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Recent Progress and Challenges in Tropical Cyclone Intensity Prediction Using COAMPS-TC

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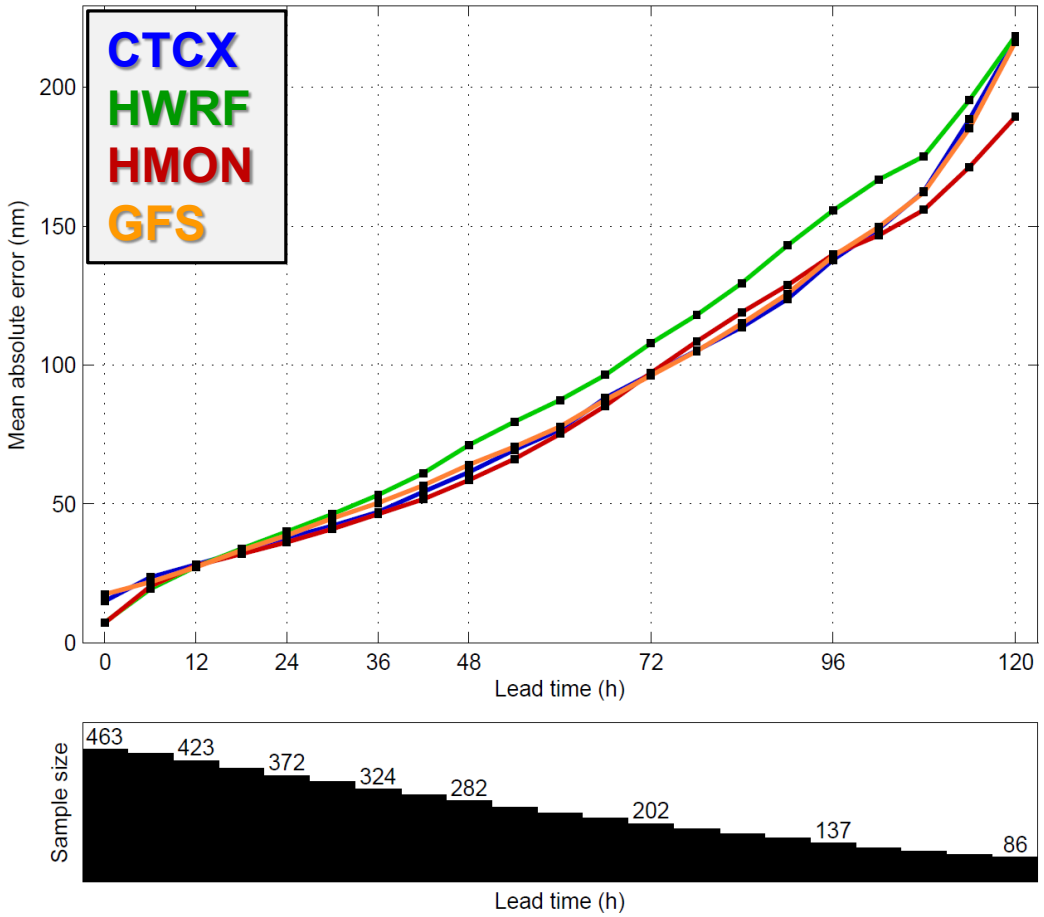
Sponsors: Office of Naval Research

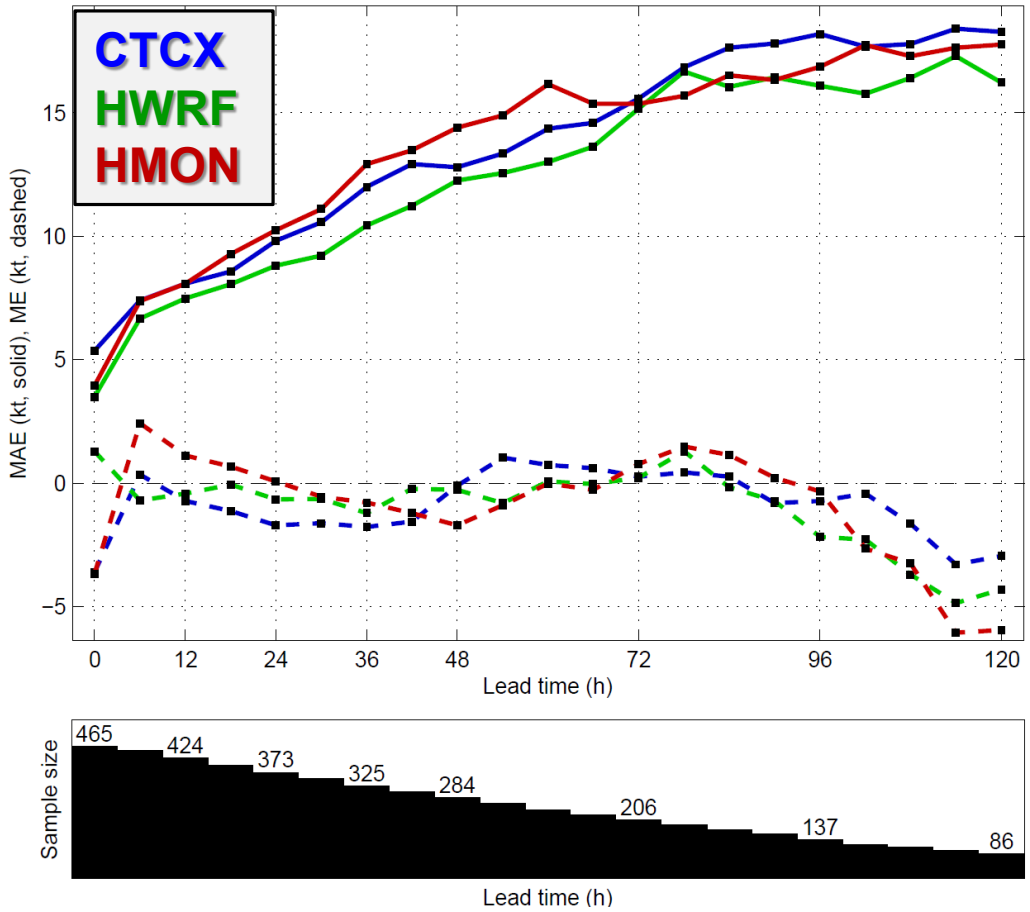
COAMPS-TC Performance

2020 Atlantic Forecast Errors (01L-28L)

Track Mean Absolute Error (nm)



Intensity MAE (solid) and ME (dashed)

