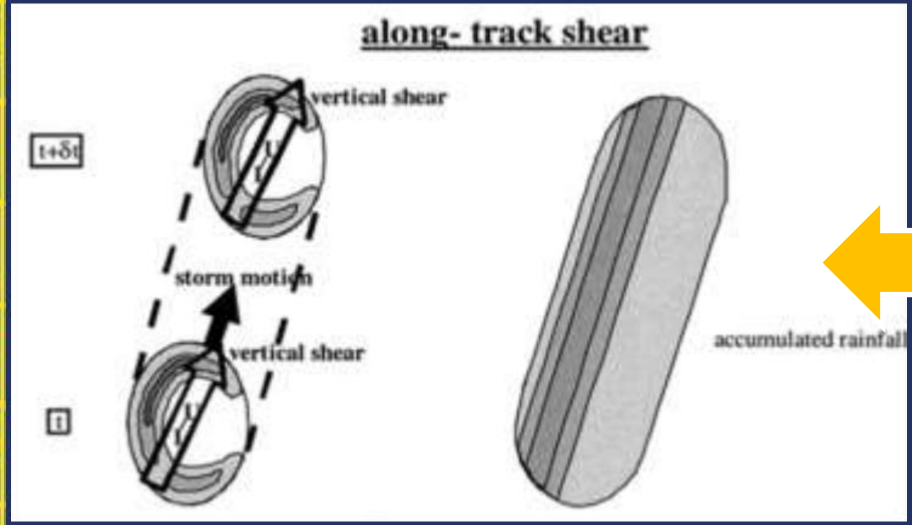
Factors Influencing TC Rainfall

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

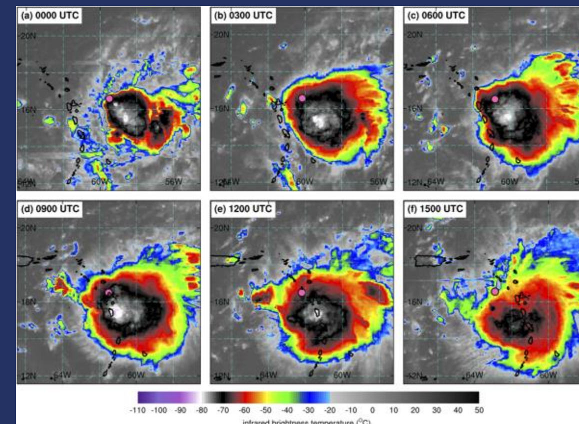
Rogers et al, 2003

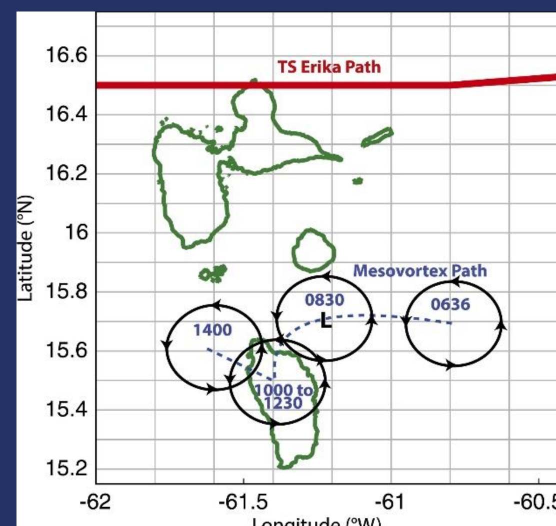
Factors Influencing TC Rainfall

Shear, Mesovortices, and Topography

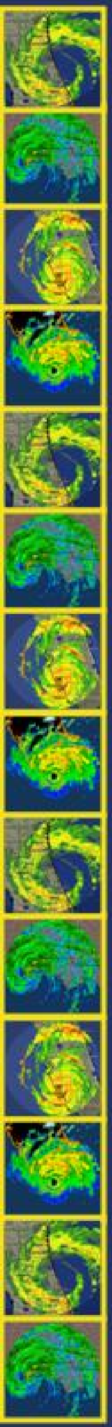
- Downshear region of strong convection associated with Erika (2015) passed directly over Dominica, producing over 500 mm of rainfall
  - Driven by 500-850 mb shear rather than deep layer shear

- Meosvortex on the scale of ~ 100 km developed within Erika's circulation and persisted over Dominica for 3 hours, likely due to topographic effects, enhancing heavy rainfall





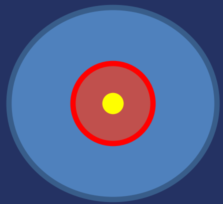
Nugent and Rios-Berrios (2018, MWR)



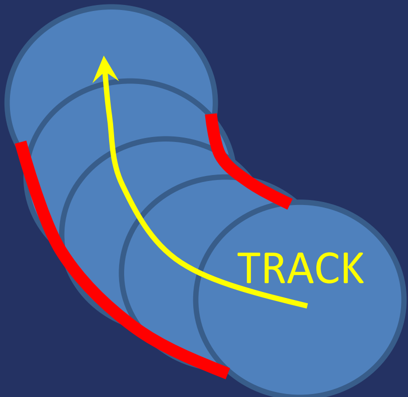
Factors Influencing TC Rainfall

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



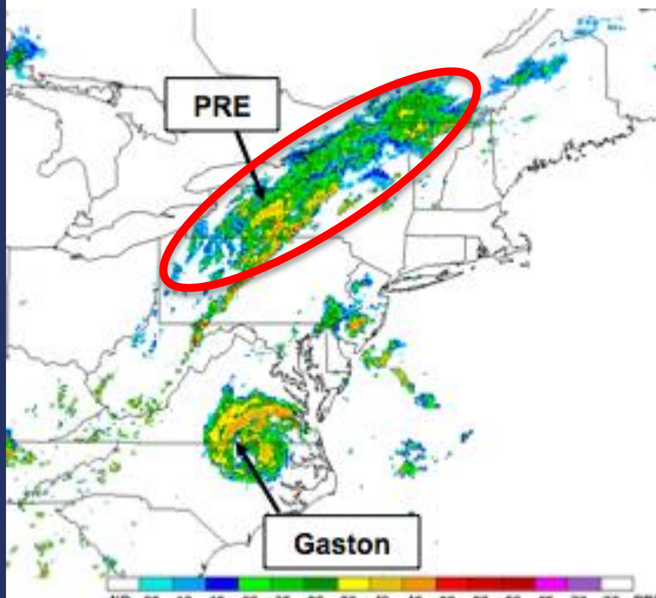
Even rainfall distribution = Rain over smaller area on right side = Higher totals

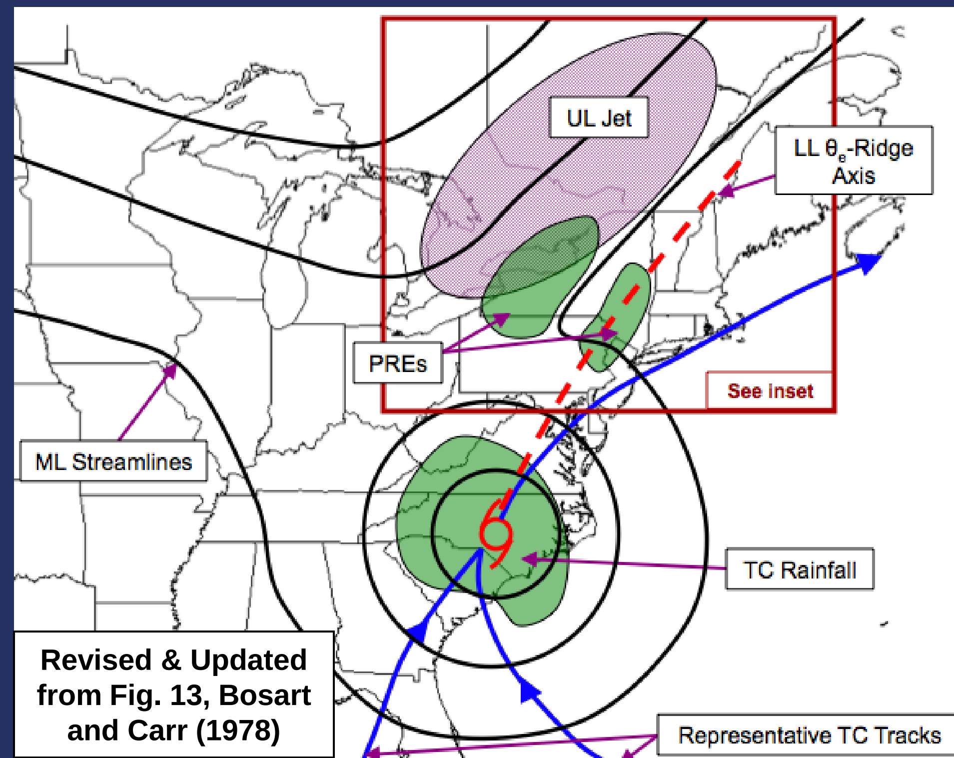
- TCs that recurve due to significant upper troughs in the westerlies often produce most of their rain *left* of their track
  - Rainfall may spread well in advance of the TC due to interaction with the upper jet on the leading edge of the trough

Factors Influencing TC Rainfall

Predecessor Rainfall Events

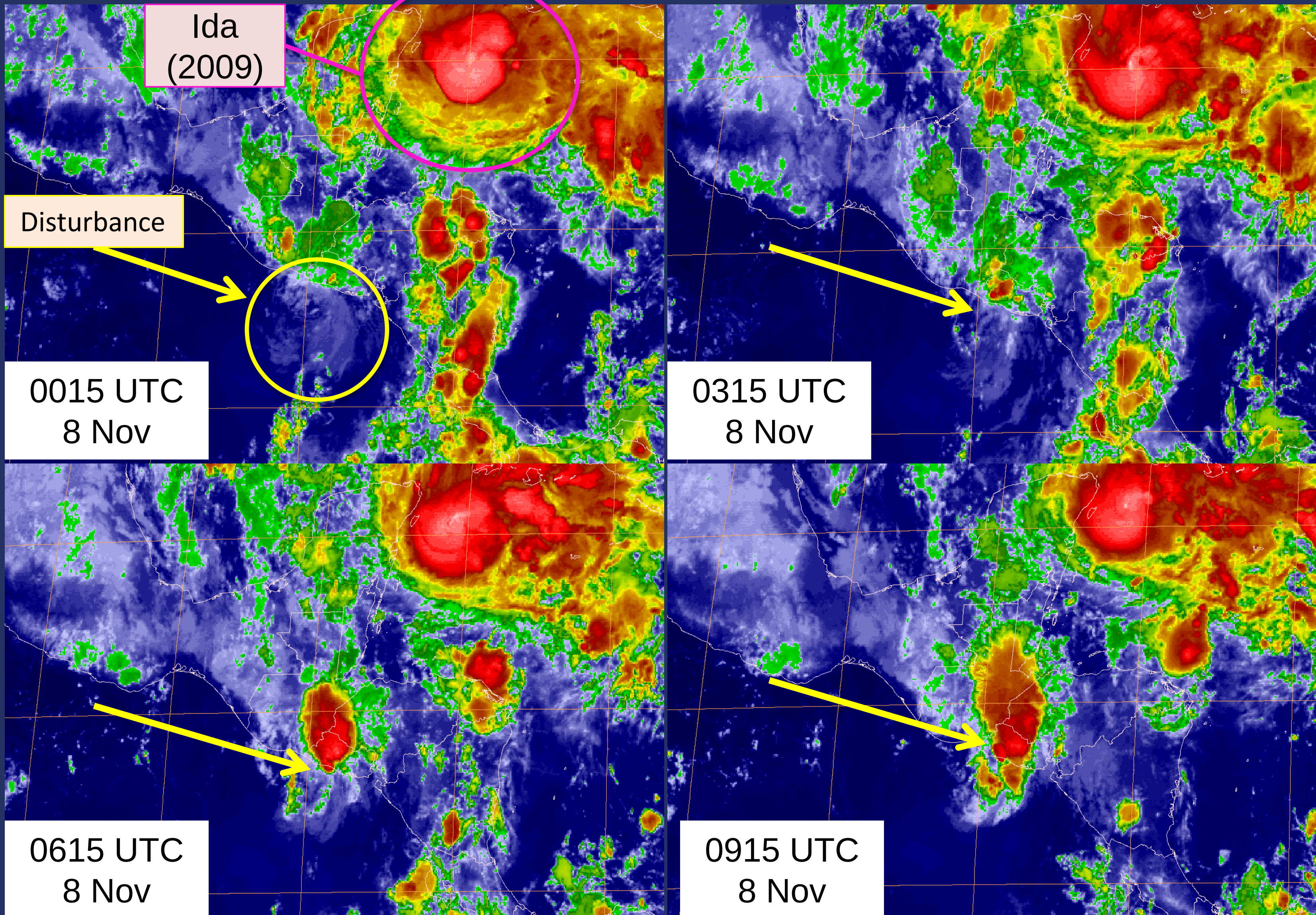
Predecessor Rainfall Event (PRE)
Image from Matt Cote and Lance Bosart – SUNY Albany



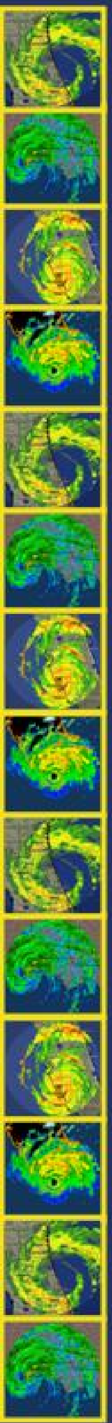


- Moisture transport well ahead of TC itself
- Coherent area of rain displaced north of the TC (near a front or over terrain)
- Maximum rainfall rates can exceed 200 mm in 24 hr
- Occurs for approximately 1 of 3 landfalling TCs in U.S.

