UNIVERSITY OF MIAMI
ROSENSTIEL
SCHOOL of MARINE &
ATMOSPHERIC SCIENCE

Development of a Tropical Cyclone Probabilistic Rainfall Model

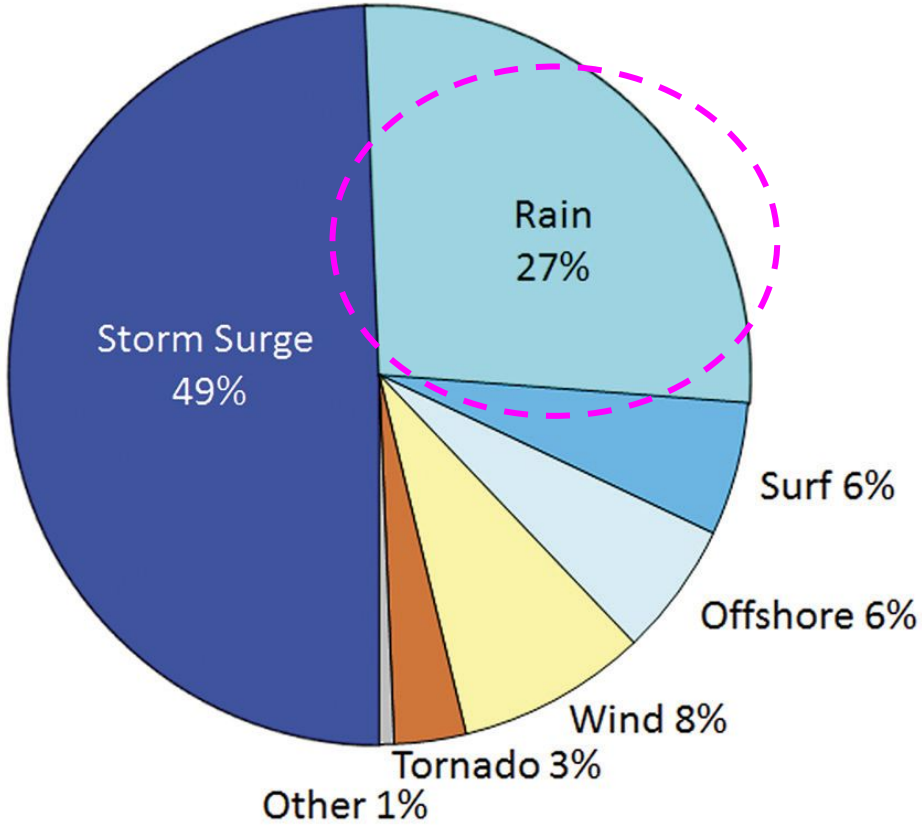
Frank Marks[1], Brian McNoldy[2], Mu-Chieh Ko[3], and Andrea Schumacher[4]

[1]NOAA/AOML
[2]University of Miami/RSMAS
[3]University of Miami/CIMAS
[4]Colorado State University/CIRA

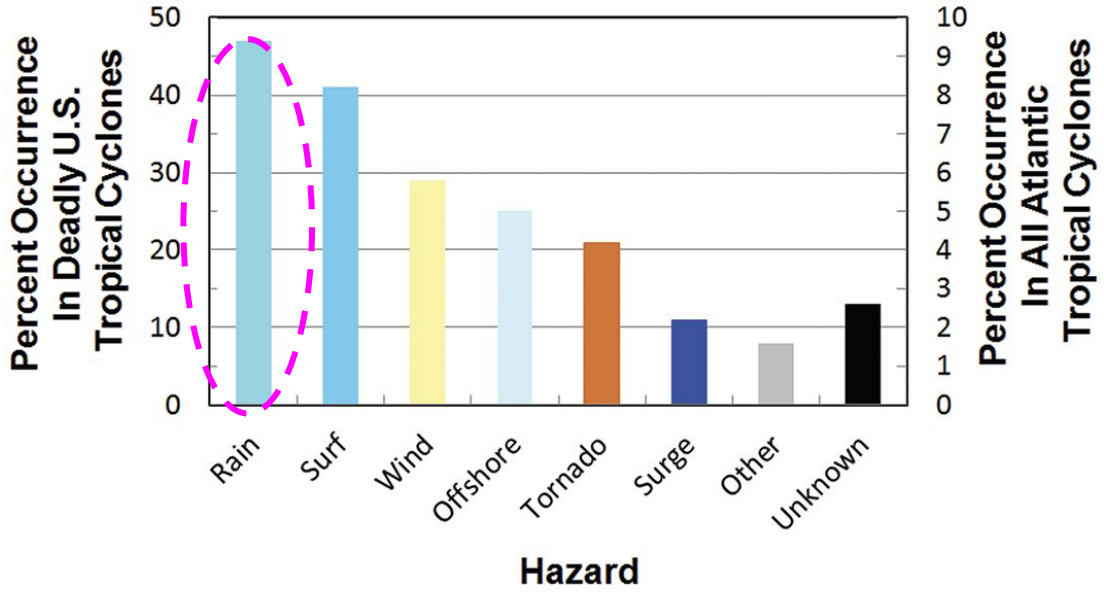


UNIVERSITY OF MIAMI
ROSENSTIEL
SCHOOL of MARINE &
ATMOSPHERIC SCIENCE

Why TC rainfall is important:

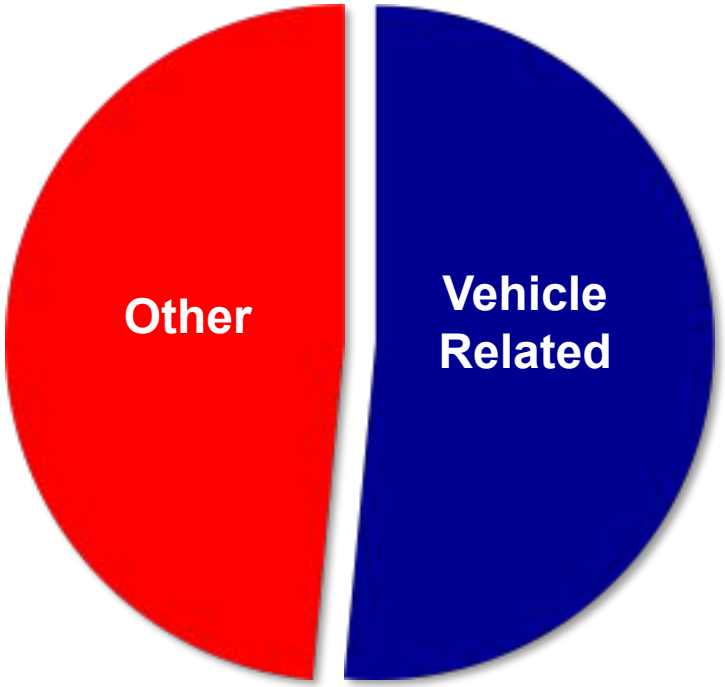


Rappaport 2014



Flood Related Vehicle Fatalities

- From 2016-2018, *more than half of* the U.S. tropical cyclone water-related fatalities were vehicle related!