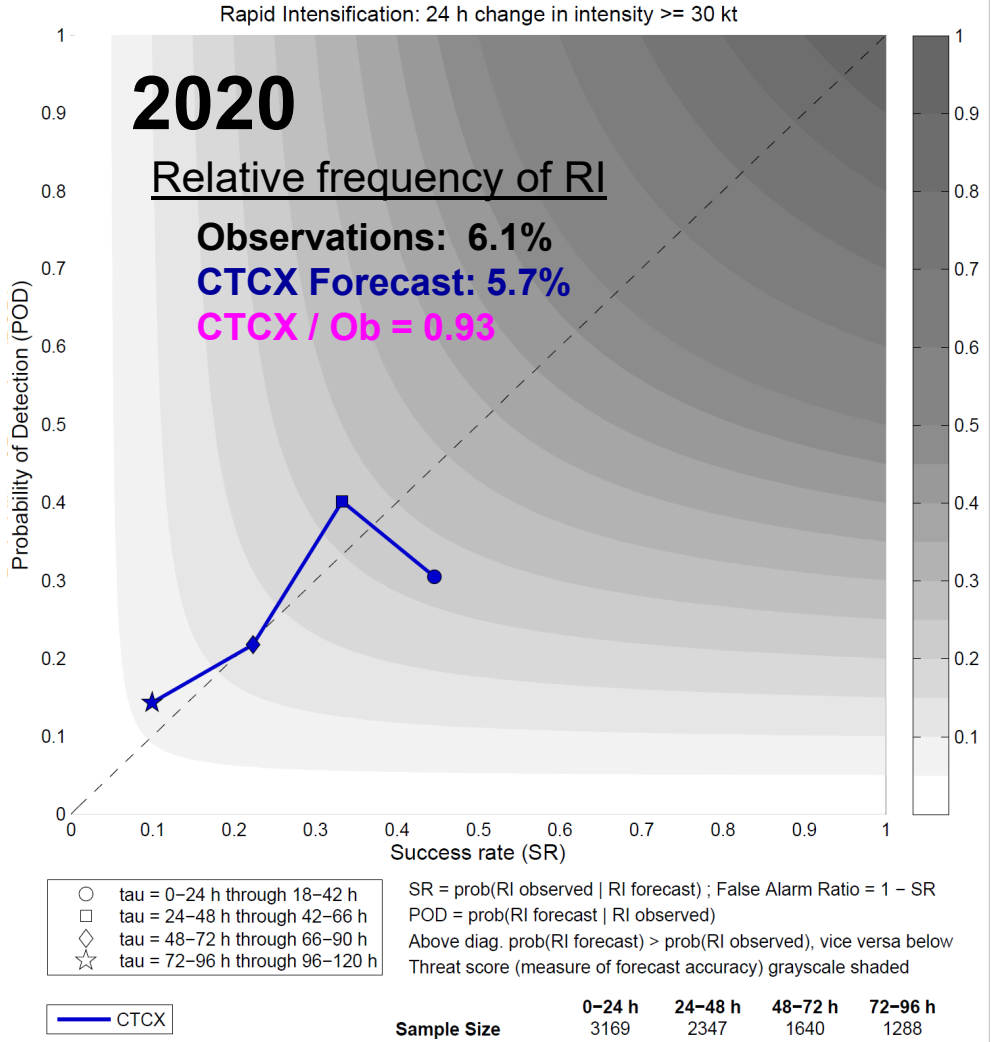


- CTCX track error was very good and nearly identical to GFS track error
- CTCX intensity trailed HWRF by ~0.5-1 kt (0-72h)