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 Rainfall Product

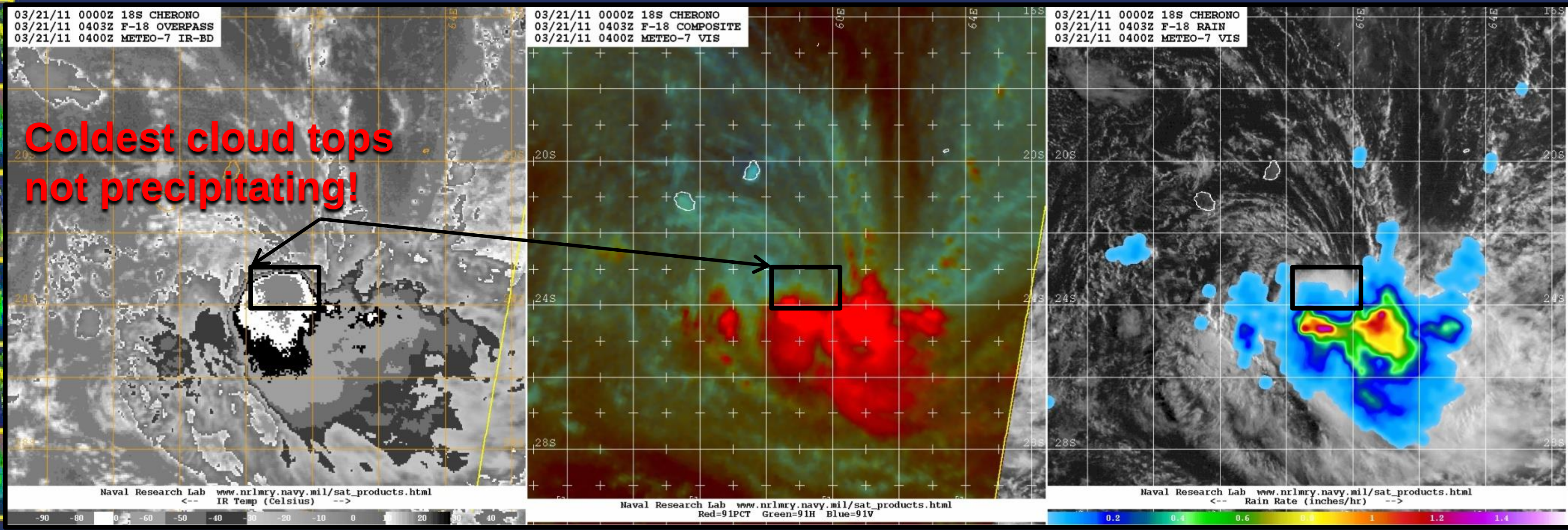
Incorporates microwave (MW) satellite data rainfall rates

- NHC uses two different merged satellite rainfall estimation techniques:
  - 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?

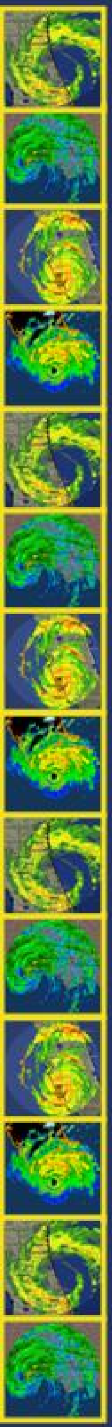
- Geostationary IR data provides excellent spatiotemporal resolution, but is not optimal for rain estimation
- Microwave provides improved rainfall accuracy but at low temporal resolution
- Quantitative precipitation estimate (QPE) products leverage each method's strength…

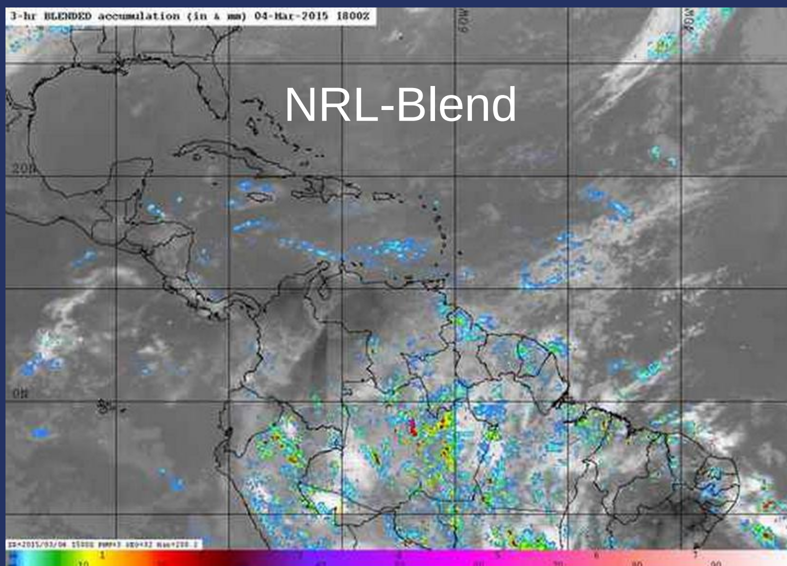


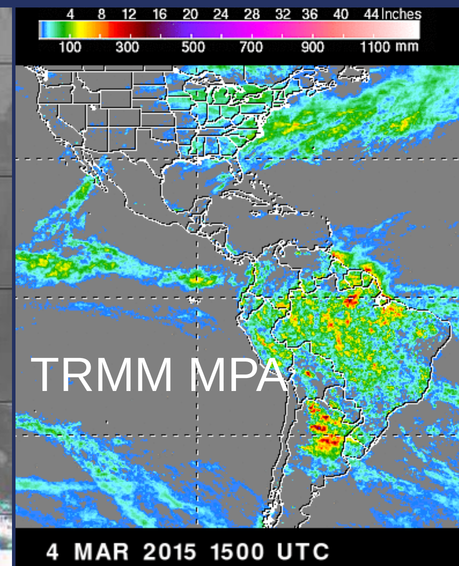
Satellite Rainfall Estimates

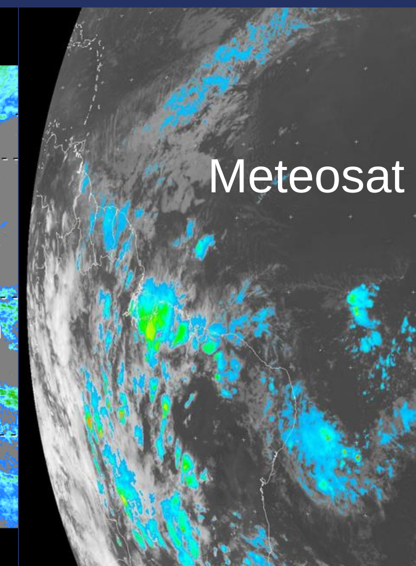
International Precipitation Working Group (IPWG) has an exhaustive list of data sources for precipitation information, some of it in real time.

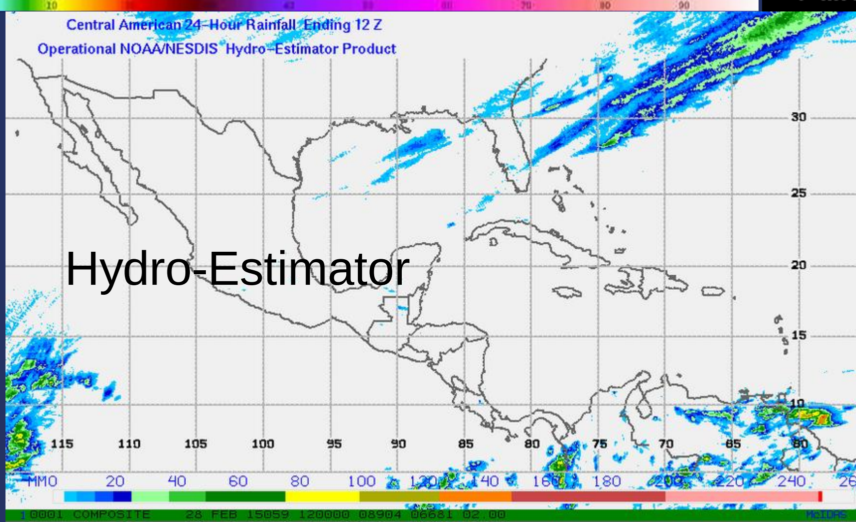
http://www.isac.cnr.it/~ipwg/data/datasets.html

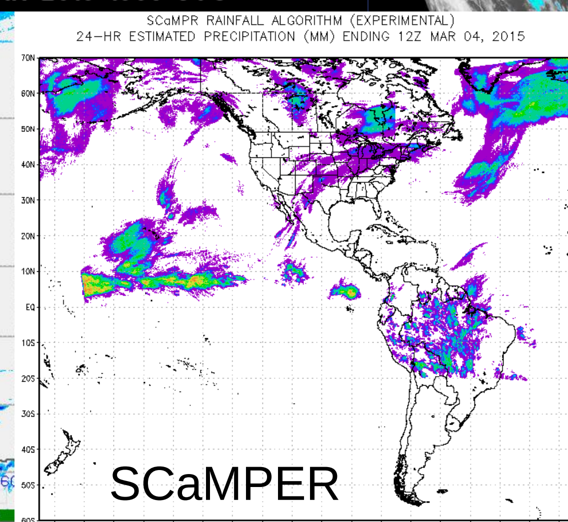


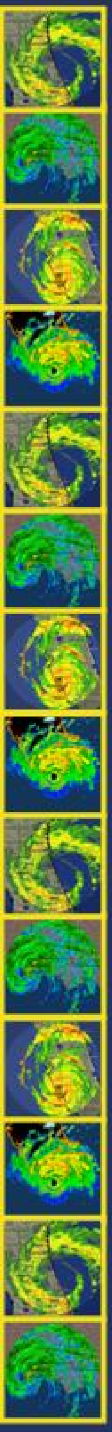








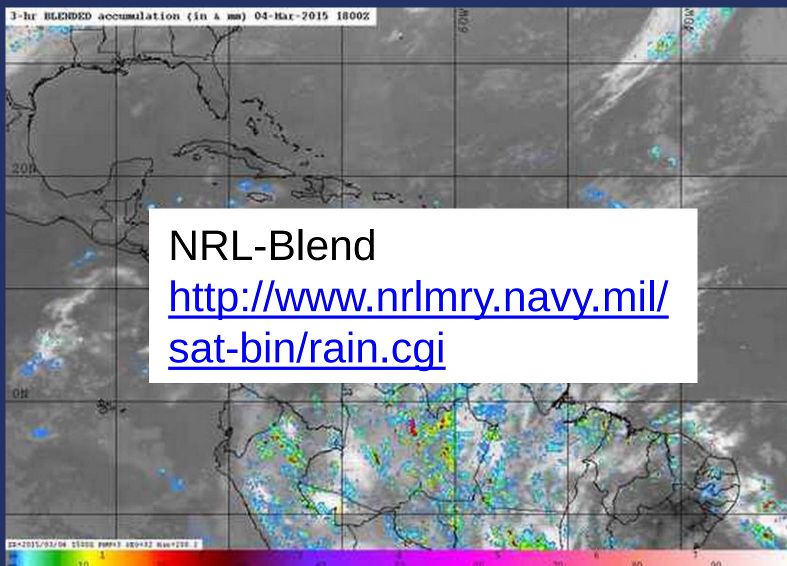




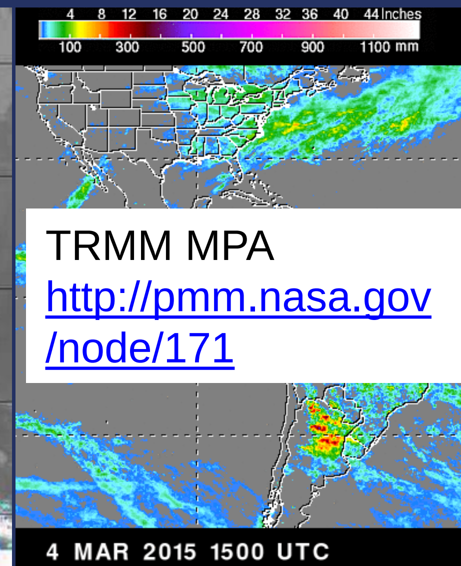
Satellite Rainfall Estimates

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

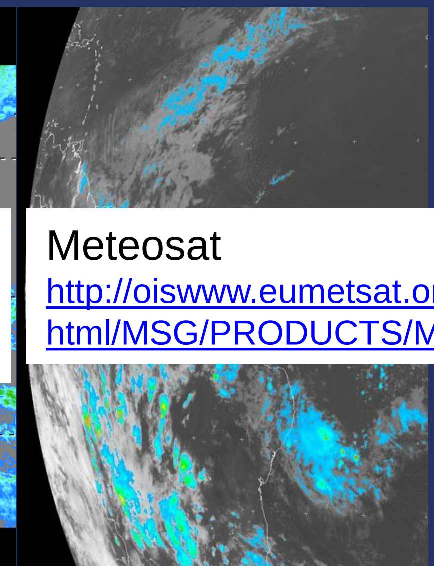
http://www.isac.cnr.it/~ipwg/data/datasets.html



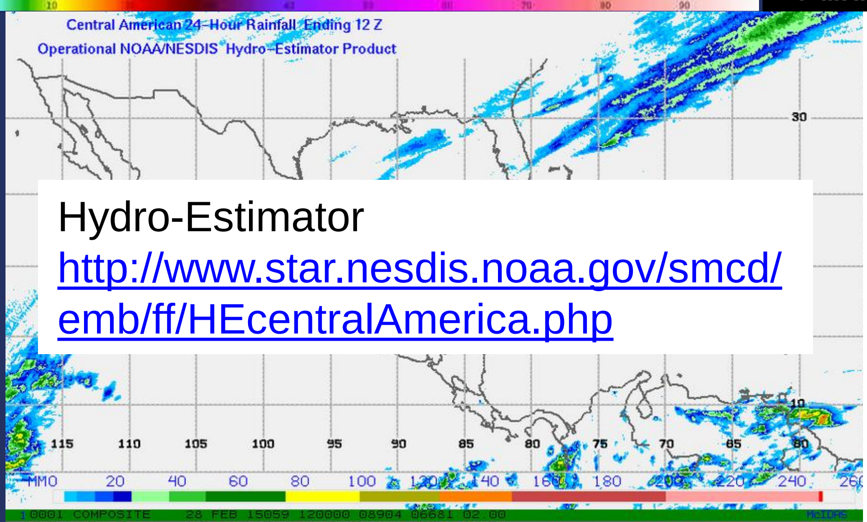
NRL-Blend
http://www.nrlmry.navy.mil/sat-bin/rain.cgi