2016-18 U.S. Tropical Cyclone Water Related Fatalities

HFIP Goals & Metrics: Rainfall

Goal 4.5	**Improve accuracy & lead time of WPC Excessive Rainfall Outlook for TCs.**
Metric 4.5	Brier Score of Day-3 Excessive Rainfall Outlook for landfalling Atlantic basin TCs
Baseline	Current Brier Score of Day-3 Excessive Rainfall Outlook, 2015-17 CONUS-landfalling TCs.
Target	Current Brier Score of Day-2 Excessive Rainfall Outlook:
Goal 4.6	**Improve skill of Quantitative Precipitation Forecasts (QPF) for landfalling TCs.**
Metric 4.6	QPF Brier Score for TCs affecting CONUS, Puerto Rico, and USVI
Baseline	QPF Brier Score for TCs affecting CONUS, Puerto Rico, and USVI 2015-17
Target	10% improvement over baseline
Goal 4.7	**Create a probabilistic TC QPF product based on HAFS/HWRF ensemble output.**
Metric 4.7	Disseminate probabilistic TC QPF for CONUS, Puerto Rico, & USVI TC threats.
Baseline	N/A
Target	Disseminate probabilistic TC QPF for CONUS, Puerto Rico, & USVI TC threats.

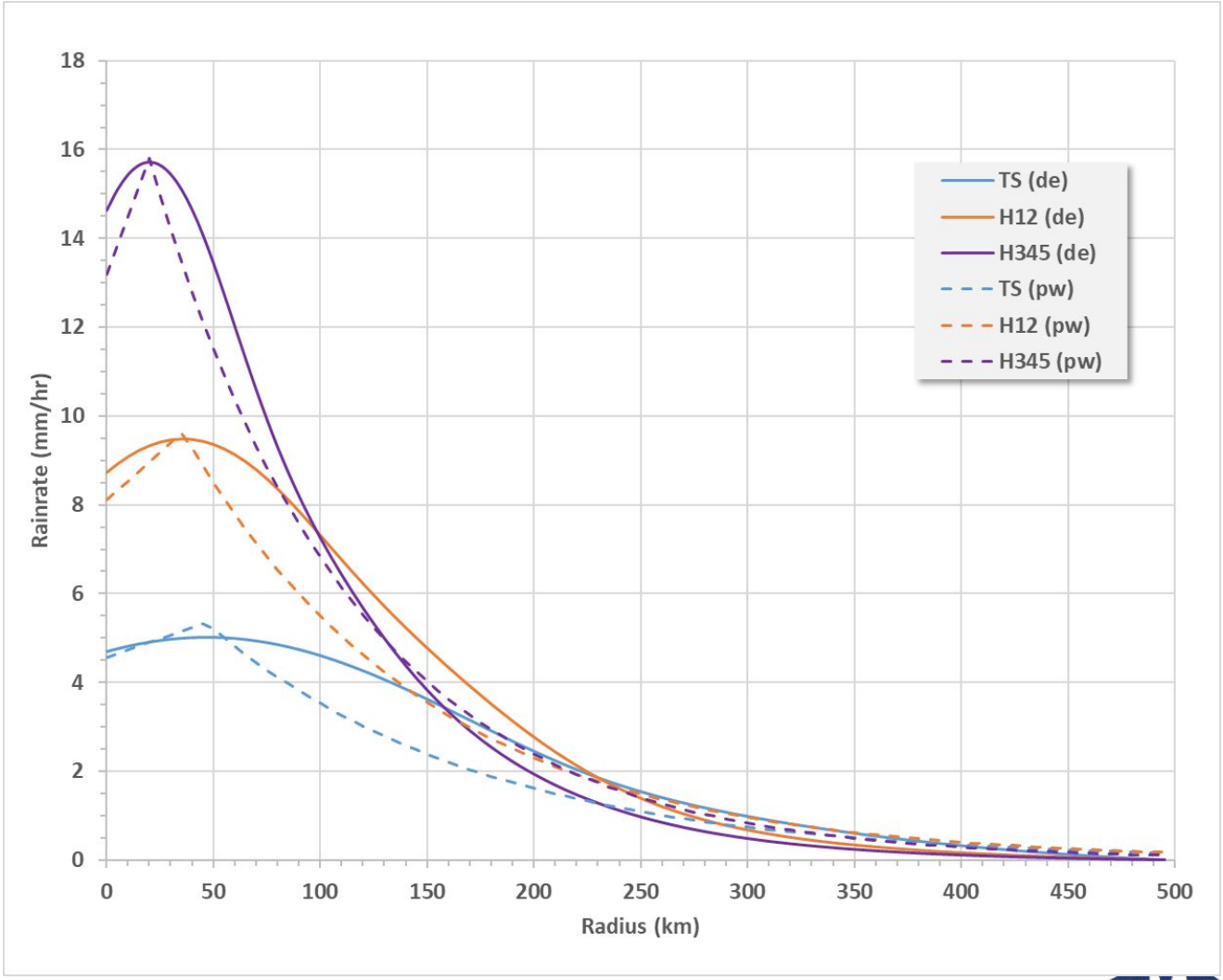
see Appendix A of HFIP Strategic Plan

Parametric Modeling of TC Rainfall

- **R-CLIPER**: Rainfall CLImatology & PERsistence
  - Marks & DeMaria (2003), Tuleya et al (2007)
  - Accounts for intensity, size, & speed, but not shear asymmetry or topography
  - Run experimentally at NHC 2001-2003, operationally since 2004
- **PHRaM**: Parametric Hurricane Rainfall Model
  - Lonfat et al (2007)
  - Builds on R-CLIPER framework, but adds shear asymmetry & topography
  - Intensity & shear dependent parameterization of rainfall derived from TRMM data (Lonfat et al 2004 & Chen et al 2006)
- **Rainfall Probability**: Probabilistic PHRaM
  - Utilize 1000-member Monte-Carlo track ensemble used for Wind Speed Probability
  - Run PHRaM on 1000 members to get probabilistic information

R-CLIPER

- 2121 TC cross-sections of rainfall collected from TRMM during 1998-2003
  - Partitioned by intensity (TS, H12, H345)
- Replaced piecewise formulation in R-CLIPER with dual-exponential
- Rain rate scales continuously with intensity, $V_{max} \geq 35kt$, $R_{max} \leq 100km$