COAMPS-TC Performance

Rapid Intensification Forecast Errors

WATL, WPAC, EPAC, CPAC

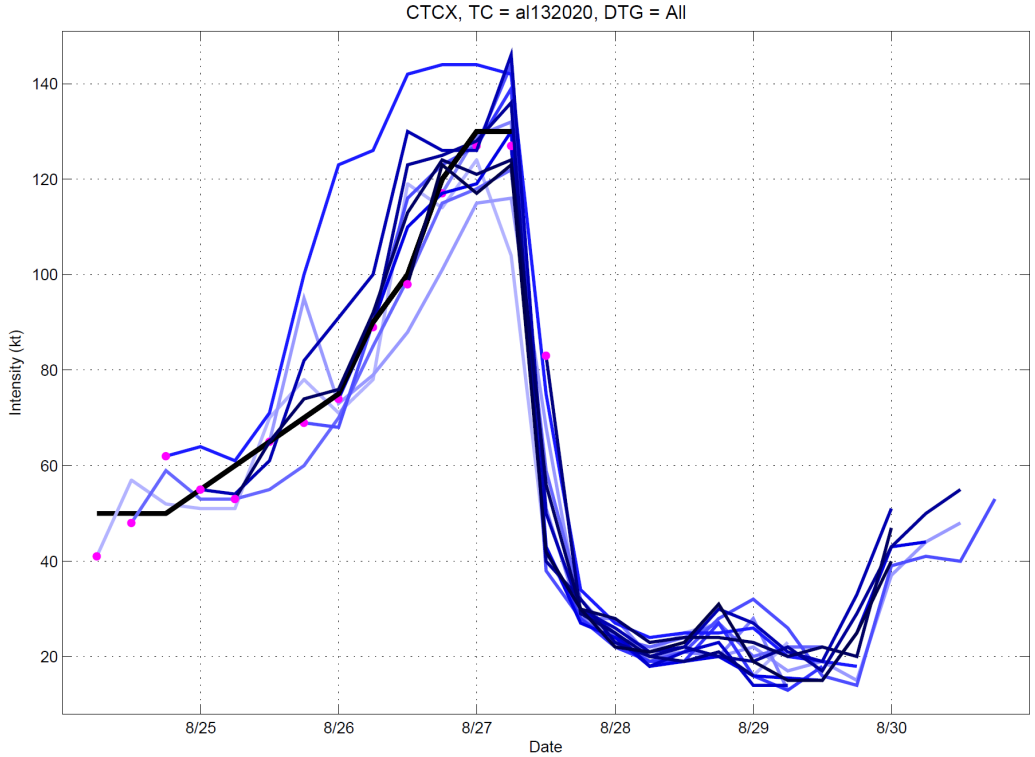


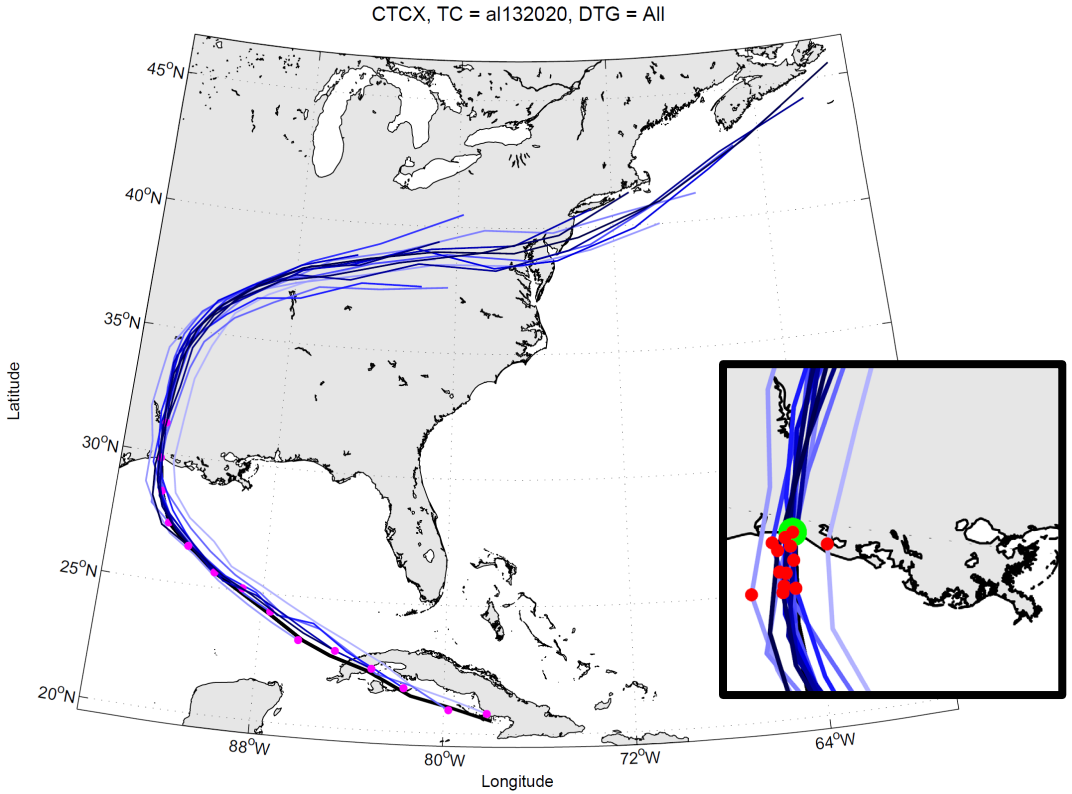
	0–24 h	24–48 h	48–72 h	72–96 h
Sample Size	3169	2347	1640	1288
prob(RI observed)	0.078	0.065	0.042	0.033
prob(RI forecast)	0.053	0.078	0.041	0.047

- CTCX Rapid Intensification forecasts improved markedly over last 5 years, especially in 2020
- Improvements in threat score, relative frequency – first time ever RI Forecast/Obs ~ 1

COAMPS-TC RI Performance

Hurricane Laura (13L) ('The Good')





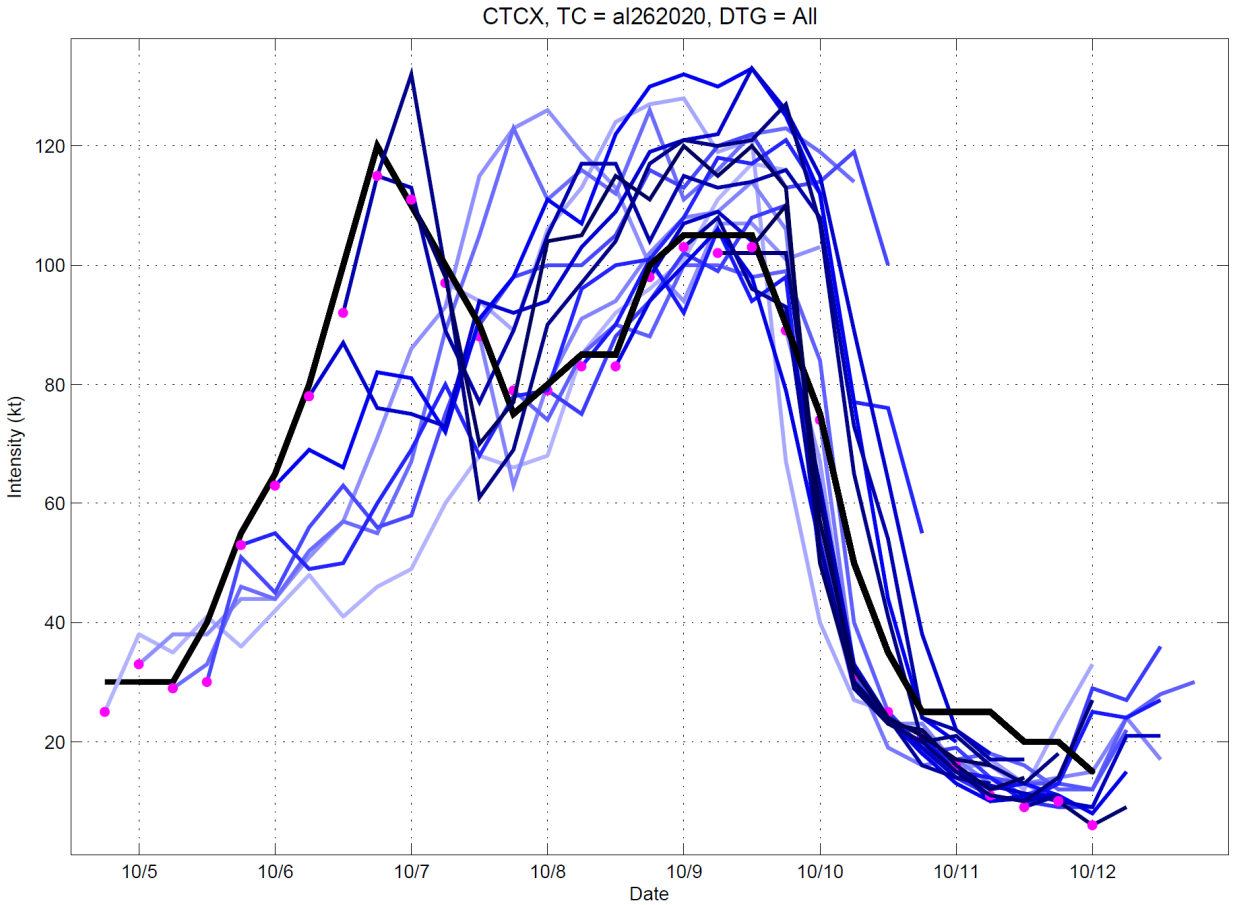
Time	Init. Intensity (kt)	Forecast Peak Intensity (kt) CTCX	HWRF	HMON	DSHP	LGEM
2020082406	55	124	131	115	75	73
2020082412	50	122	130	96	76	71
2020082418	50	144	129	62	76	74
2020082500	55	146	117	102	89	87
2020082506	55	124	117	107	86	85
2020082512	65	116	111	102	86	88
2020082518	70	144	108	107	90	93
2020082600	75	130	123	131	90	90
2020082606	90	136	122	137	99	102
2020082612	100	123	122	129	106	110
2020082618	120	132	119	119	120	125
2020082700	130	139	134	118	130	130
		131.7	121.9	110.4	93.6	94.0