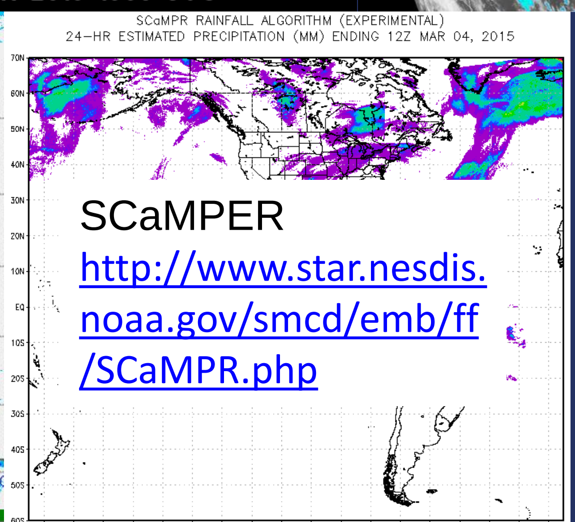
TRMM MPA
http://pmm.nasa.gov/node/171



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

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

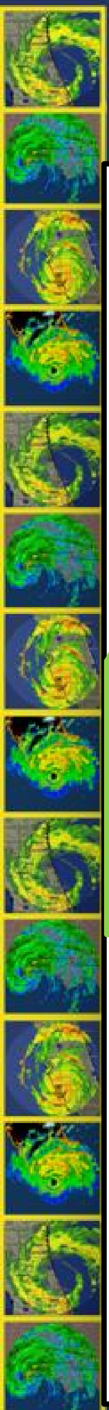
Can be created for any disturbance

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")
- Available at: http://www.nhc.noaa.gov/marine/rainfall/

New NHC Rainfall Product: Text



TCCA22 KNHC 291843
STDWCA

SATELLITE TROPICAL DI…
NWS NATIONAL HURRICAN…
2115 UTC TUE AUG 29 …

SYSTEM NAME

T.S ANDRES

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

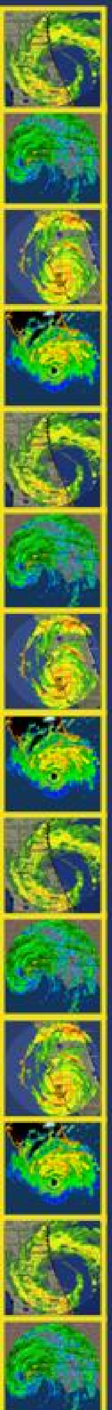
RAINFALL MAY BE UNDERESTIMATED ON THE WINDWARD SIDE OF TERRAIN

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

FORECASTER NELSON

- Lat-lon grid of rainfall accumulation
- 6-h accumulation ranges (in mm)
- Differences in the 3 rainfall estimates reveal uncertainty
- Available at: http://www.nhc.noaa.gov/marine/rainfall/

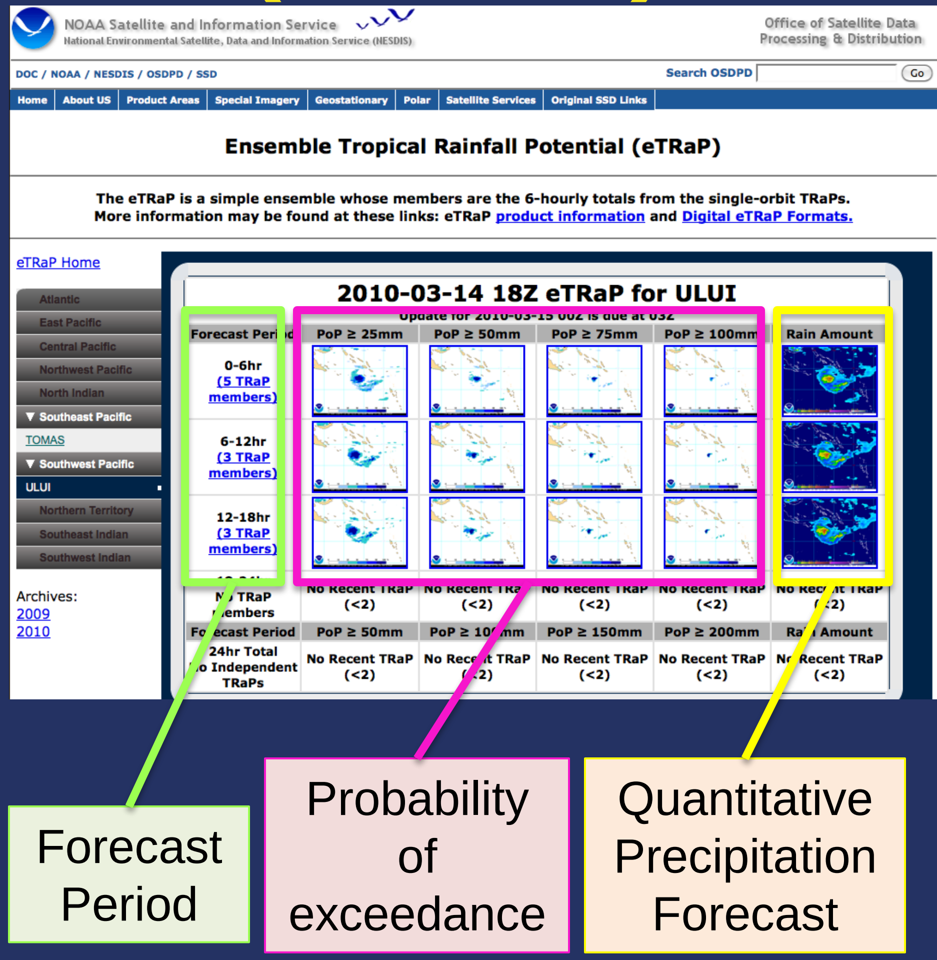
Ensemble Tropical Rainfall Potential Product (eTRaP)



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

  (AMSU, SSMI, AMSR, GPM)

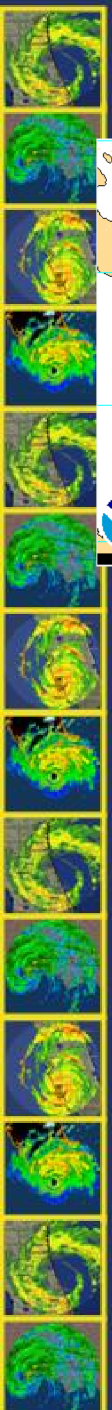
- A satellite “member” is included when its path passes over the TC
- “Members” are weighted according to age of pass and past performance of sensor
- Official forecast of TC track & at least 2 members needed to create a forecast
- Updated daily at 0315, 0915, 1515, and 2115 UTC

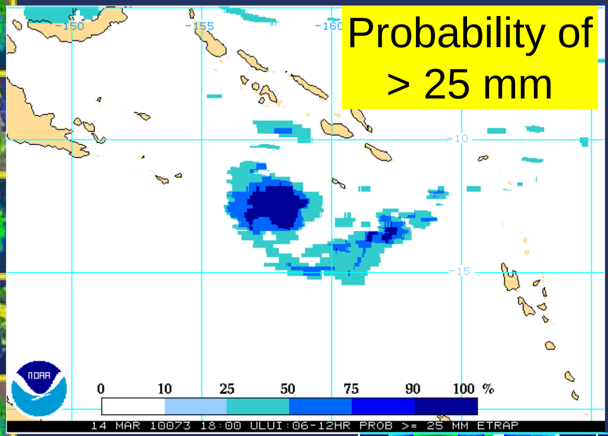


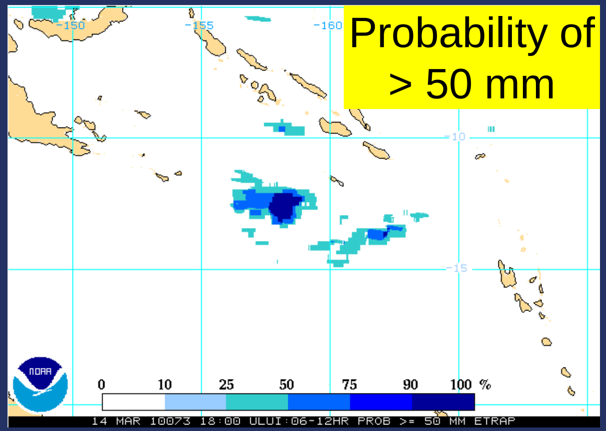
http://www.ssd.noaa.gov/PS/TROP/etrap.html

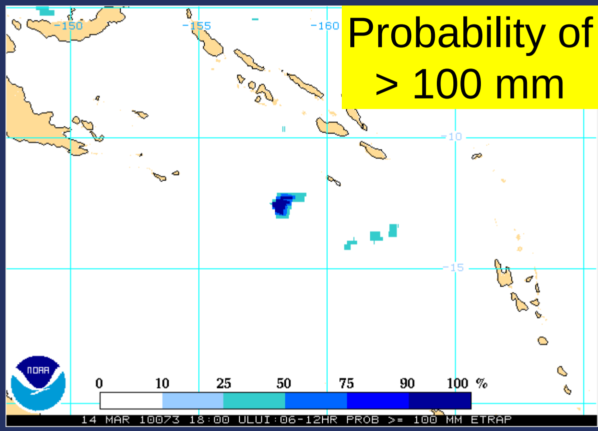
NATIONAL HURRICANE CENTER MIAMI FL

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



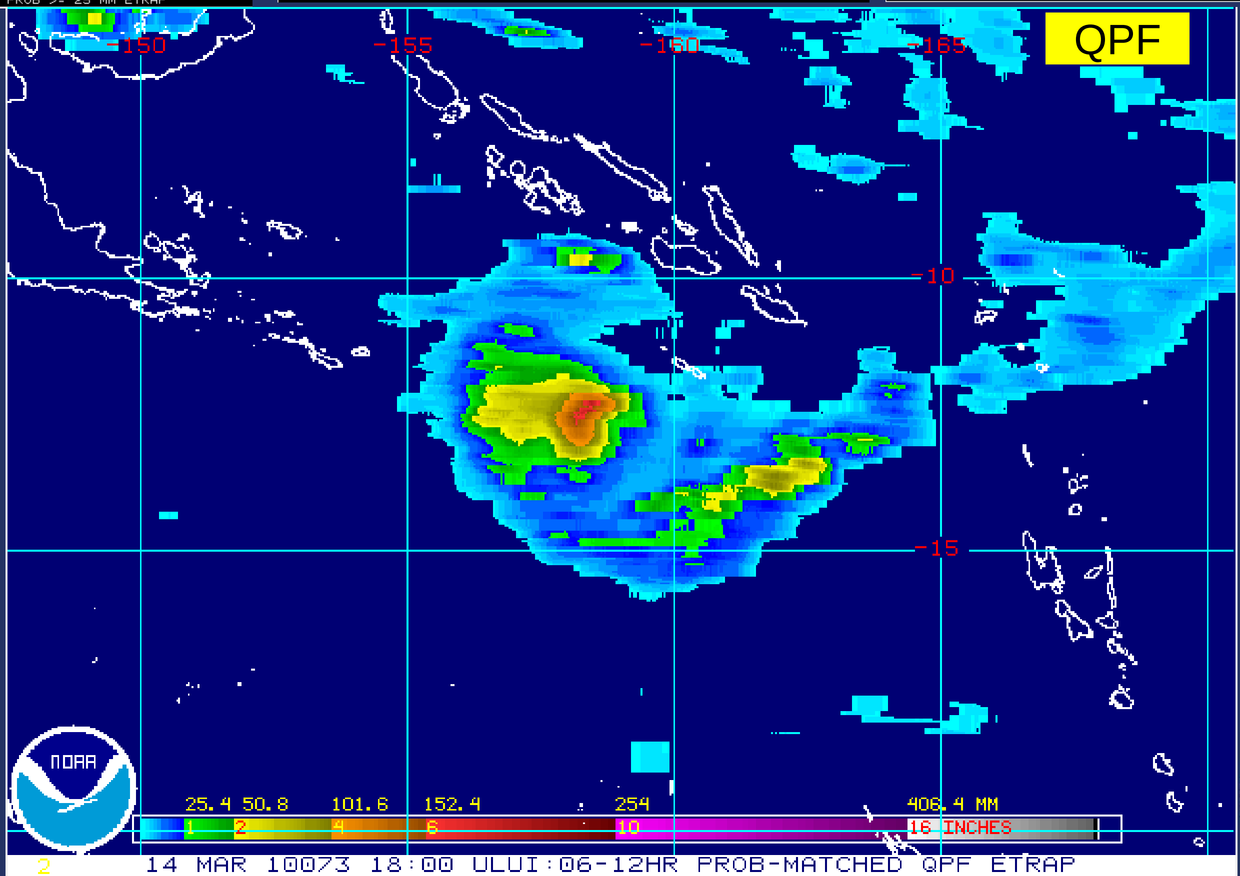






Typhoon Ului

06-12 hr eTRaP forecast



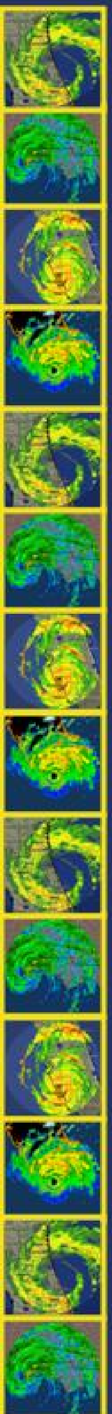
CLIQR: Picking an Analog for a TC Rainfall Event

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

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.