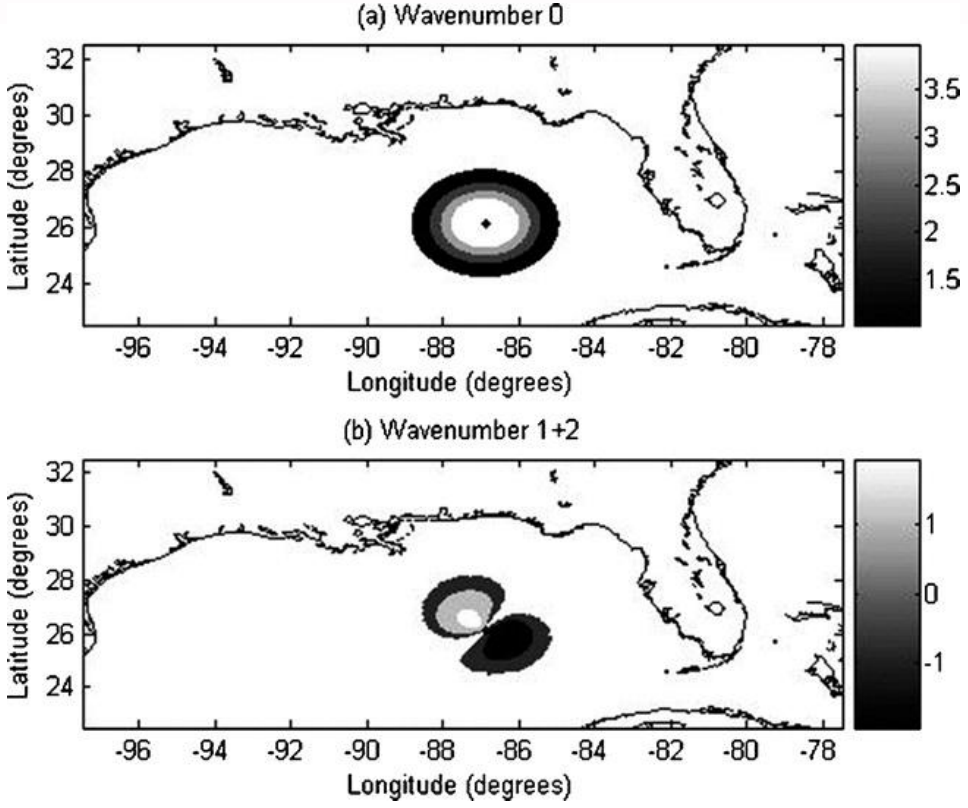
Marks and DeMaria (2003)

PHRaM

$$R_{\text{PHRaM}} = R_{\text{R-CLIPER}} + R_{\text{shear mod}} + R_{\text{topography}},$$

$$R_{\text{shear mod}}(r, \theta) = \sum a_i(r) \cos(i\theta) + \sum b_i(r) \sin(i\theta),$$

$$R_{\text{topography}} = c\mathbf{V}_s \cdot \nabla h_s,$$



- *c* proportionality constant, $\mathbf{V}_s$ 10 m wind field, & h_s is elevation. Use Willoughby et al. (2006) wind model

$$V(r) = V_{\max}\left(\frac{r}{R_{\max}}\right)^n, \quad (0 \le r \le R_{\max}),$$

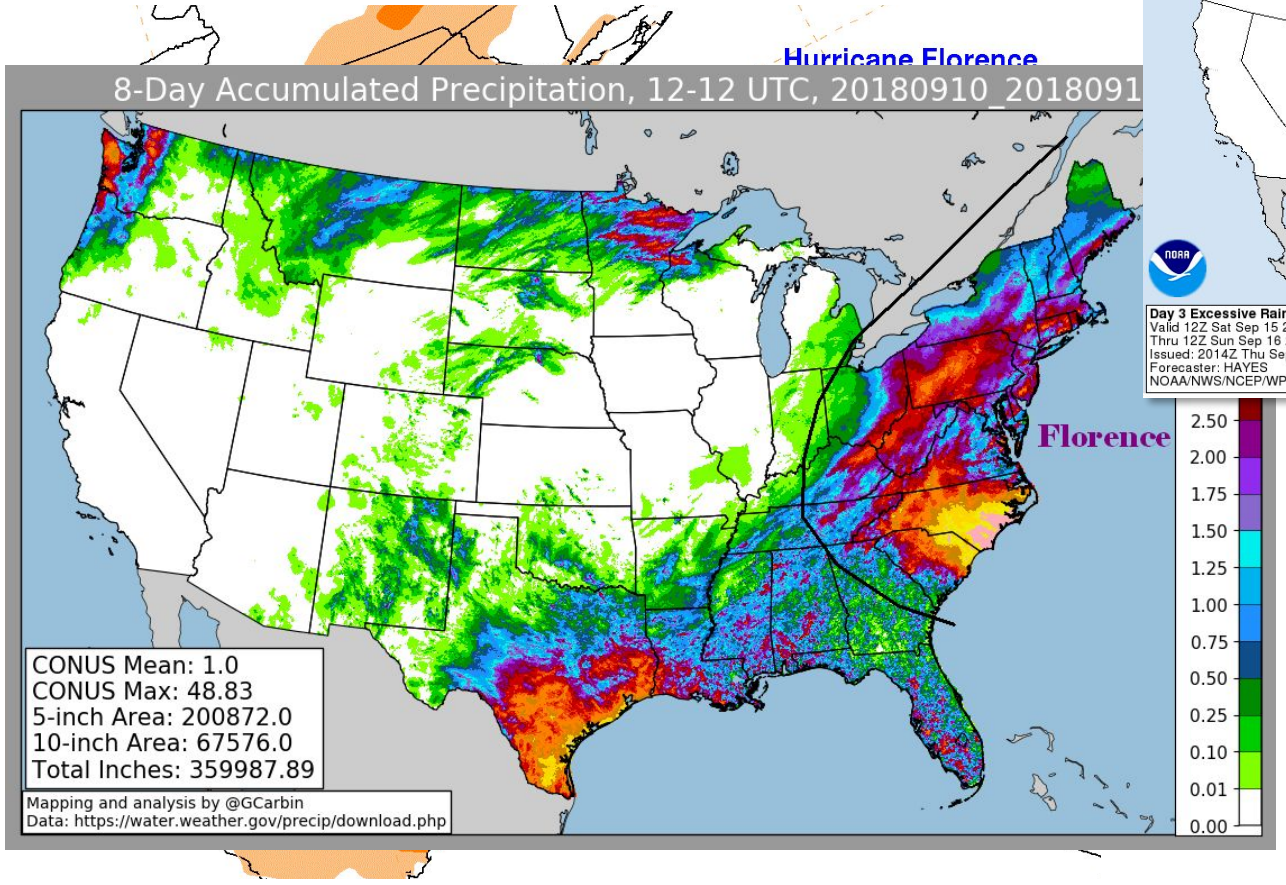
$$V(r) = V_{\max} \exp\left(-\frac{r - R_{\max}}{X_1}\right), \quad (R_{\max} \le r),$$