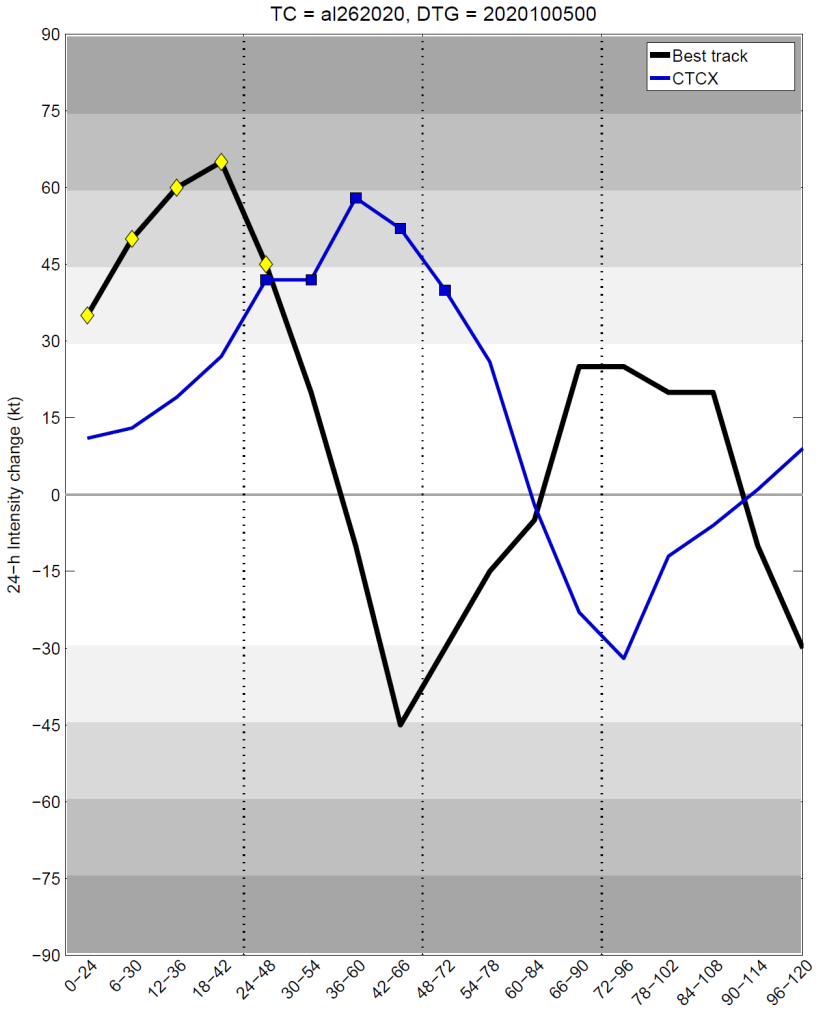
TS: 33-63 kt
Cat 1: 64-82 kt
Cat 2: 83-95 kt
Cat 3: 96-112 kt
Cat 4: 113-136 kt
Cat 5: 137+ kt

- CTCX RI forecasts for Hurricane Laura (13L) were amazingly good, as was the track and landfall location
- Large-scale environment was well-predicted

COAMPS-TC RI Performance

Hurricane Delta (26L) ('The Bad or Not so Bad')