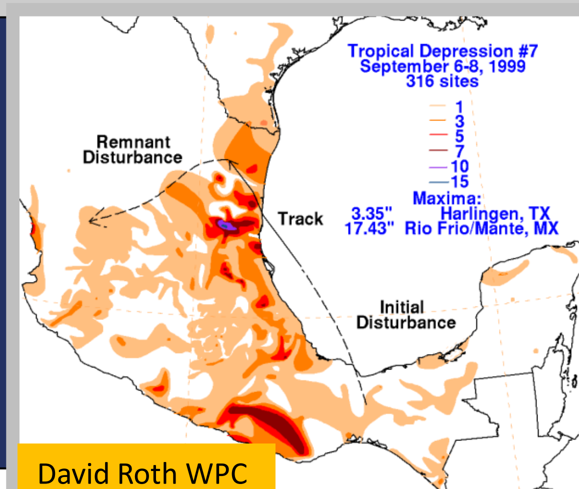
Select Storm By Name	Rainfall analogs to current tropical cyclones	Select Storm By Year
Select Storm By Region Of Impact	Select Storm By Point Of Entry	Tropical Cyclone Maxima Per U. S. State
Tropical Cyclone Maxima Per Mexican State	Point Maxima for Tropical Cyclones	Tropical Cyclone Averages and Maxima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



David Roth WPC

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

NATIONAL HURRICANE CENTER MIAMI FL

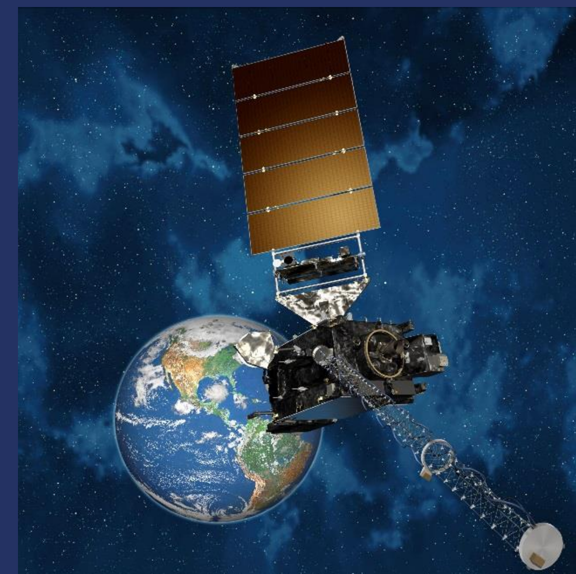
GOES-16/17 Products

GOES-16 launched in October 2016
GOES-17 launch scheduled for Thursday

Rainfall Rate Algorithm

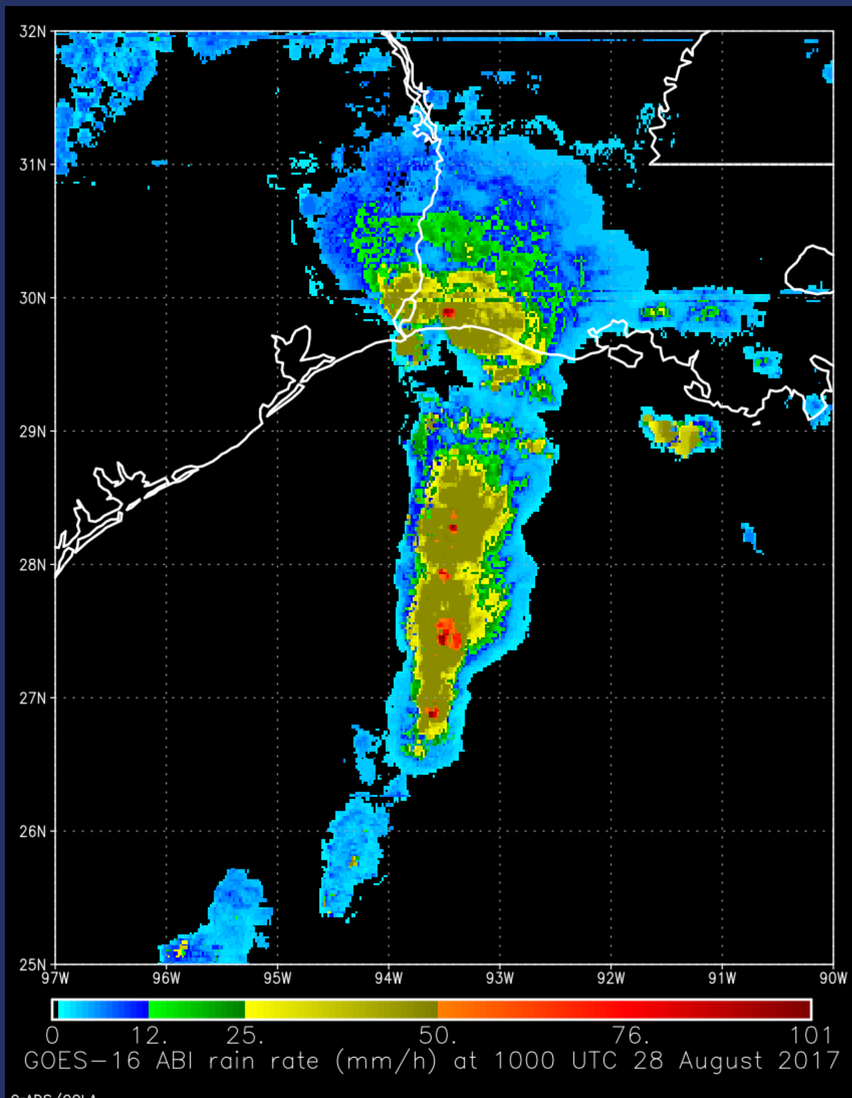
Rainfall Potential Algorithm

Probability of Rainfall Algorithm



GOES-16/17 Products

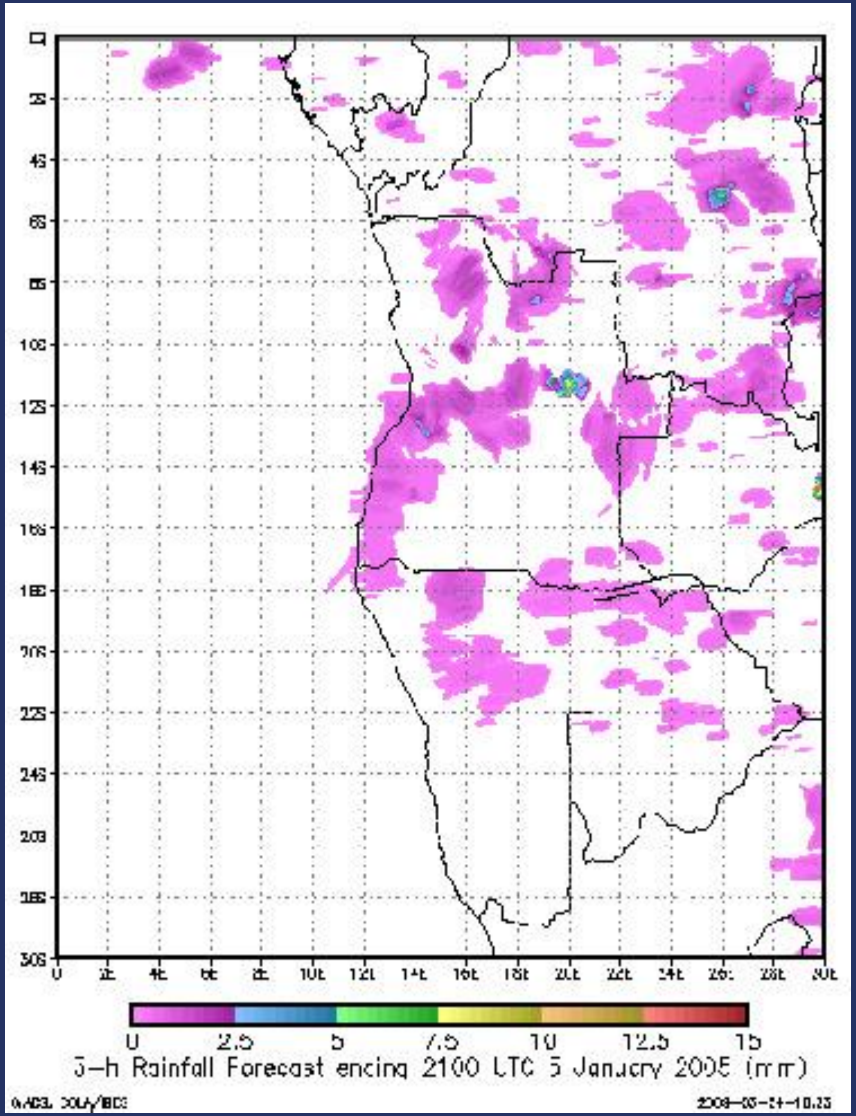
Rainfall Rate



- Algorithm generates estimates of instantaneous rainfall rate at each IR pixel
- Uses IR brightness temperatures and calibrated in real time against microwave-derived rain rates to enhance accuracy
- The higher spatial and temporal resolution available from GOES-16 will be able to automatically resolve rainfall rates on a finer scale