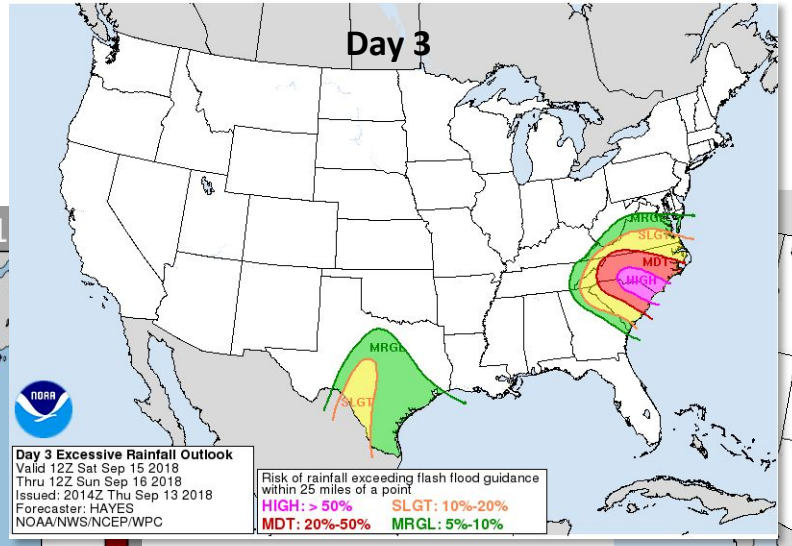
- *n* is power law exponent inside R_{max} (=1), X_1 is exponential decay length to 250 km radius.
- Wind field reduced by 85% for 10-m estimate
- Inflow angle not accounted for

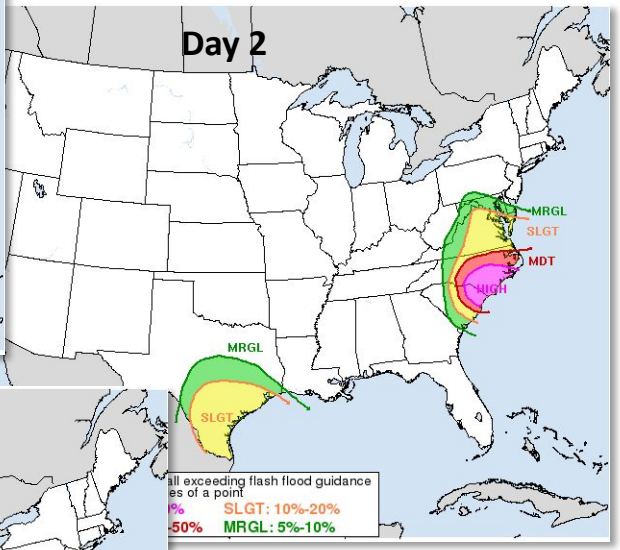
Lonfat et al. (2007)

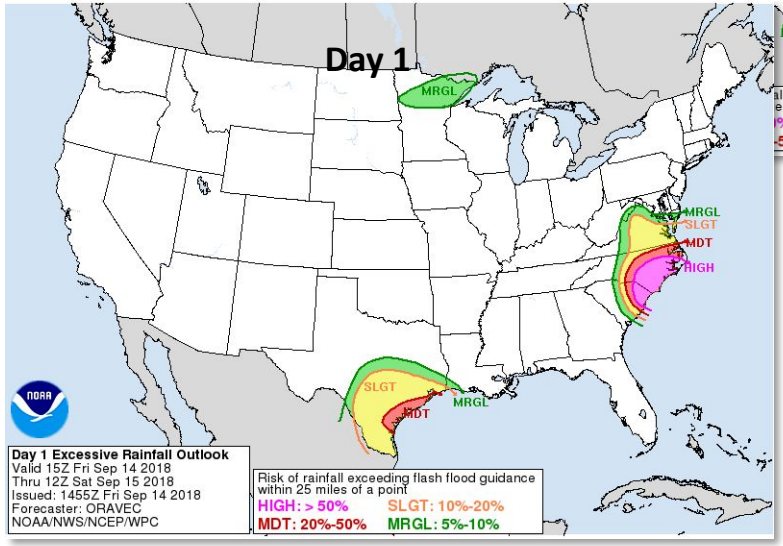
UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