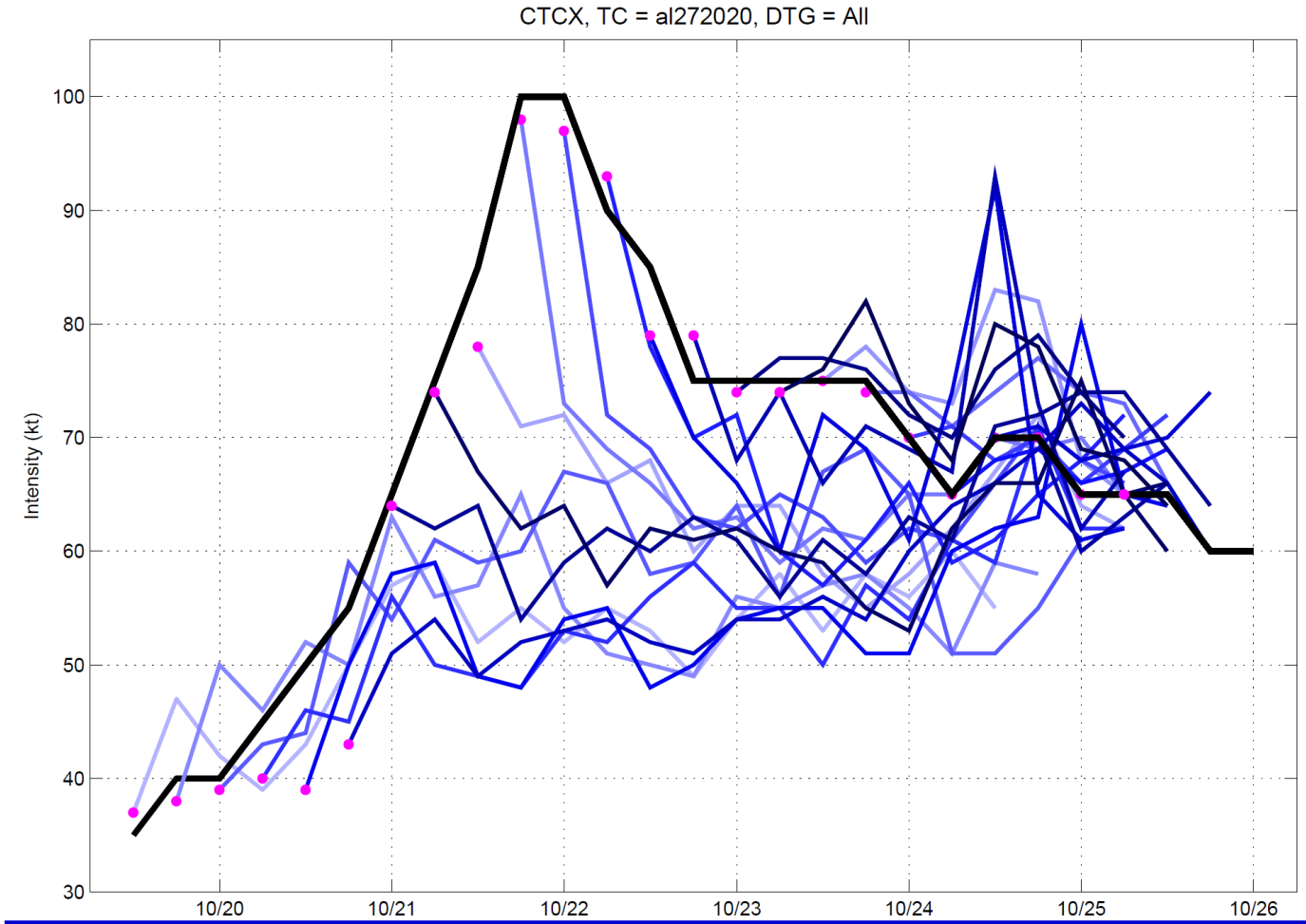


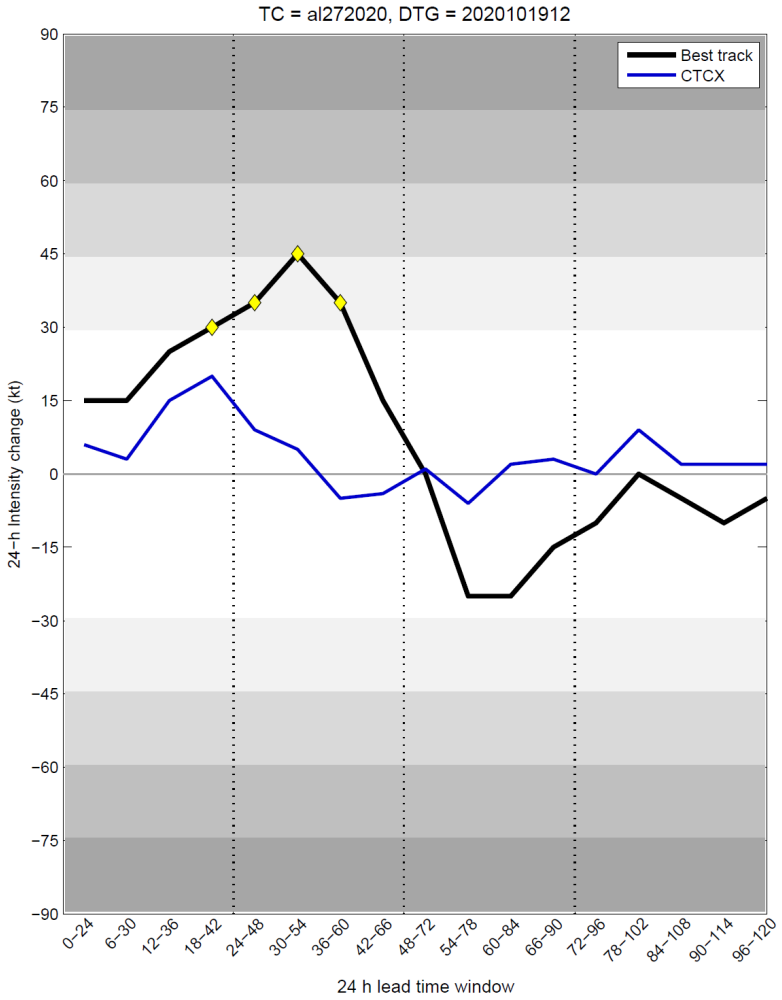


- CTCX forecasts of Delta (13L) just didn't predict the intensification soon enough. CTCX had the right idea, but was late for a number of forecasts like the one shown here.
- For forecasts of the 0-24 through 66-90 h windows:
  - 2 hits, 18 misses, 11 false alarms

COAMPS-TC RI Performance

Hurricane Epsilon (27L) ('The Ugly')





- Epsilon had 4 overlapping observed RI intervals, max 45 kt / 24 h
- For forecasts of the 0-24 through 66-90 h windows:
  - 0 hits, 22 misses, 0 false alarms
- Epsilon developed in a very challenging environment

Probabilistic Prediction of RI using COAMPS-TC

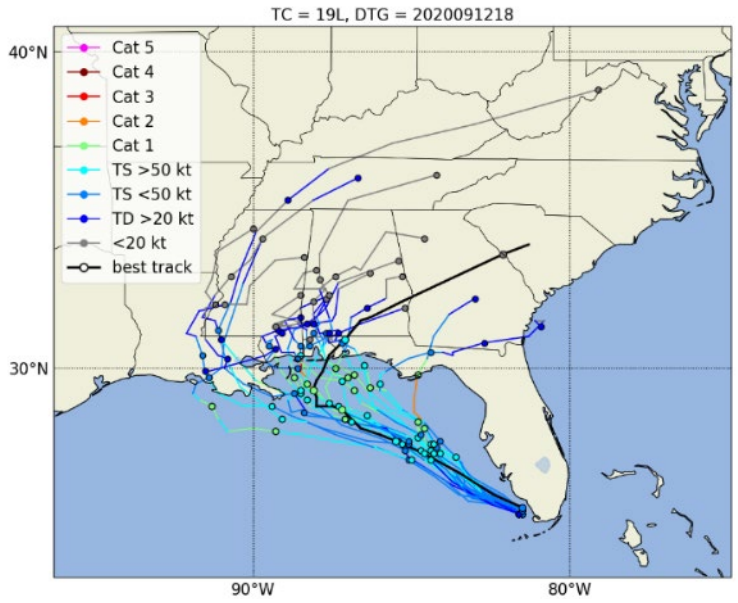
Operational ensemble run at FNMOC

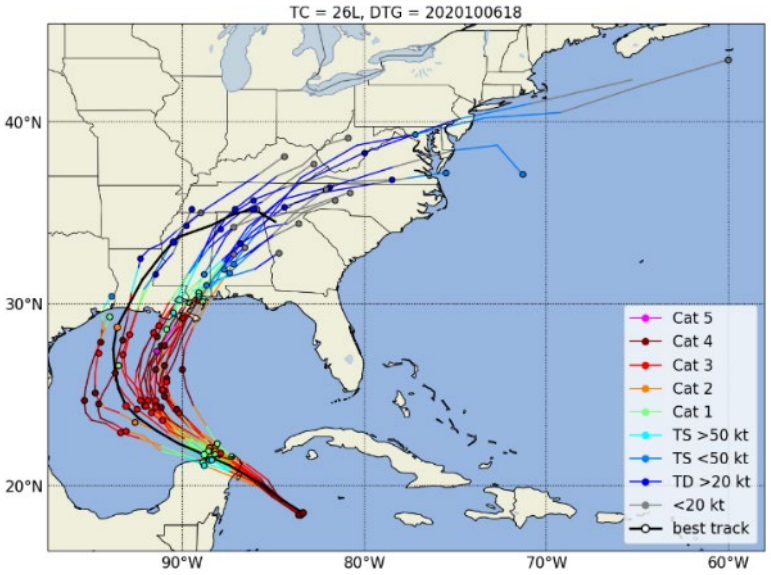
- The first fully-operational high-resolution tropical cyclone ensemble system
- GFS initial and boundary conditions
- 36/12/4-km resolution
- 11 members
- Available in ATCF

Experimental ensemble run at NRL

- 21 members
- Tuned IC/BC perturbation parameters
- Improved graphics suite
- Available online at:

https://www.nrlmry.navy.mil/coamps-web/web/ens

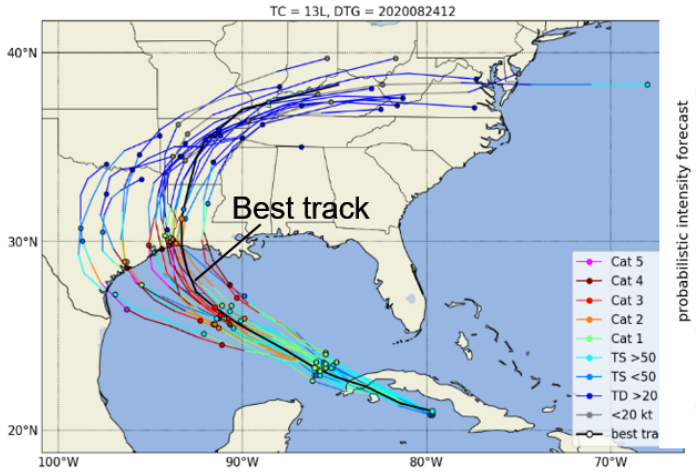




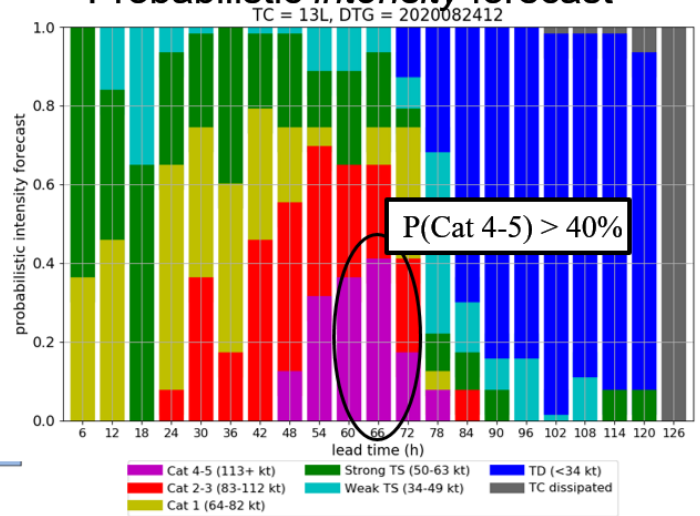
Both operational and experimental versions of COAMPS-TC Ensemble had strong performance for both track and intensity for U.S.-landfalling TCs in 2020, including Laura, Sally and Delta