GOES-16/17 Products

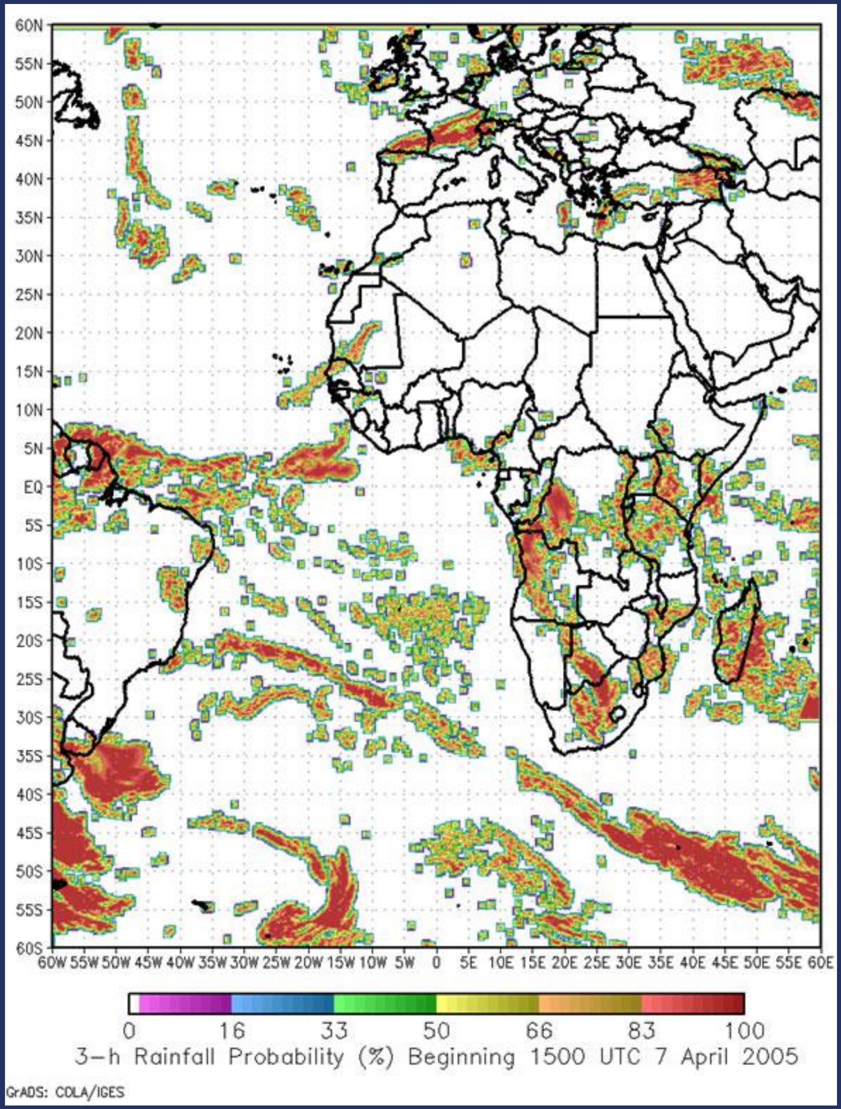
Rainfall Potential



- 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

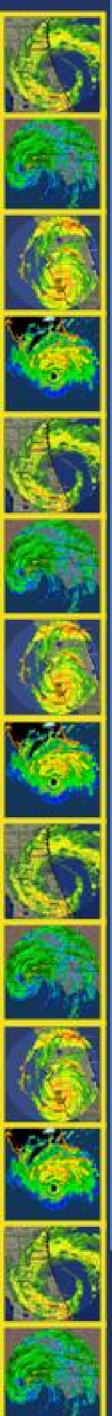
GOES-16/17 Products

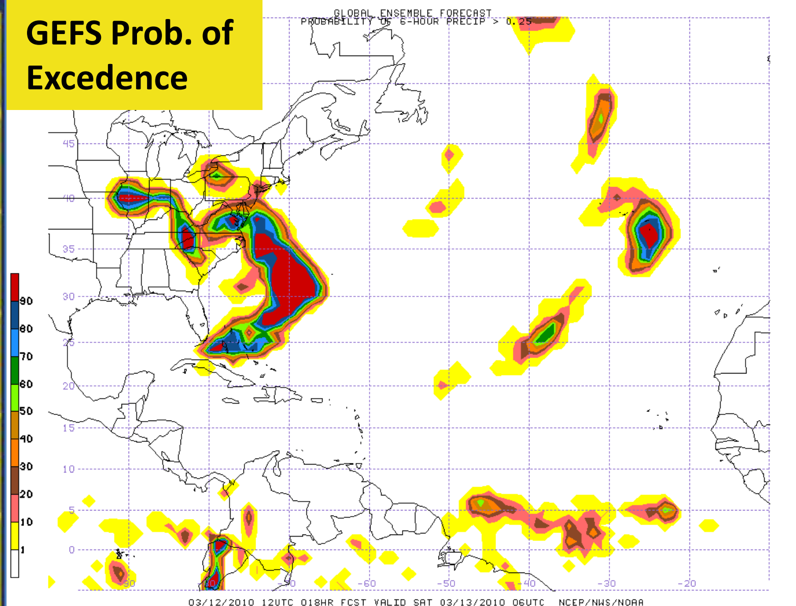
Probability of Rainfall

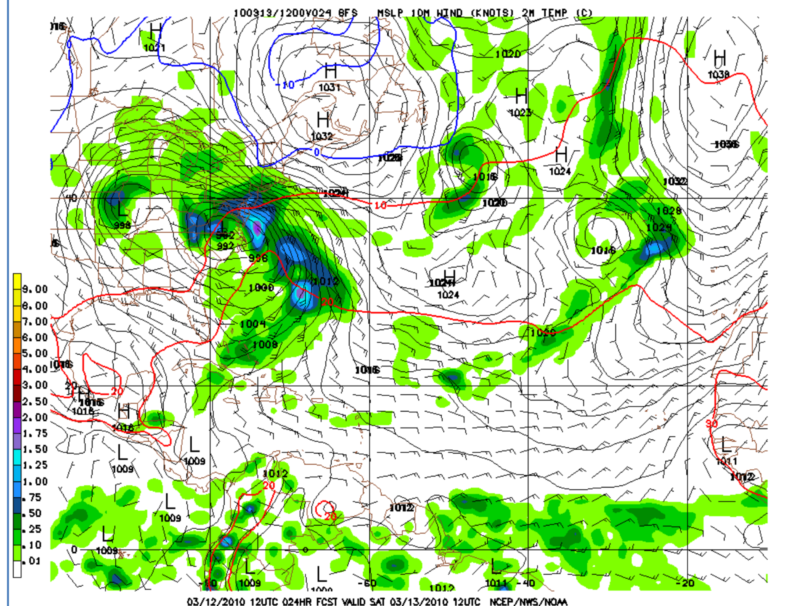


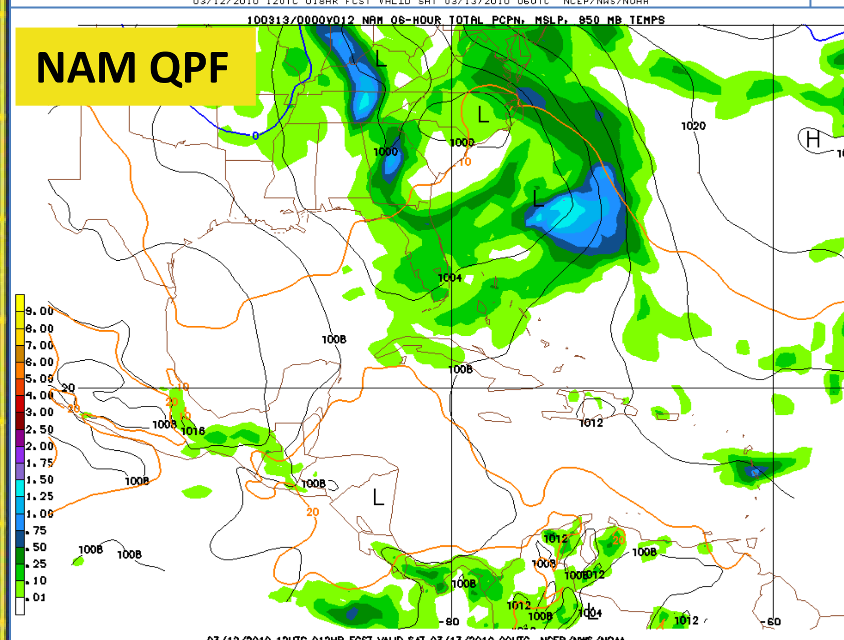
- Generates a gridded probability of at least 1 mm of rainfall during the next 3 hours at the satellite pixel scale

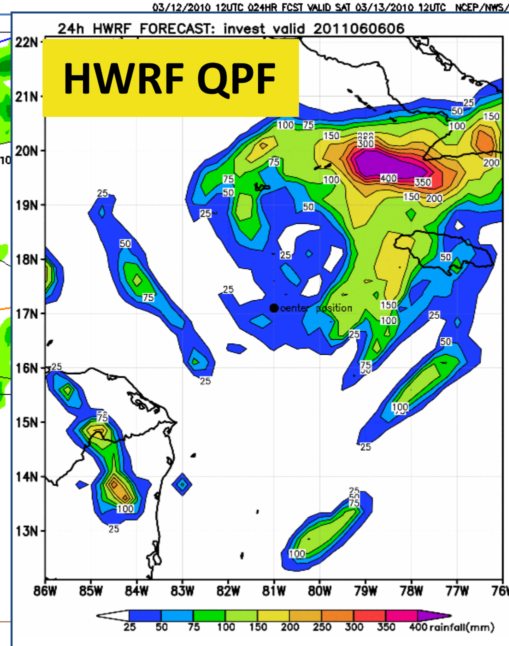
- Uses intermediate rainfall rate forecasts from the Rainfall Potential Algorithm as input to a statistical model calibrated against estimates from the Rainfall Rate Algorithm

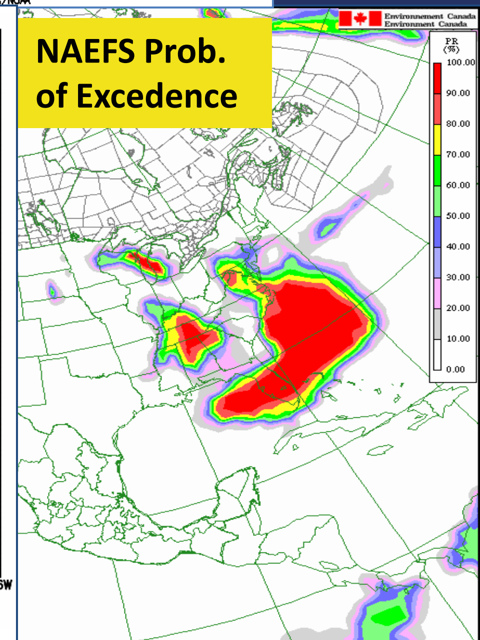








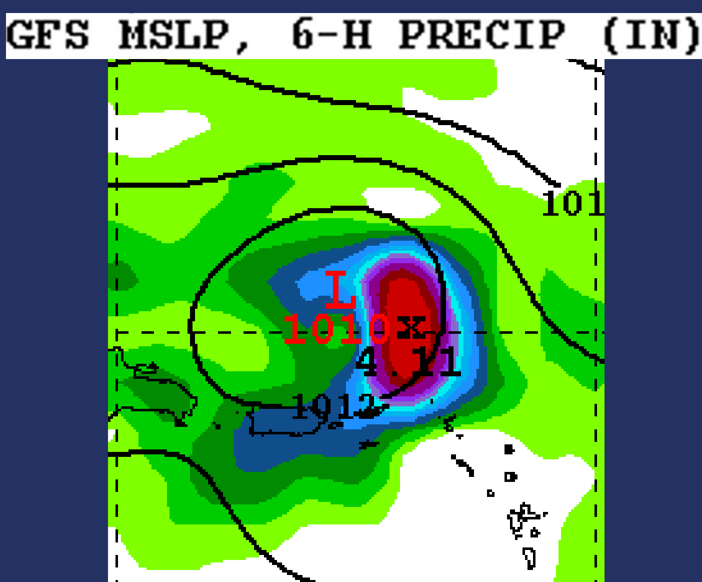


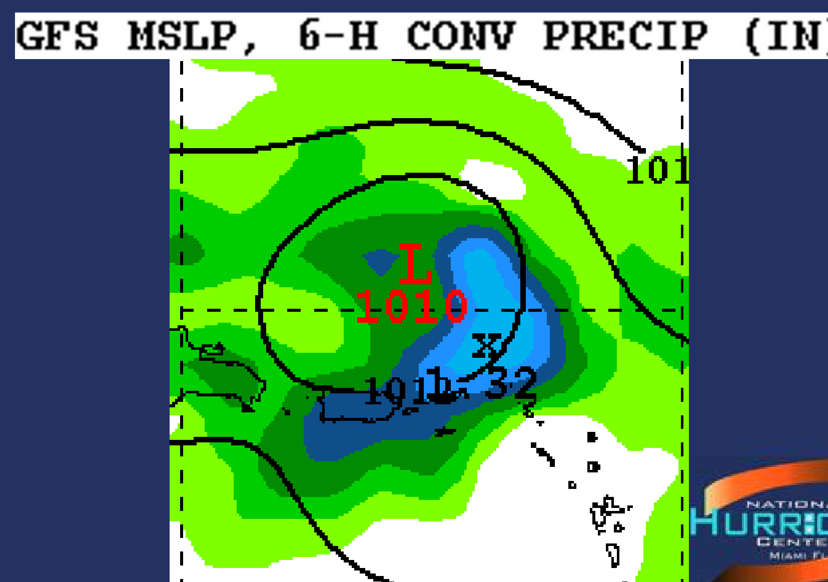


Model Forecasts

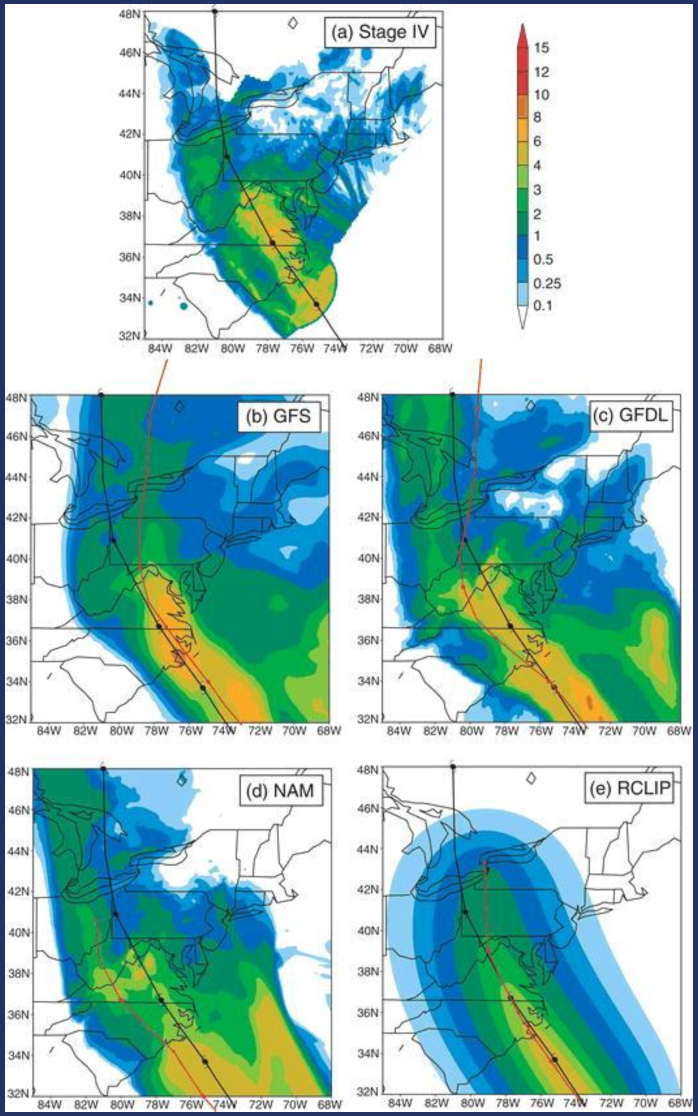
NCEP Model QPF Biases

- **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



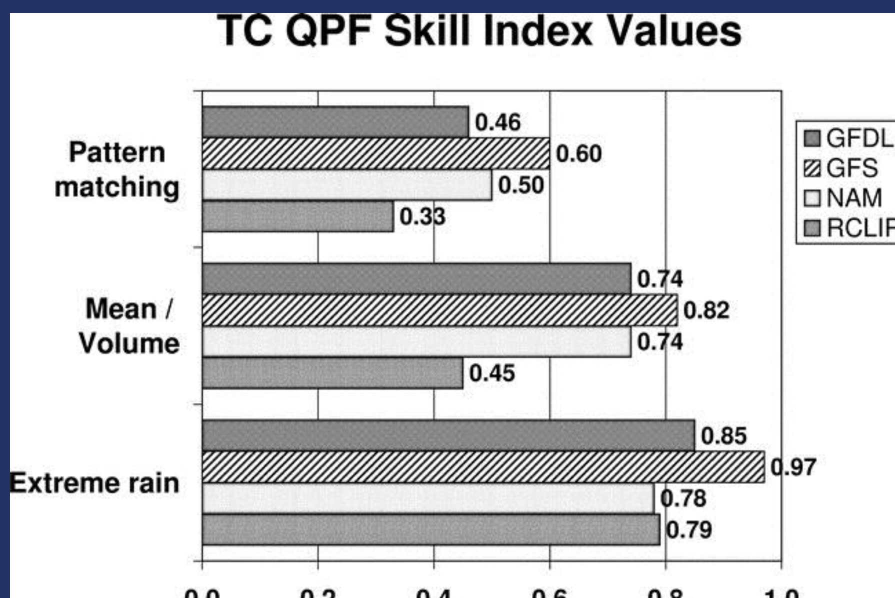
1998-2004 U.S. landfalling TC QPFs from the GFS, GFDL hurricane model, the NAM, and the R-CLIPER (Rainfall Climatology and Persistence)