Florence Excessive Rainfall Outlook



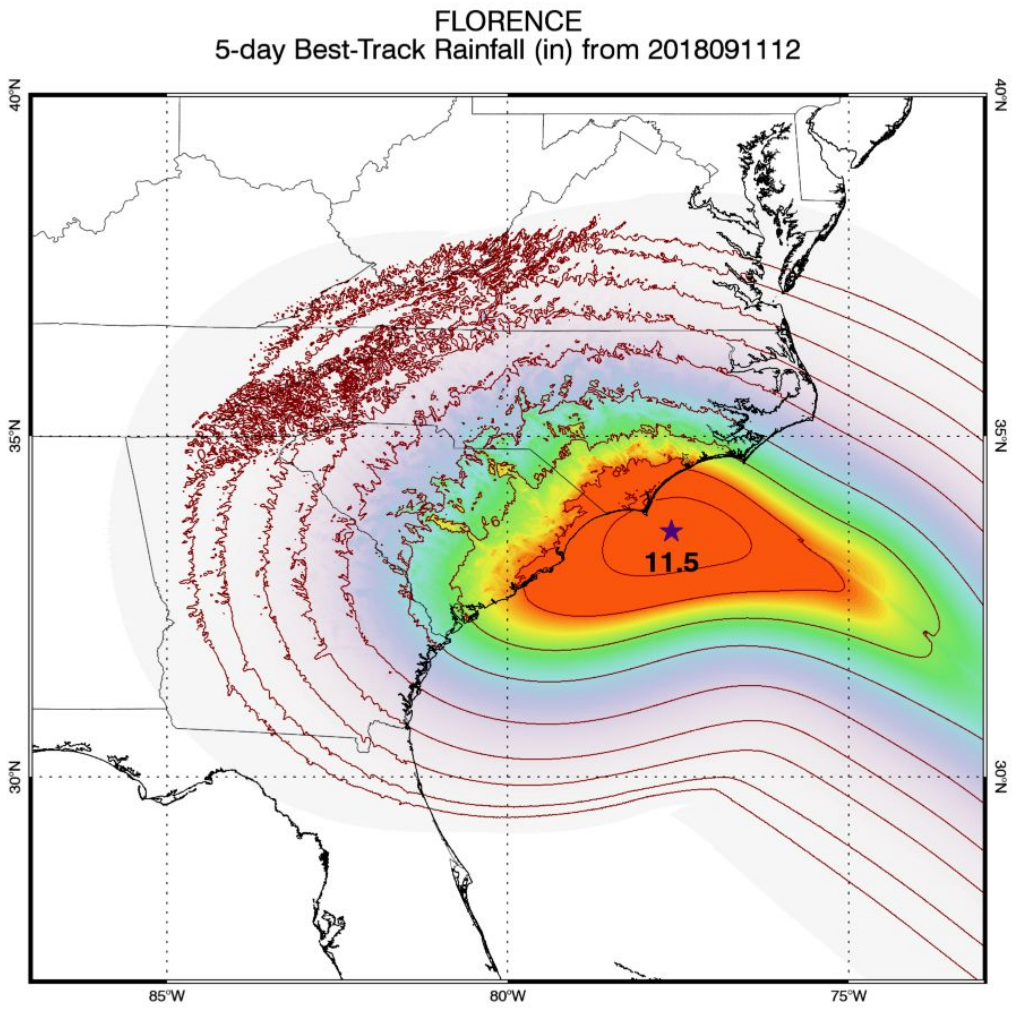






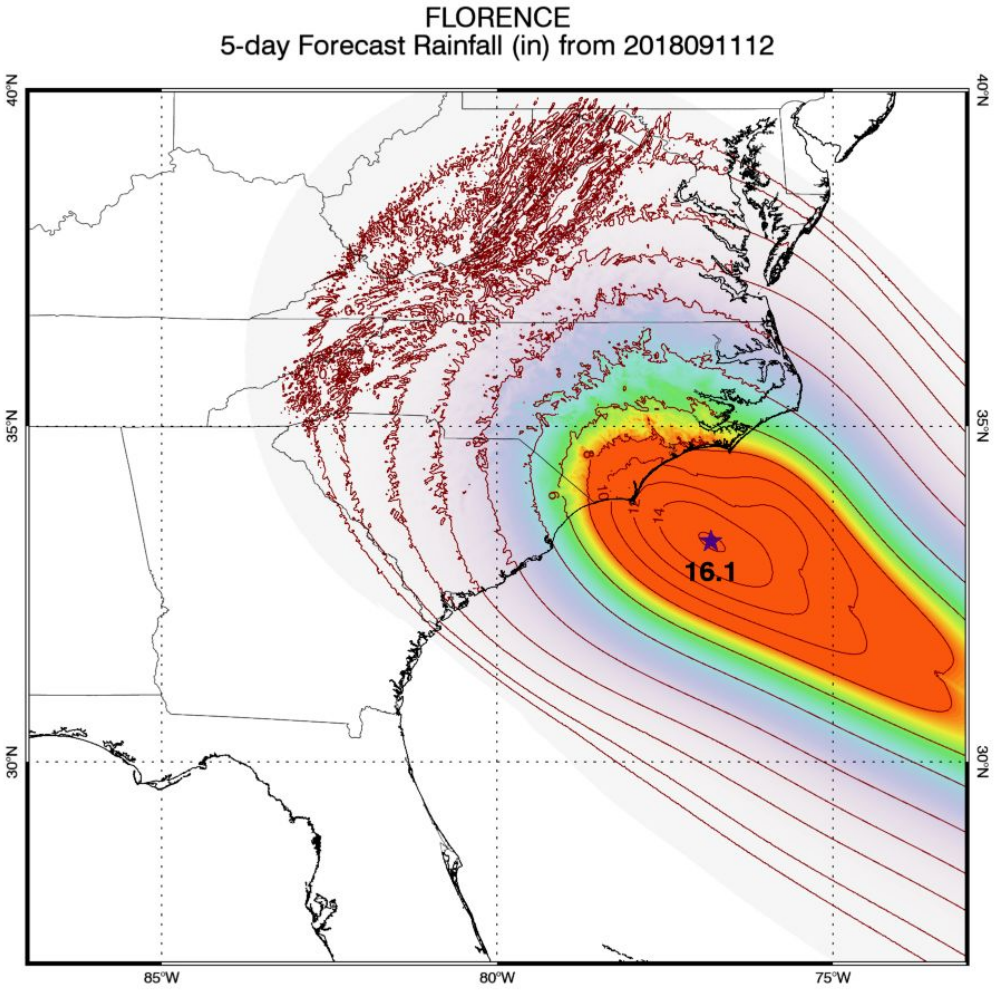
Best Track PHRaM

- Example using *best-track* position, intensity, shear, RMW for Florence (2018) from 1200 UTC 11 September (3 days prior to landfall)
  - RMW values from Extended Best-Track



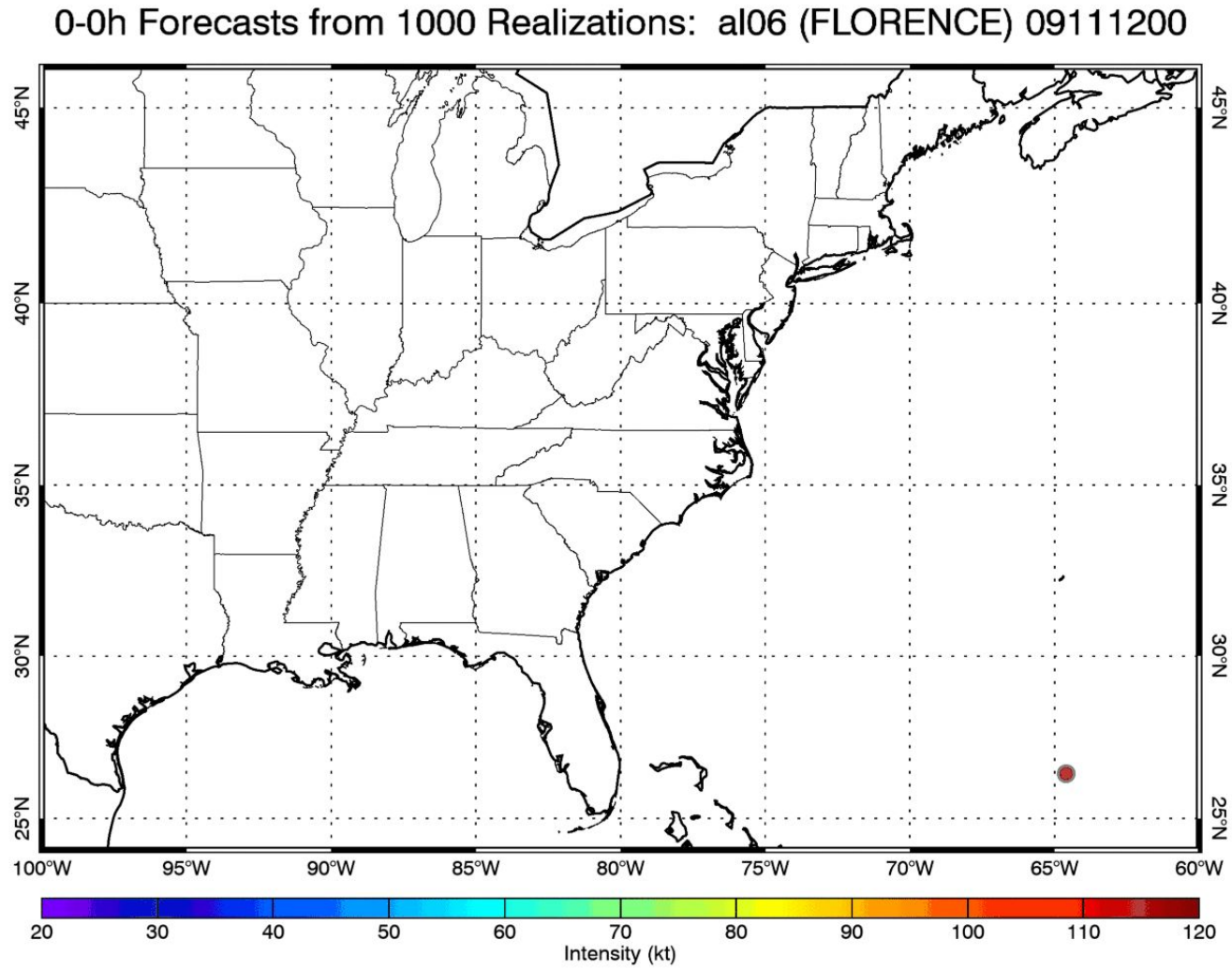
Forecast Track PHRaM

- Example using *forecast* values of position, intensity, shear, & RMW for Florence (2018) from 1200 UTC 11 September (3 Day prior to landfall)
  - RMW values from Knaff et al (2015) empirical relationship that is function of V_{max} & latitude