Probabilistic Prediction of RI using COAMPS-TC

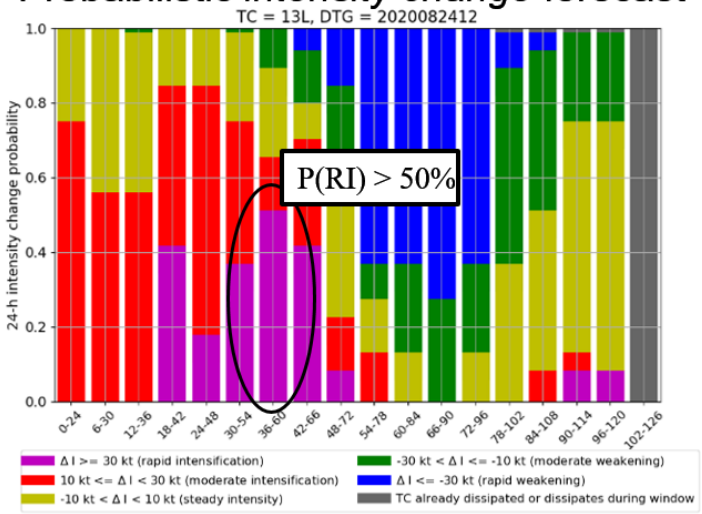
Tracks colored by intensity



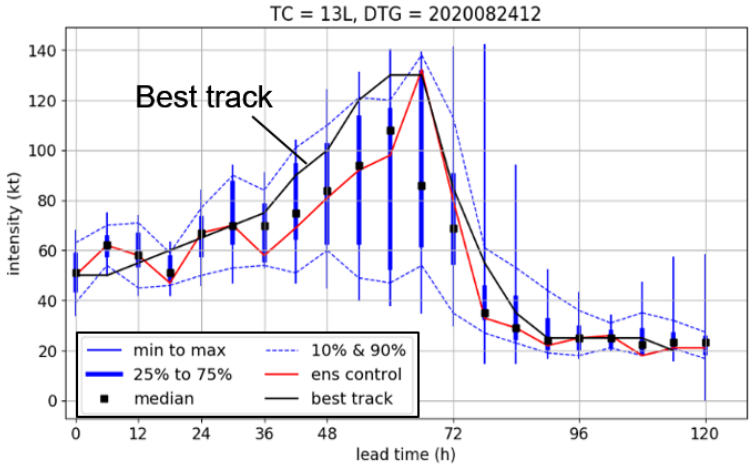
Probabilistic *intensity* forecast



Probabilistic *intensity change* forecast

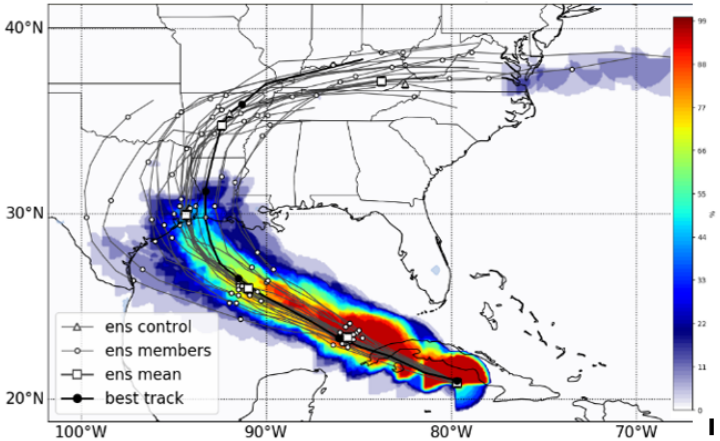


Intensity



Graphical forecast products have been developed to depict probabilistic track, intensity, chances of RI, and various wind thresholds

Probabilistic wind swath (34-kt)