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

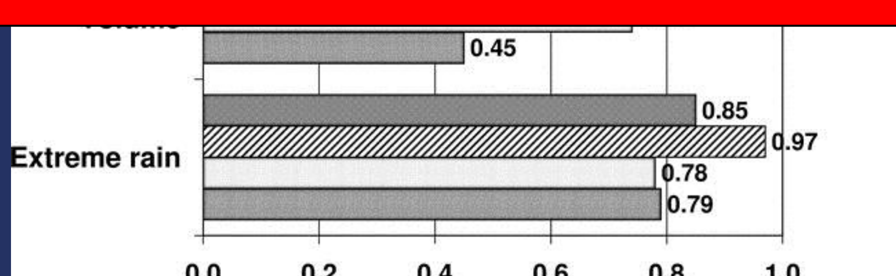
- Compared to R-CLIPER, all numerical models showed comparable or greater skill for all attributes
- GFS performed the best of all of the models for each of the categories
- GFDL had a bias of predicting too much heavy rain, especially in the core of the tropical cyclones
- NAM predicted too little of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



Model TC QPF Skill
Marchok et al, 2007

- Compared t … e or greater skill for all a …
- GFS perfor … ories
- GFDL had a … the core of the tropical …
- NAM predic …
- R-CLIPER … much too little rain at …

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



Where to Find Model QPFs

- **NHC Tropical Rainfall Webpage (storm-specific GFS, hindcasts)**

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

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

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**

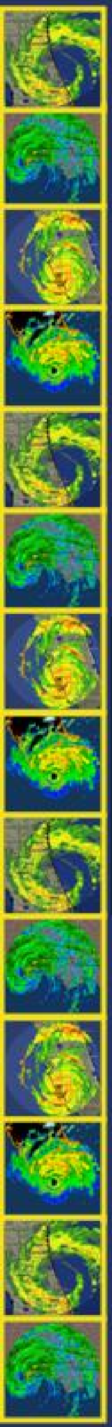
http://schumacher.atmos.colostate.edu/weather/ecmwf.php

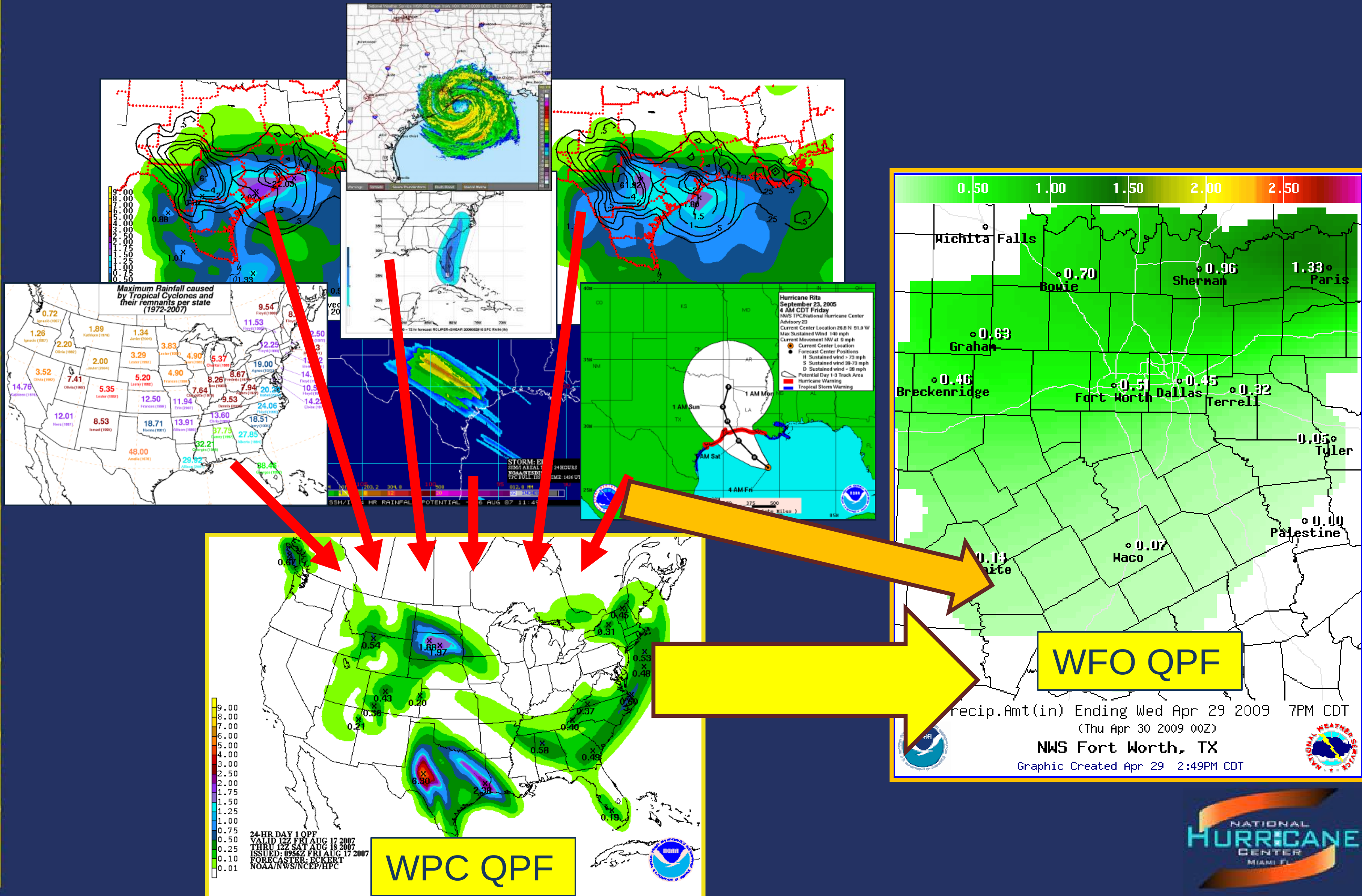
- **Penn State Tropical Atlantic E-Wall**

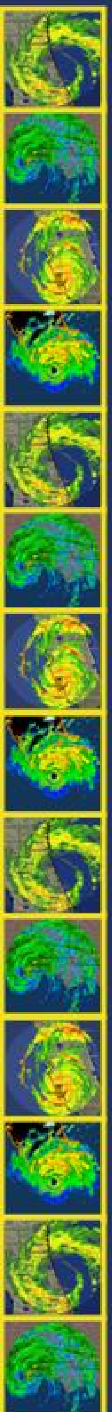
http://mp1.met.psu.edu/~fxg1/ewalltropatl.html

TC QPF Forecast Process

NWS Tropical Cyclone Quantitative Precipitation Forecasts (QPF)

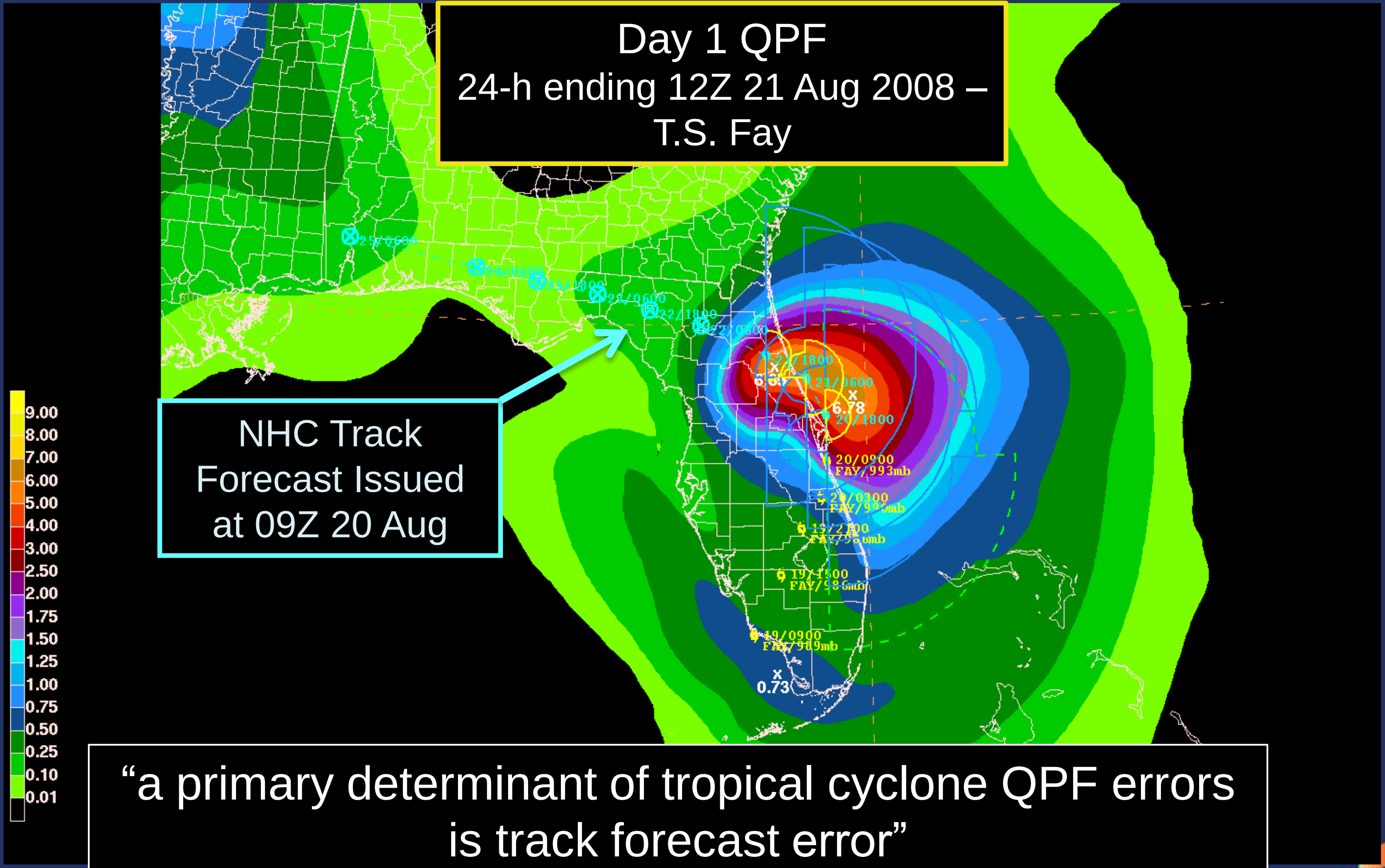






Production of Tropical Cyclone Quantitative Precipitation Forecasts

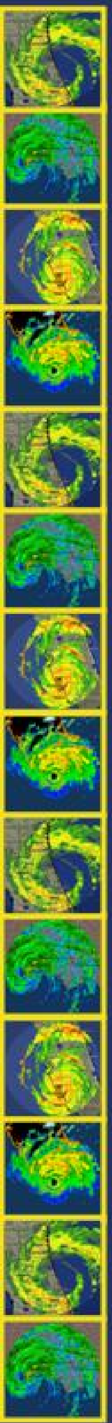
A good place to start is the model closest to the NHC track forecast

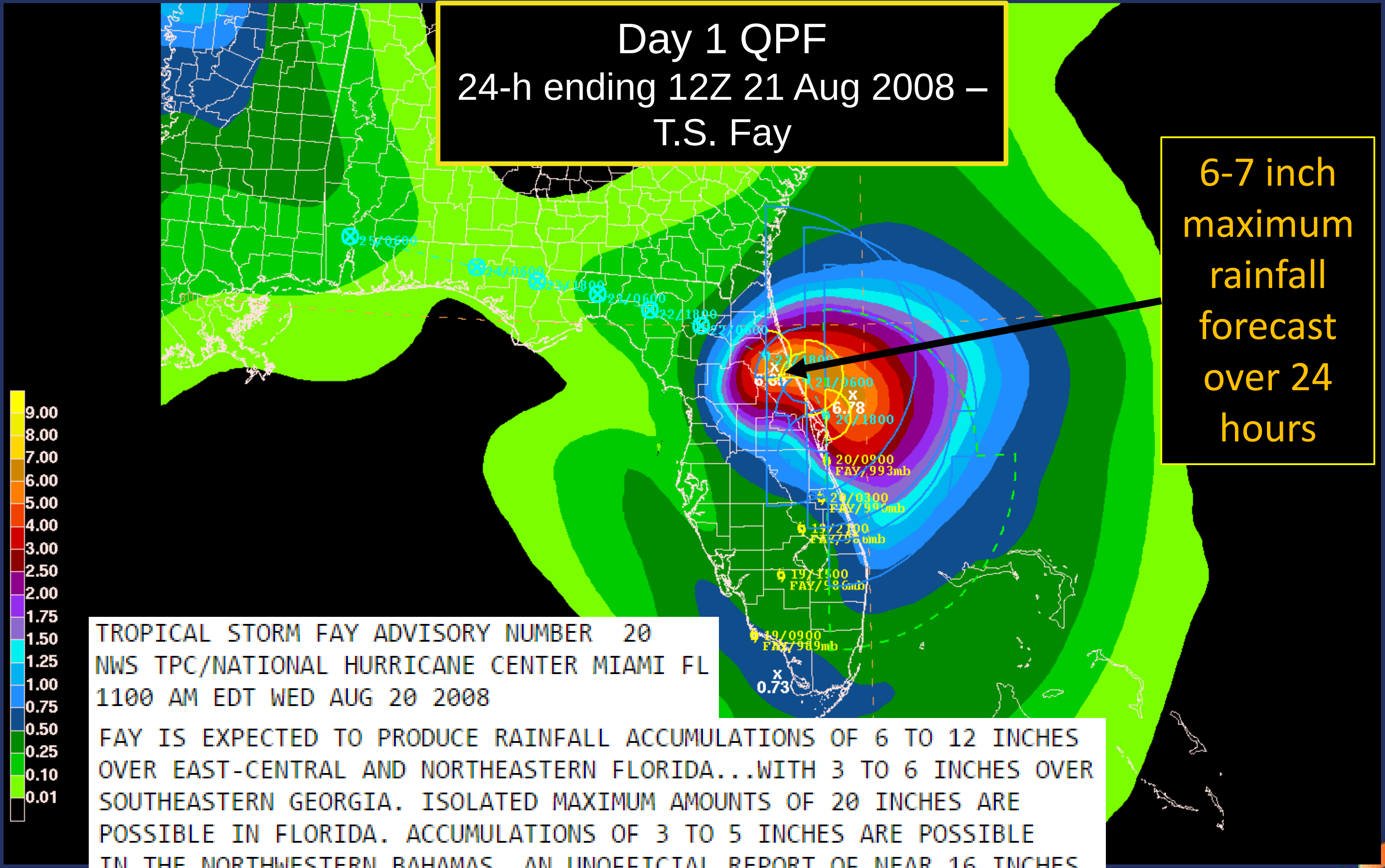


“a primary determinant of tropical cyclone QPF errors is track forecast error”
– Marchok et al 2007

Production of Tropical Cyclone Quantitative Precipitation Forecasts

How well do the models match the NHC rainfall statement?