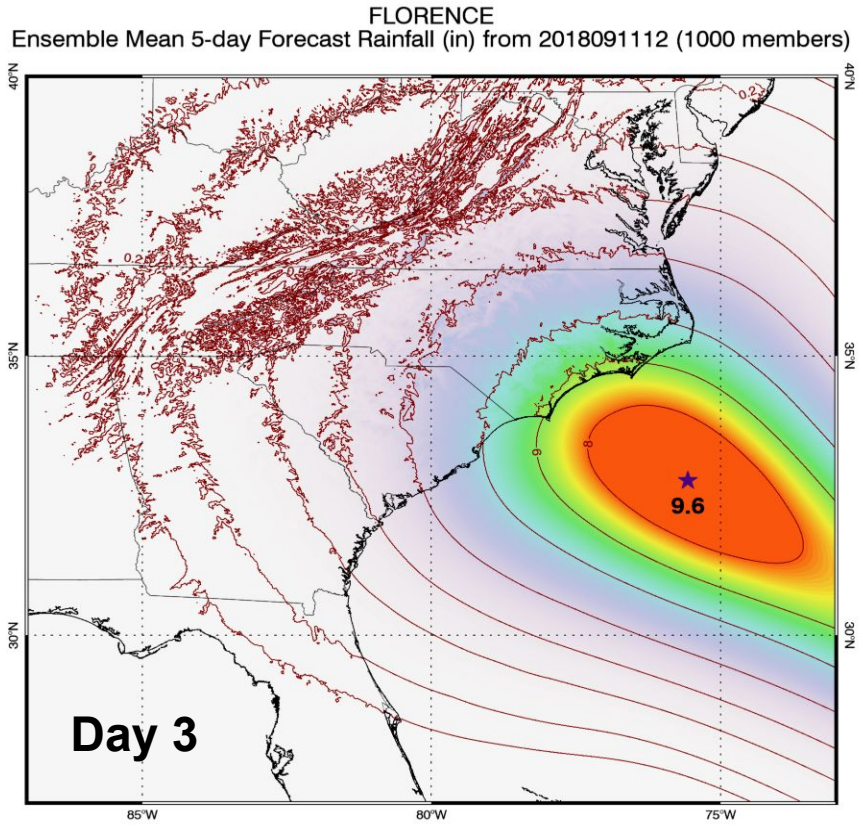
TC Ensemble

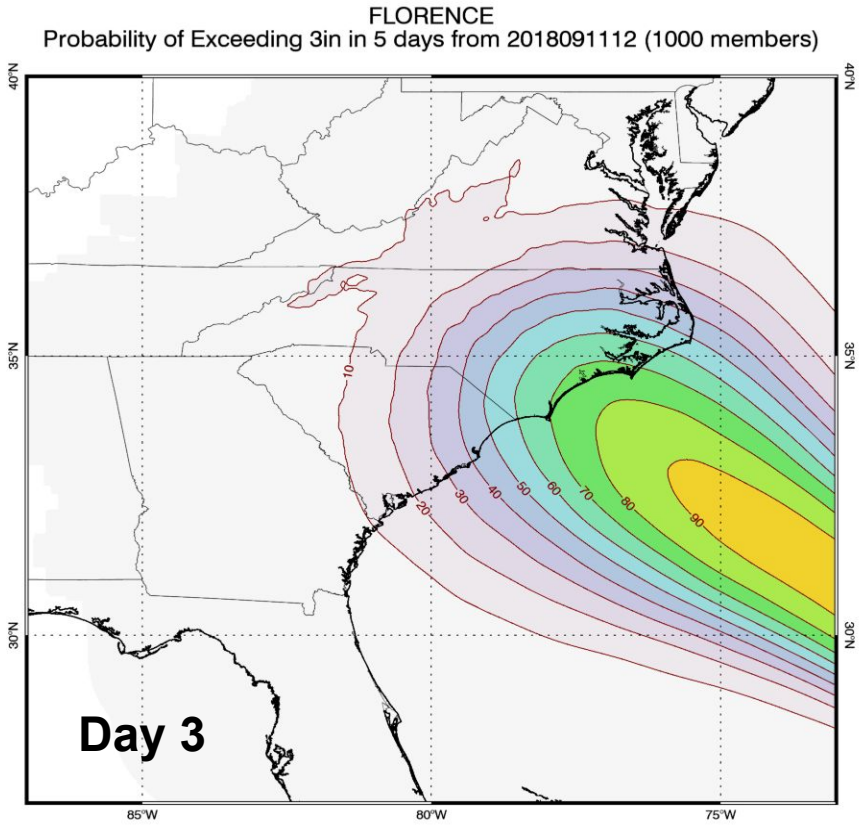
- Operational Monte Carlo 1000-member track ensemble (DeMaria et al 2009)
  - Includes uncertainties in track, intensity, & size randomly selected from NHC error distributions over past 5 years
- Used to generate 34 kt, 50 kt, and 64 kt wind speed probabilities.
- Why not reuse for rainfall probabilities?



Rainfall Probability

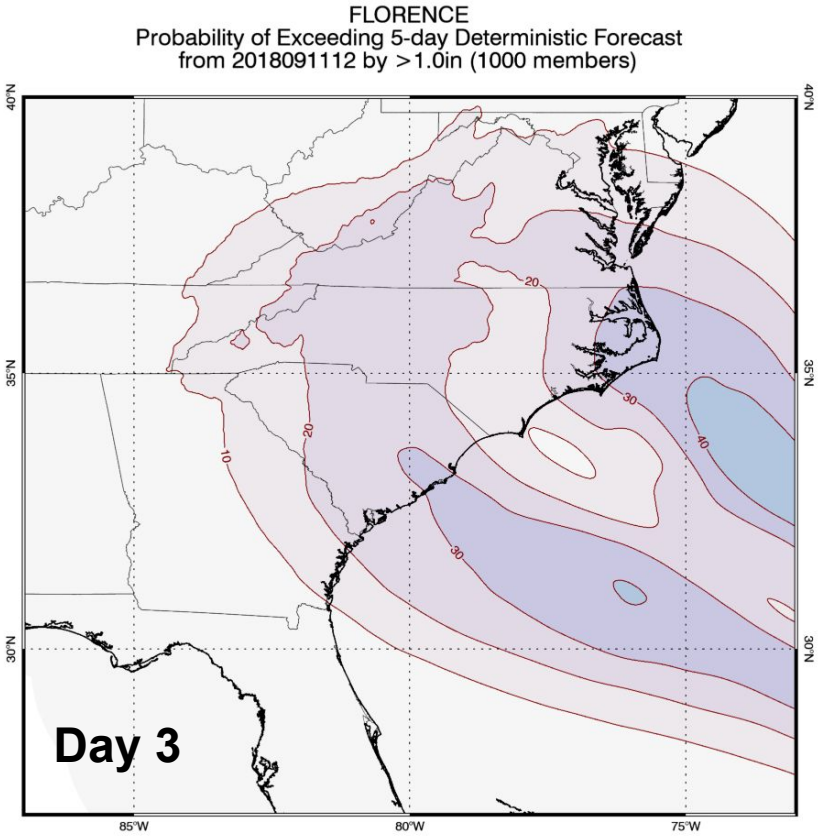
- Ensemble-based products include an ensemble mean & probability of exceeding a fixed amount