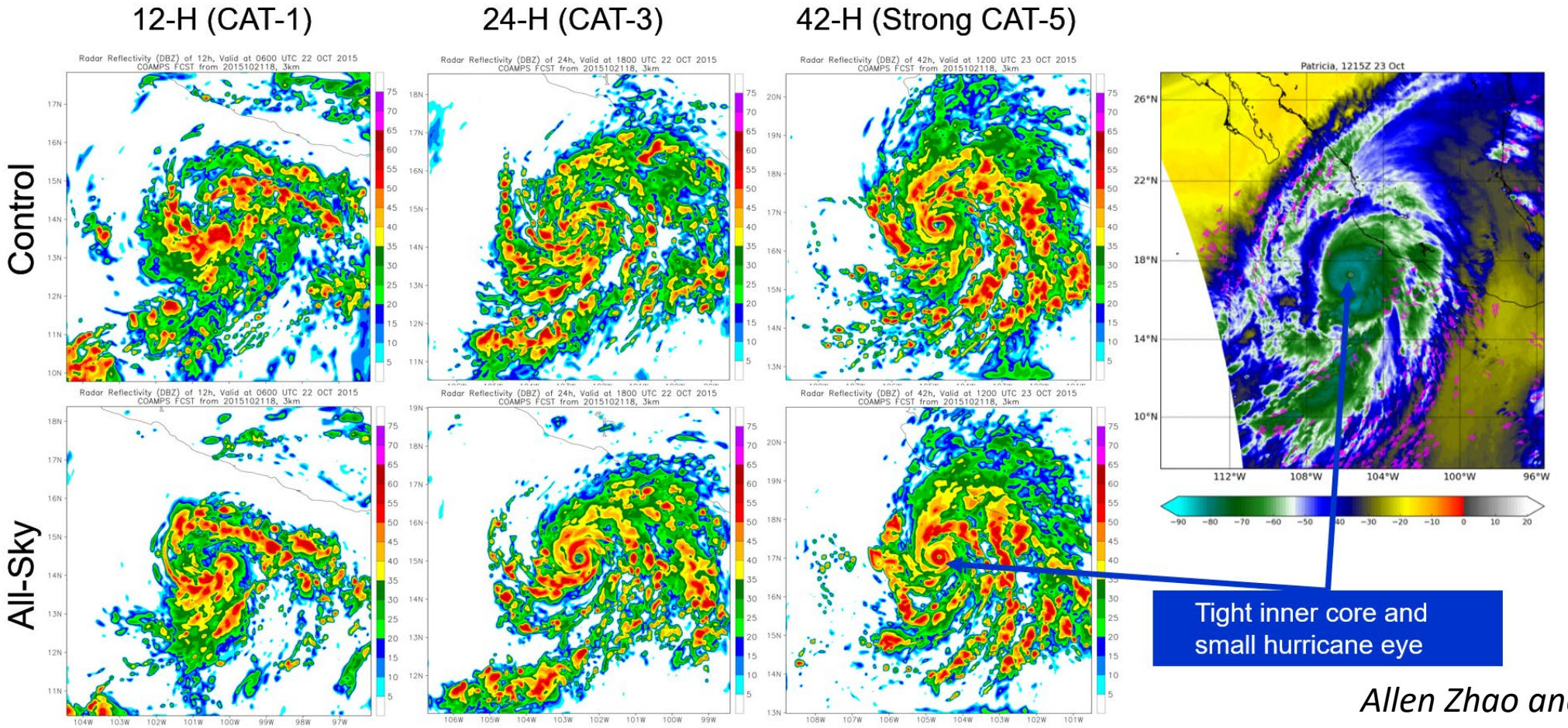


Will Komaromi

- Ensembles for genesis of basin scale regions could address non-classical TC genesis concerns
- High-resolution ensembles have the capability to increase the accuracy and better capture uncertainties (e.g., run-to-run consistency) of track and intensity forecasts for developing TCs

COAMPS-TC All Sky Radiance Assimilation

Improving model initialization and forecasts for non-classical TC genesis cases (particularly for multi-vortex disturbances such as monsoon depressions and Central America Gyres)

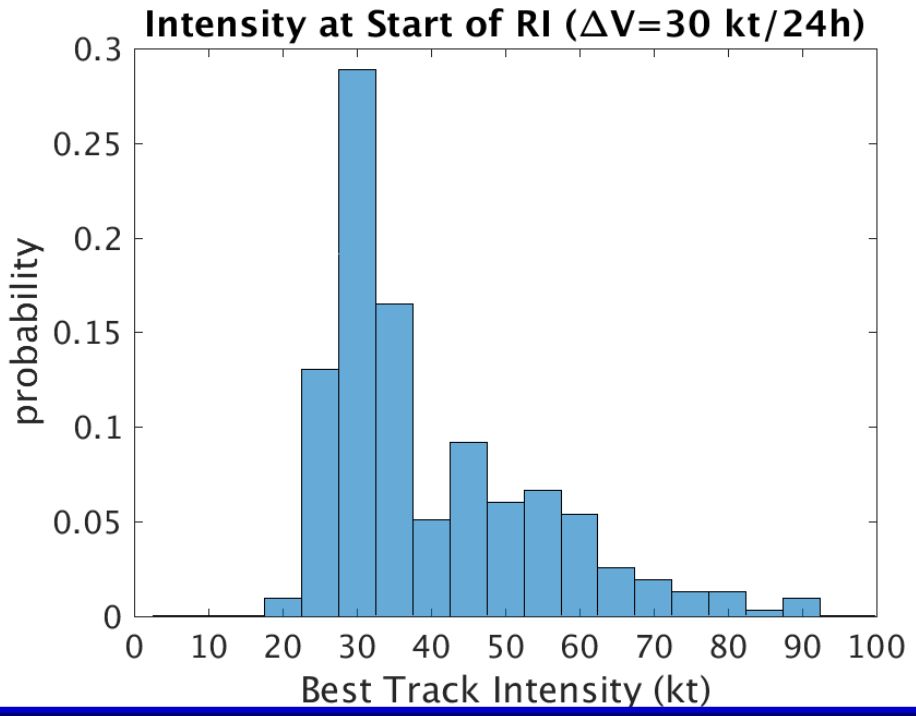


Allen Zhao and Yi Jin

- All sky radiance assimilation (assimilate radiances every 15 mins) in COAMPS-TC looks promising and should improve initialization for non-classical TC genesis cases
- Also, CTCX now initializes directly off of the GFS with no bogus for storms < 50 kts

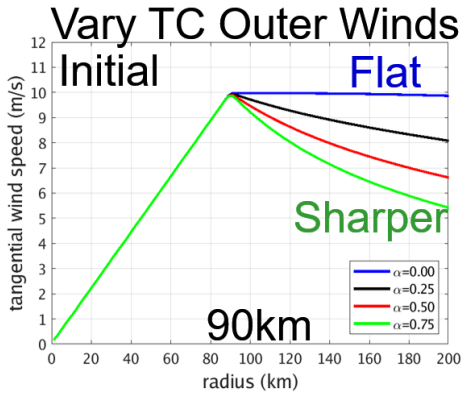
Influence of Initial Vortex Structure on Rapid Intensification

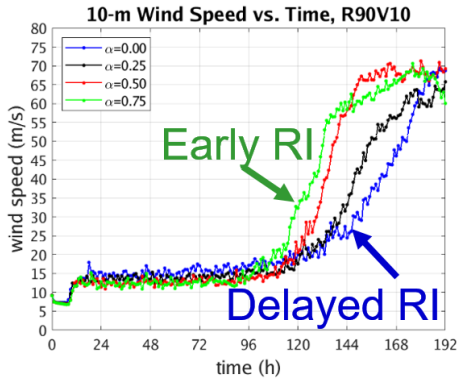
Distribution of Intensity at RI Onset Time

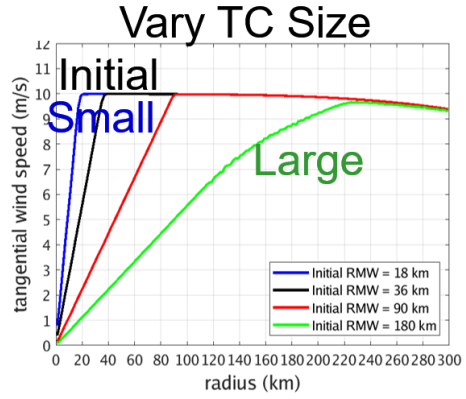


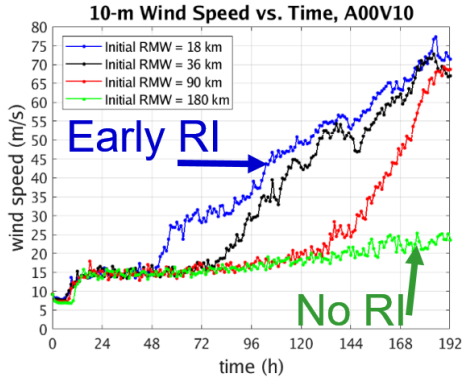
- Onset of RI most often occurs at very weak (25-35 kt) intensities.
- Prior to RI, wind profiles tend to be flat, with no well-defined maximum.
- A wind maximum forms near the time of RI onset.