6-7 inch maximum rainfall forecast over 24 hours

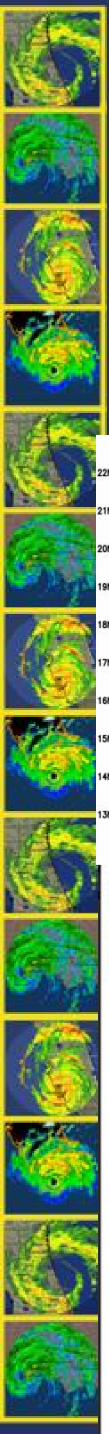
TROPICAL STORM FAY ADVISORY NUMBER 20
NWS TPC/NATIONAL HURRICANE CENTER MIAMI FL
1100 AM EDT WED AUG 20 2008

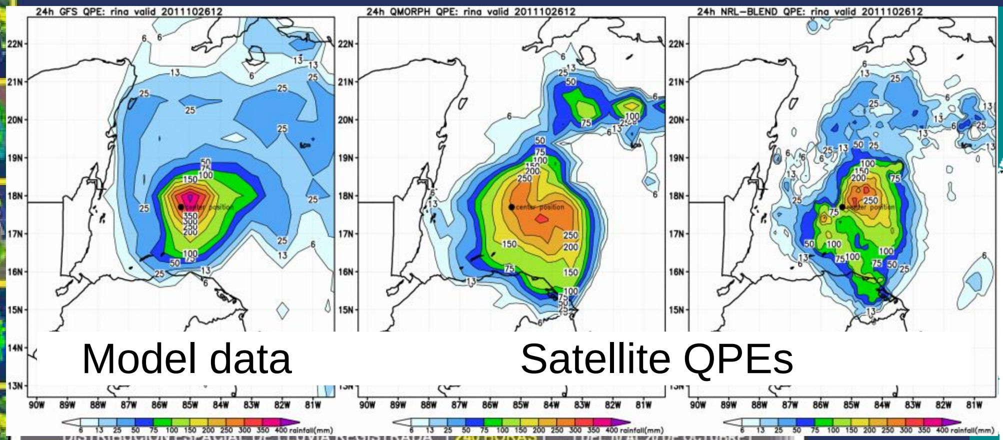
FAY IS EXPECTED TO PRODUCE RAINFALL ACCUMULATIONS OF 6 TO 12 INCHES OVER EAST-CENTRAL AND NORTHEASTERN FLORIDA...WITH 3 TO 6 INCHES OVER SOUTHEASTERN GEORGIA. ISOLATED MAXIMUM AMOUNTS OF 20 INCHES ARE POSSIBLE IN FLORIDA. ACCUMULATIONS OF 3 TO 5 INCHES ARE POSSIBLE IN THE NORTHWESTERN BAHAMAS. AN UNOFFICIAL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

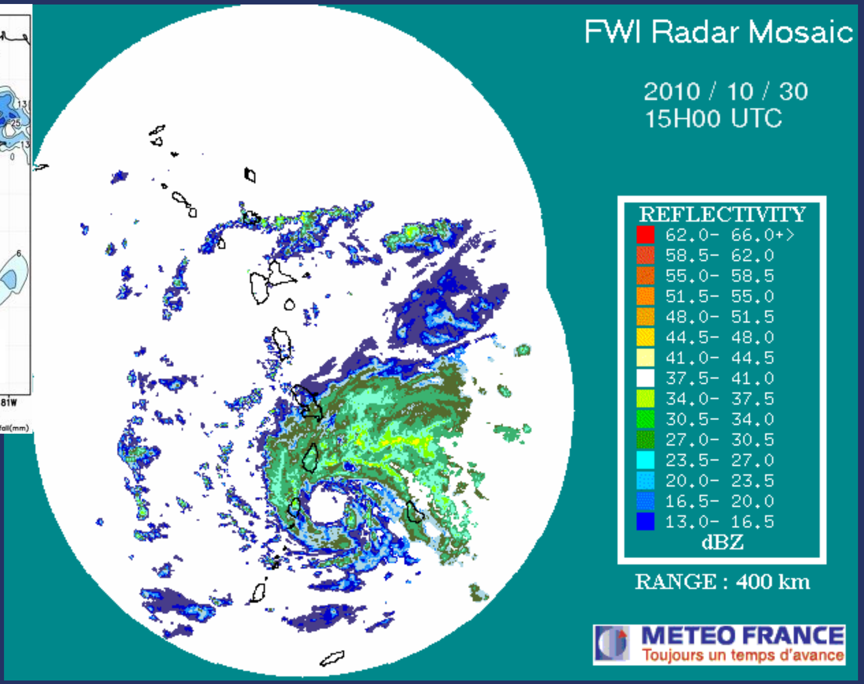
NATIONAL HURRICANE CENTER MIAMI FL

Production of Tropical Cyclone Quantitative Precipitation Forecasts

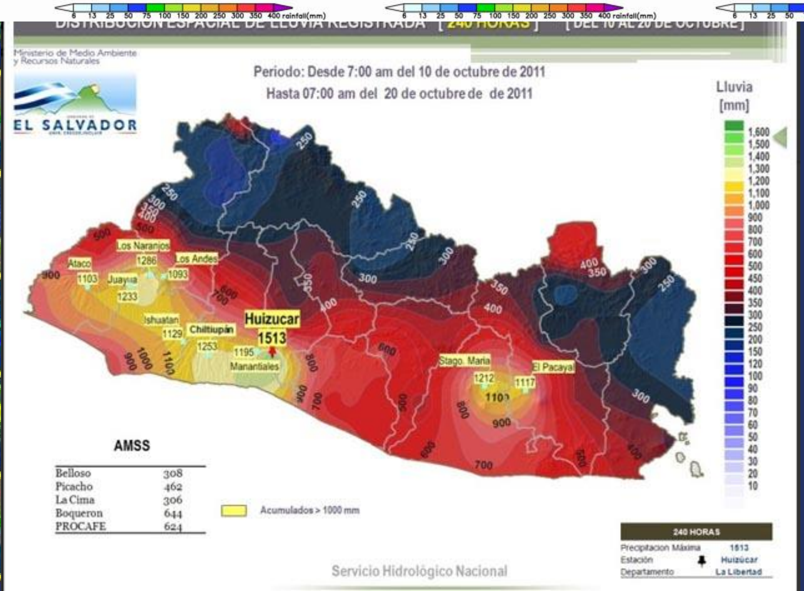
Use observations and recent model data to determine the current structure/rainfall rates







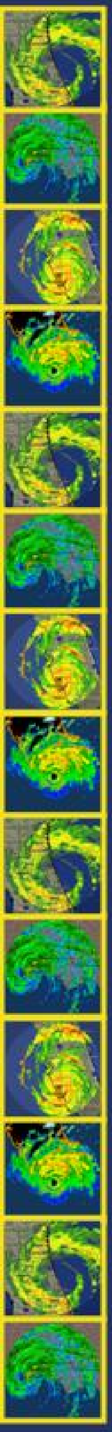
Radar

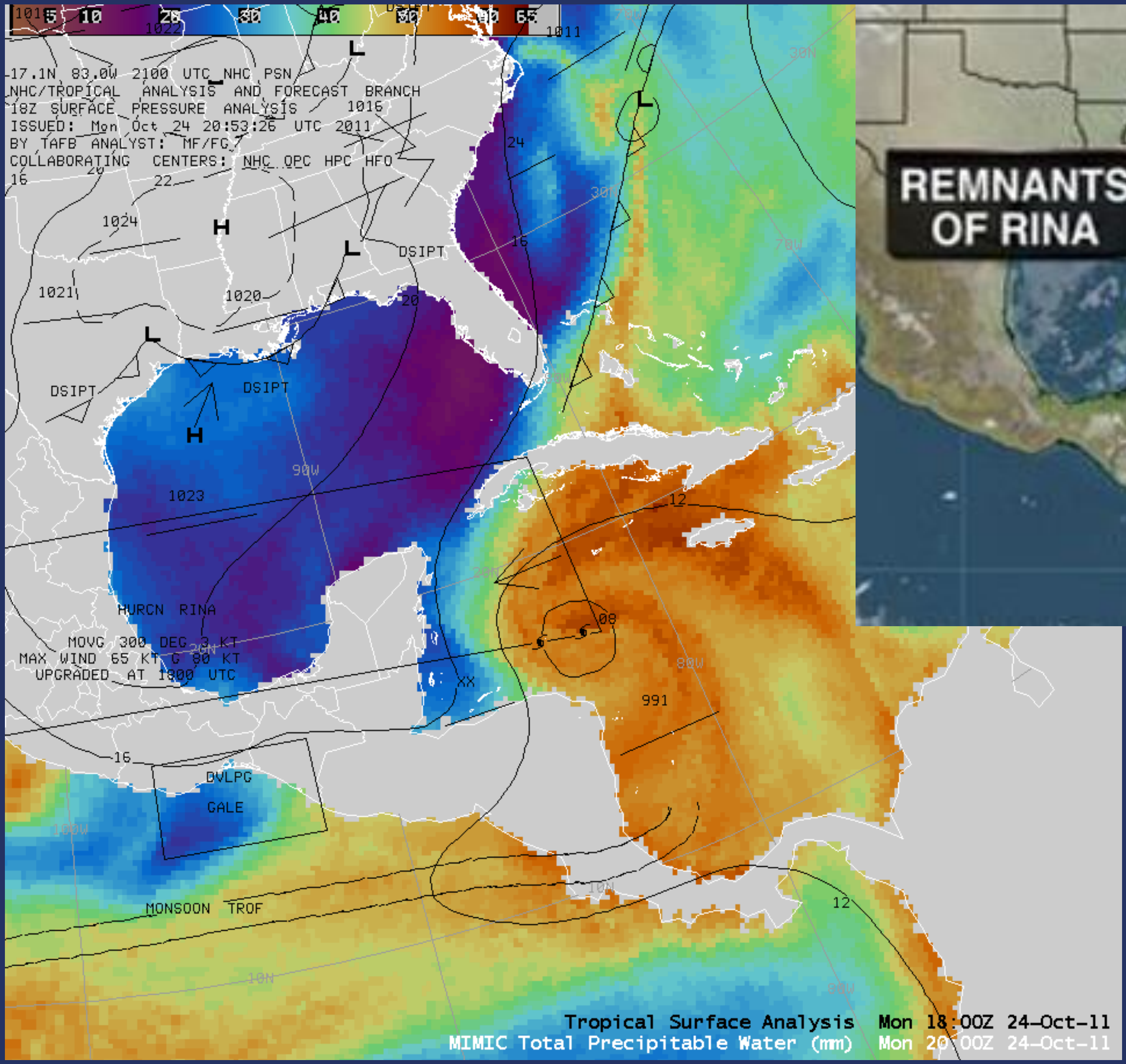


Gauge data

Production of Tropical Cyclone Quantitative Precipitation Forecasts

Locate relevant synoptic scale and meso-scale boundaries

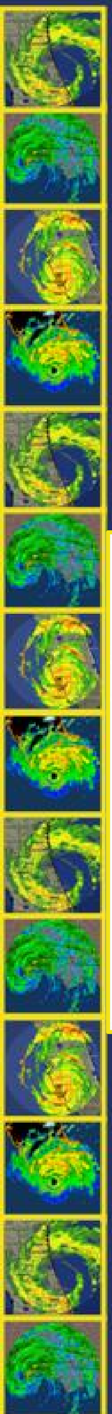


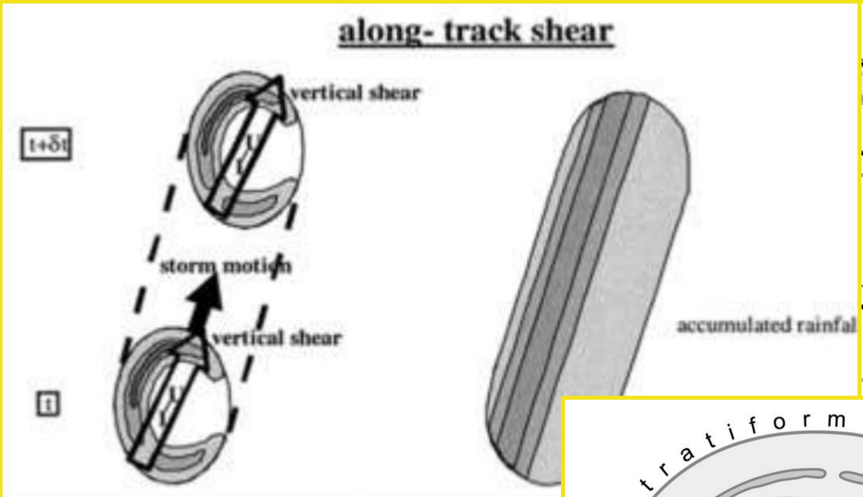


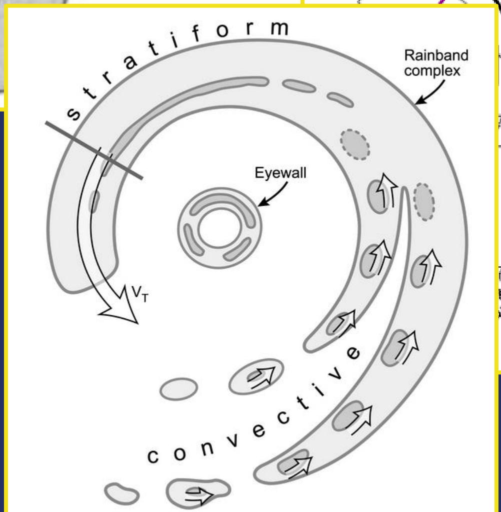
Hurricane Rina (2011)