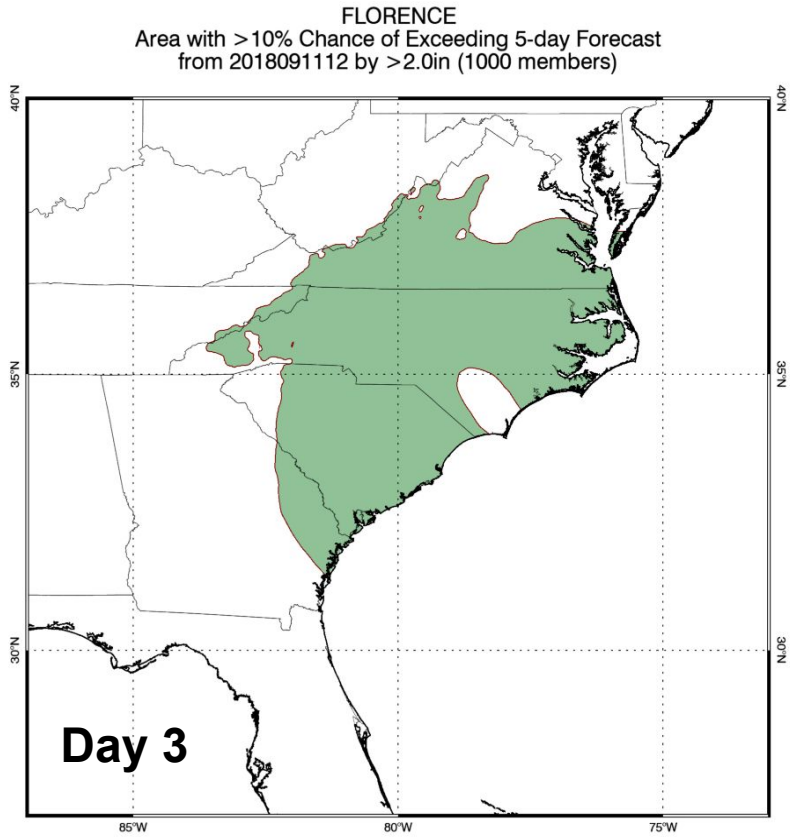




Rainfall Probability

- Probability of exceeding deterministic forecast by some amount & area with % chance of exceeding deterministic forecast





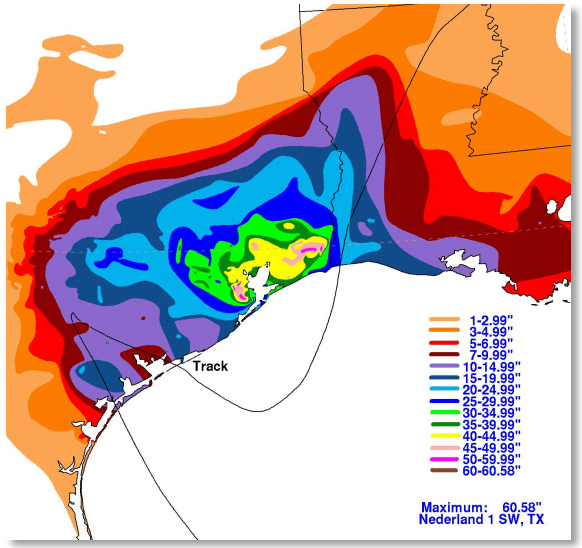
Planned Improvements

- Replace Willoughby wind model with wind model used in Wind Speed Probability product
- Determine effective rainfall guidance thresholds & lead times
- Develop earliest & most likely time of arrival of rain products
- Replace & evaluate historical track, intensity & structure uncertainty with numerical model uncertainty
- Link probabilistic rainfall guidance to flood potential guidance
- Code is available here
    - Input: TCV (A-Deck: track, intensity, radii), SHIPS output (shear)

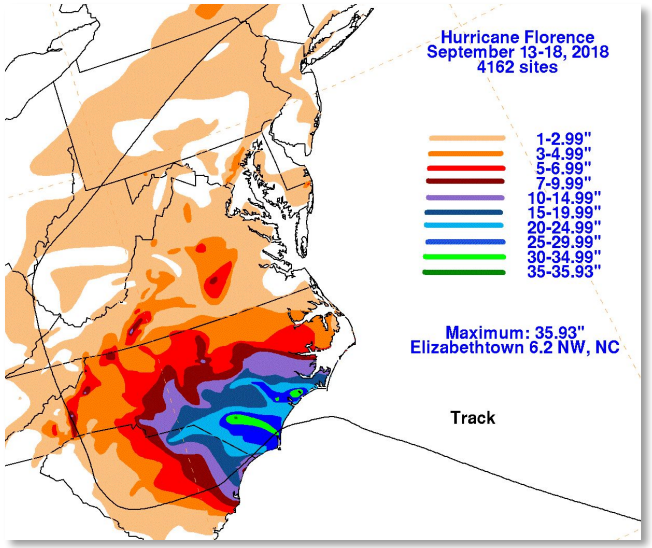
Questions?


Record-Setting Hurricane Rainfall

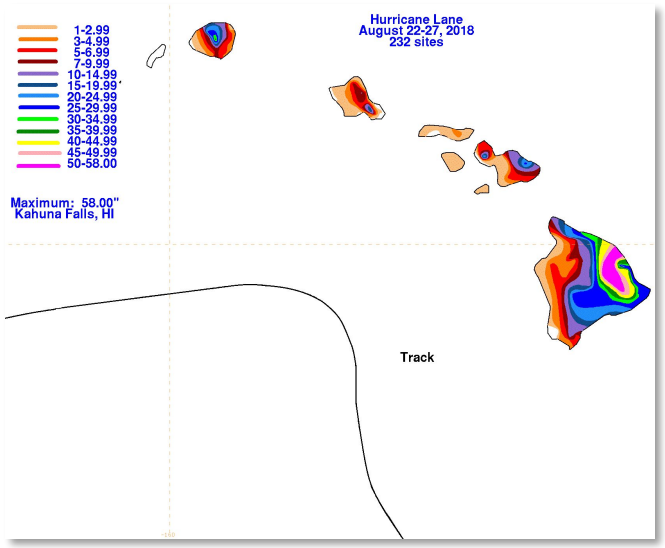
- Hurricanes Harvey, Florence, and Lane have each set state records for tropical cyclone rainfall with Harvey's rainfall of 60+ inches setting the U.S. record



Harvey (2017) - 60.58 in Texas & U.S. Record



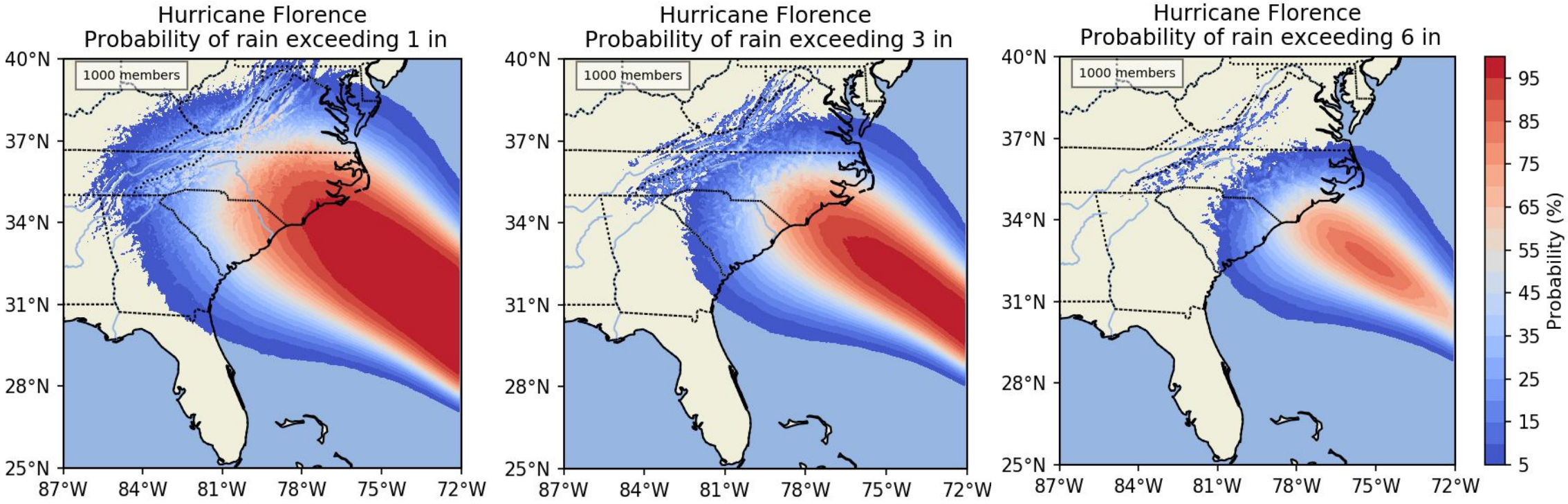
Florence (2018) – 35.93/26.63 in North Carolina/South Carolina Record



Lane (2018) – 58.00 in Hawaii Record

Rainfall Probability

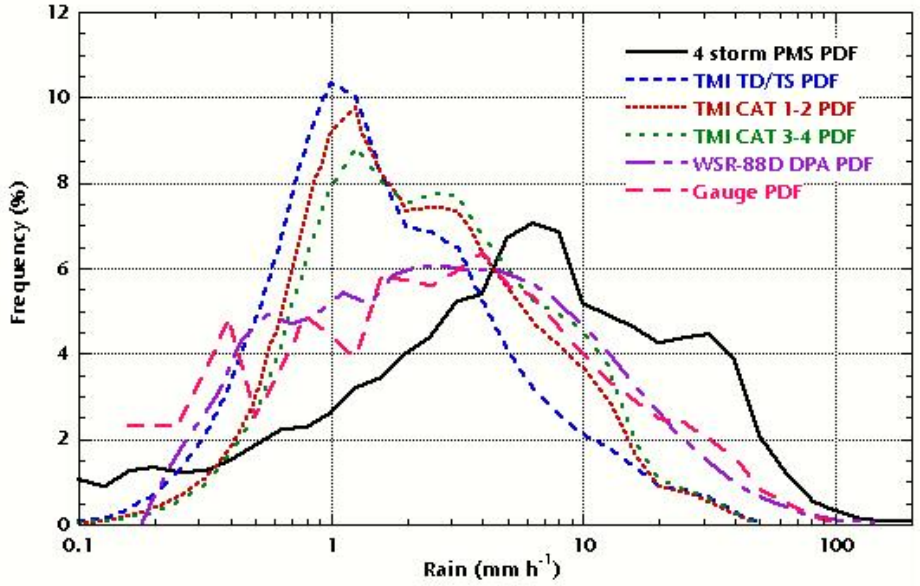
- Ensemble-based products include probability of exceeding a fixed amount

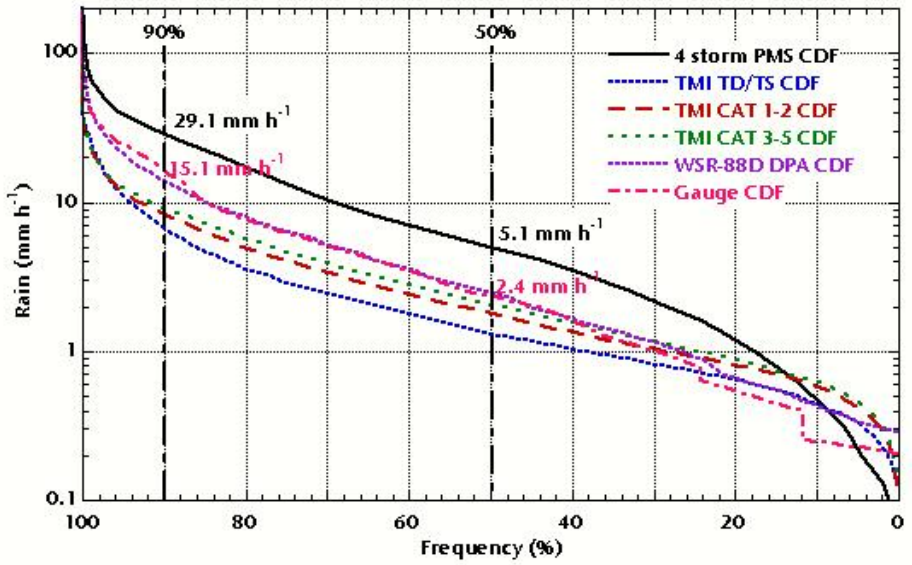


UNIVERSITY OF MIAMI
ROSENSTIEL
SCHOOL of MARINE &
ATMOSPHERIC SCIENCE

QPE Techniques in TCs

- ✔ Scale dependence:
  - 10-s PMS sample area ~1 m^{-2}
  - 1-h gage sample area ~1-16,000 m^2 (wind speed dependent)
  - 1-h radar sample area 16 km^2
  - TMI sample are 25 km^2
  - ≥10^3 gages to cover radar/TMI sample area
- ✔ PDF narrower and skewed to smaller R as area increases





Storm Motion

- Sensitivity of Rainfall maxima (R_{TOT}) to V_s from climatology.