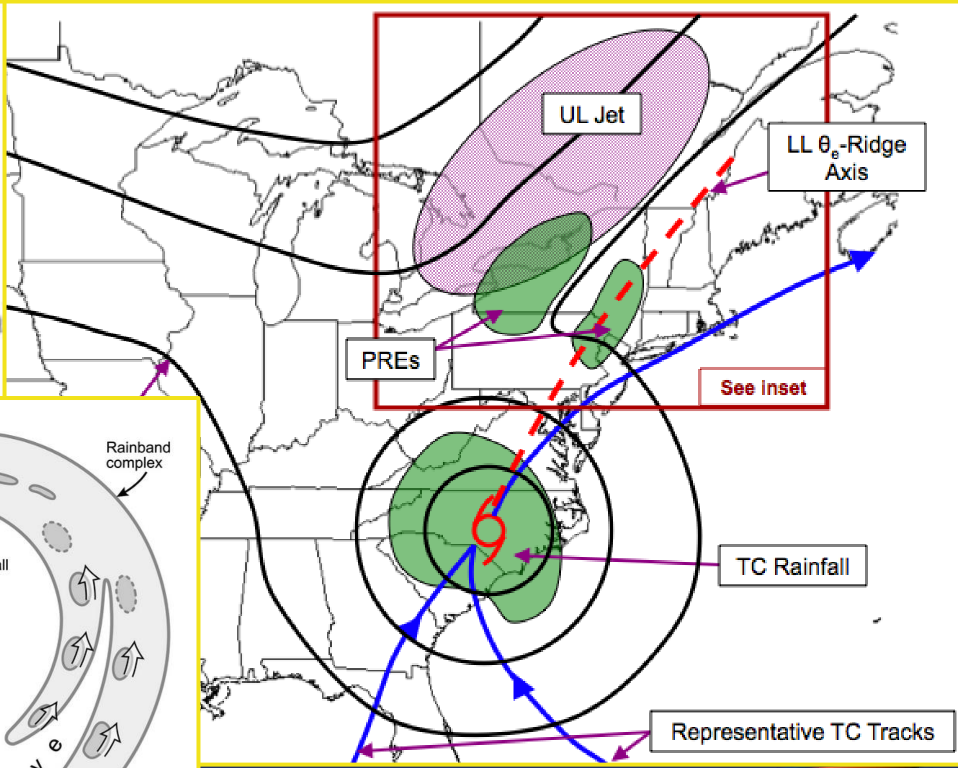
Production of Tropical Cyclone Quantitative Precipitation Forecasts

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







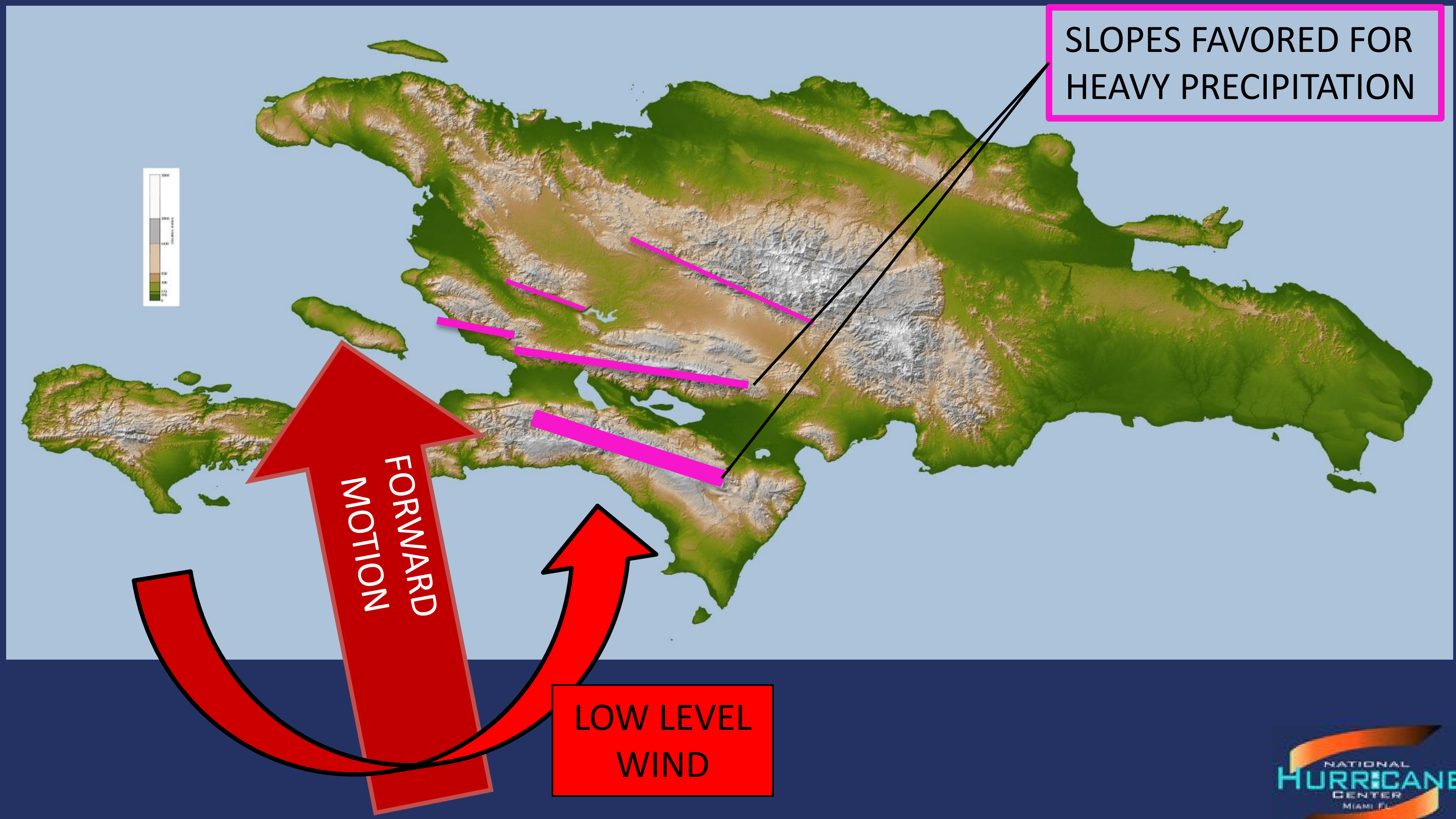


Production of Tropical Cyclone Quantitative Precipitation Forecasts

Identify areas of orographic enhancement

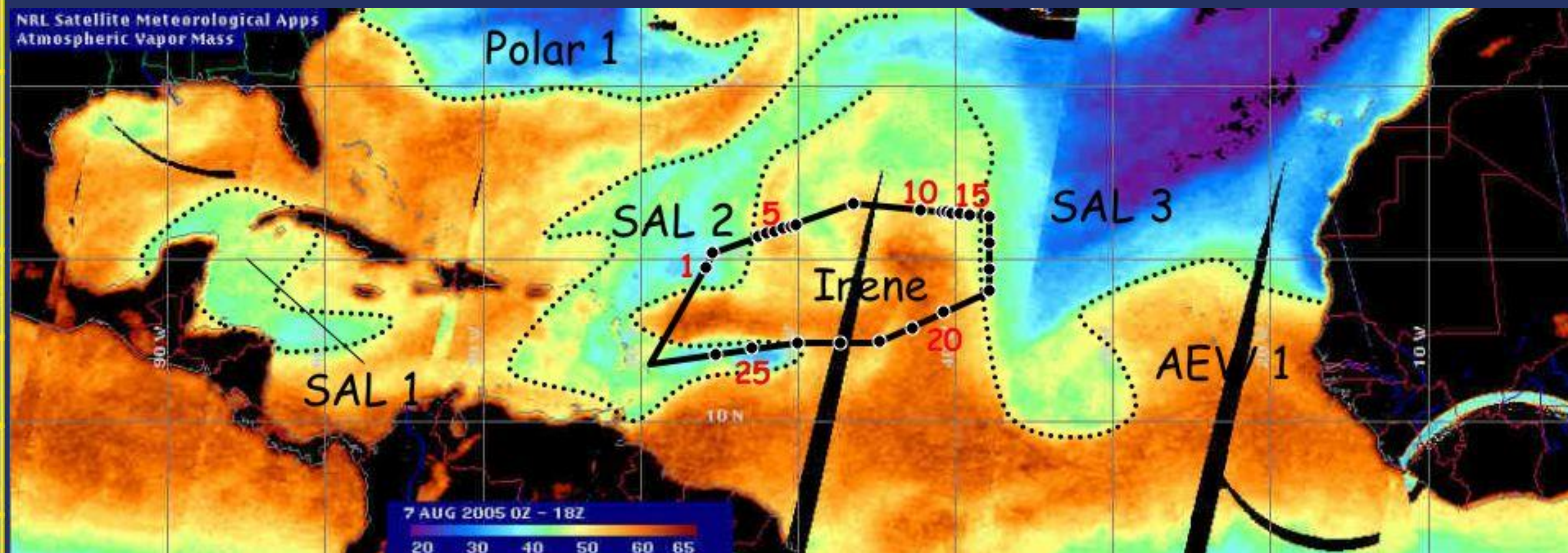
Production of Tropical Cyclone Quantitative Precipitation Forecasts

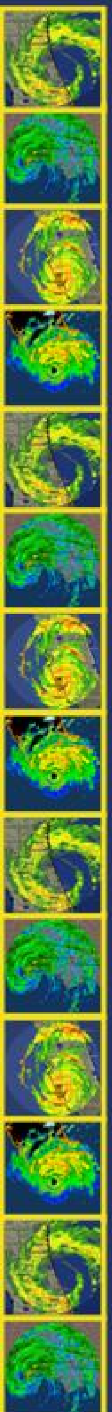
Identify areas of orographic enhancement



Production of Tropical Cyclone Related QPF

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

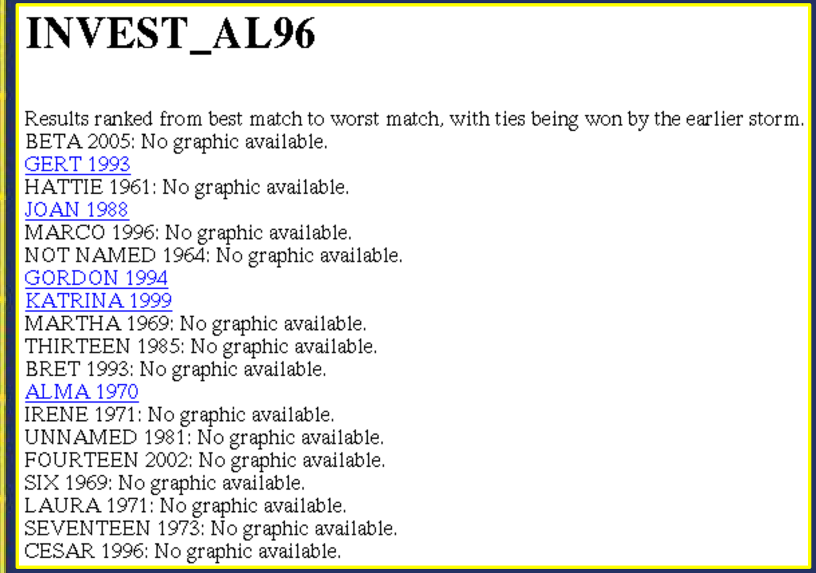




Production of Tropical Cyclone Related QPF

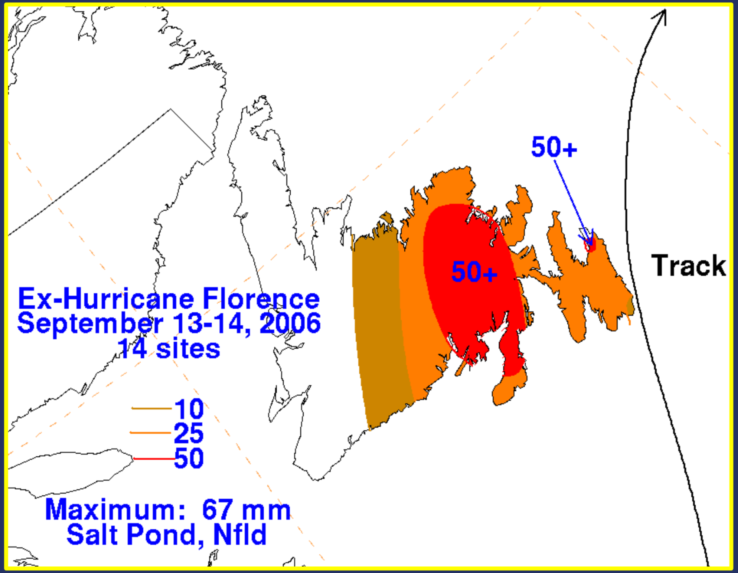
Use climatology (CLIQR, R-CLIPER, TC Rainfall Climatology) and data from past storms to:

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



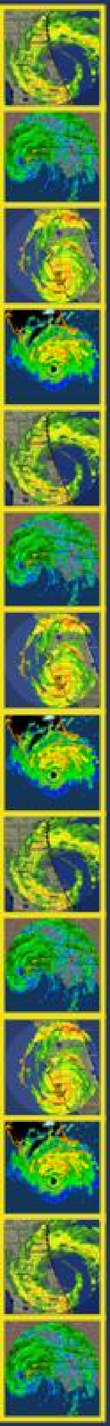
INVEST_AL96

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 (satellite rainfall products, NWP models, etc.)
- Remember, heavy rain can also occur well away from the TC itself (PRE, secondary disturbances, etc.)



Thank You

Questions?