Idealized Simulations





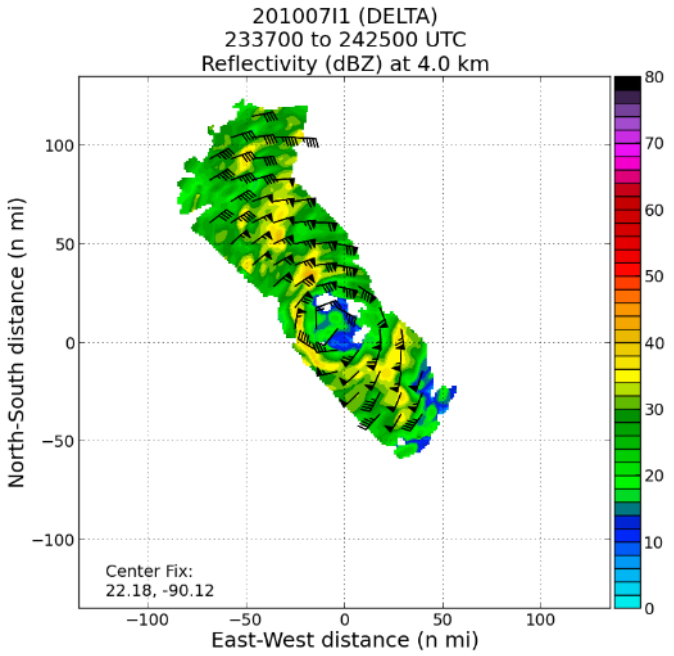


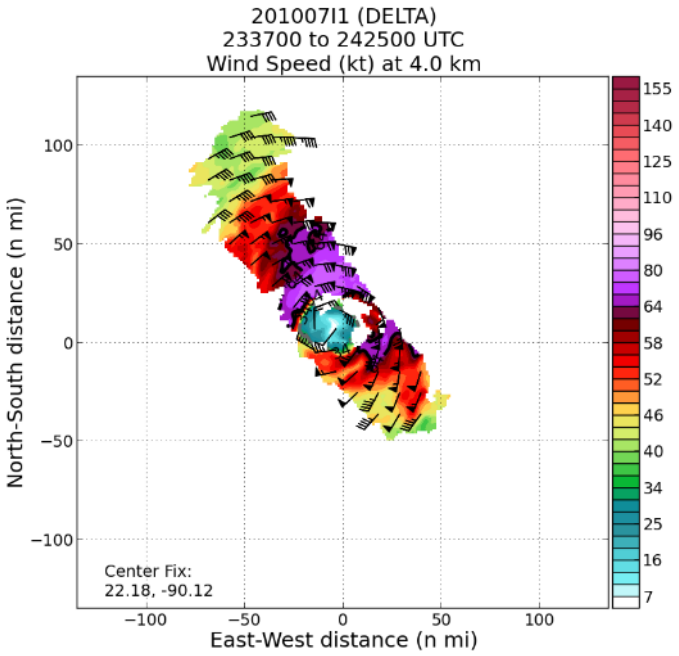


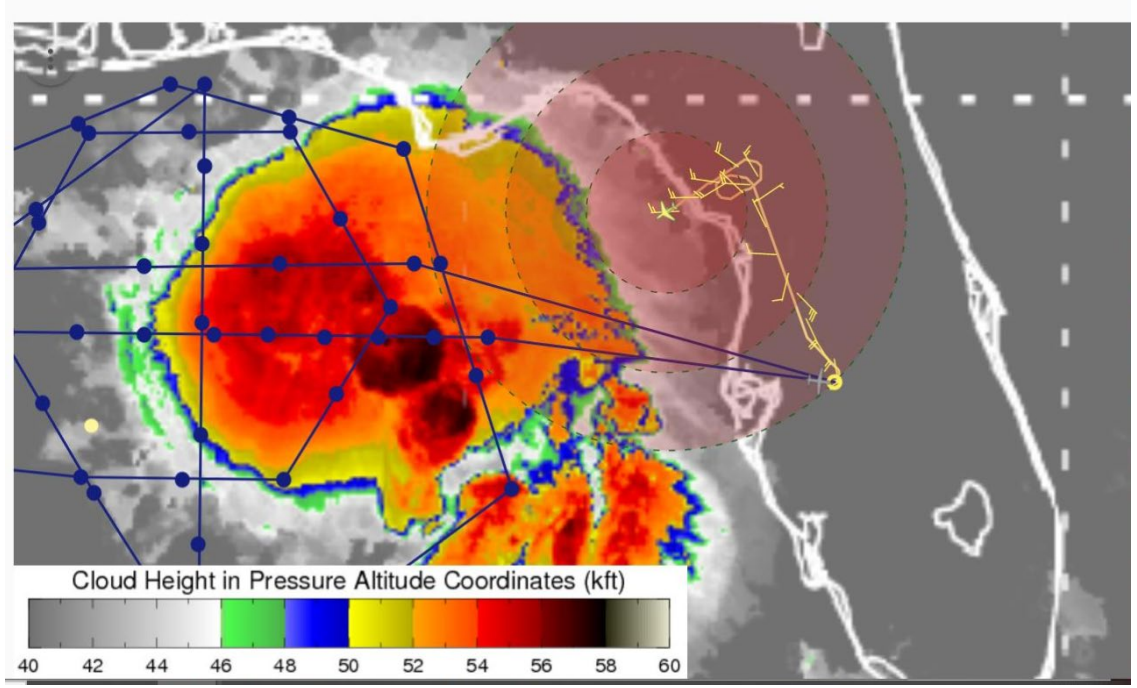
- RI occurs later for broader (realistic) profiles.
- RI occurs earlier for a smaller initial TC, even without an initial well-defined maximum.

ONR TC Rapid Intensification Program

- Conducted in close collaboration with NOAA IFEX
- 3 P-3 Flights and collaborative G-IV flights during Sally, Teddy, Delta
- Added flight modules for several other storms
- Deployed 159 additional dropsondes for TCRI
- Several flights (including Sally) captured the period prior to and during RI



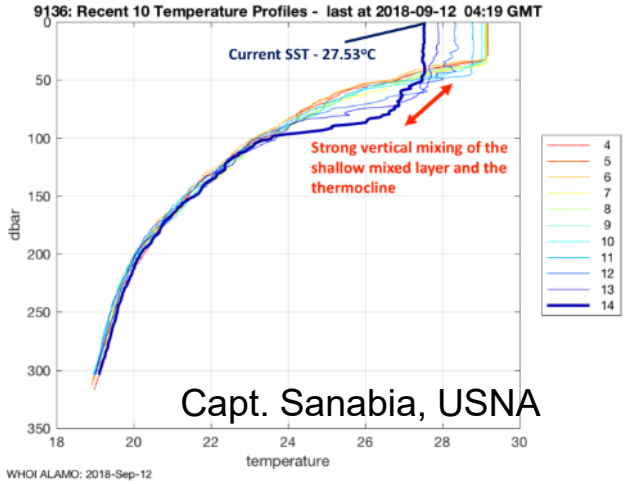




COAMPS-TC Air-Sea Coupling and PBL

- PBL is tightly linked with the air-sea fluxes
- Standard version of COAMPS-TC coupled to the ocean model (NCOM) for all basins worldwide
- In 2020, special circumstances led to CTCX being run uncoupled with SST cooling param.
- NCOM cold-started from HYCOM global model with NCODA ocean DA
- Experimenting with air/ocean/wave coupling

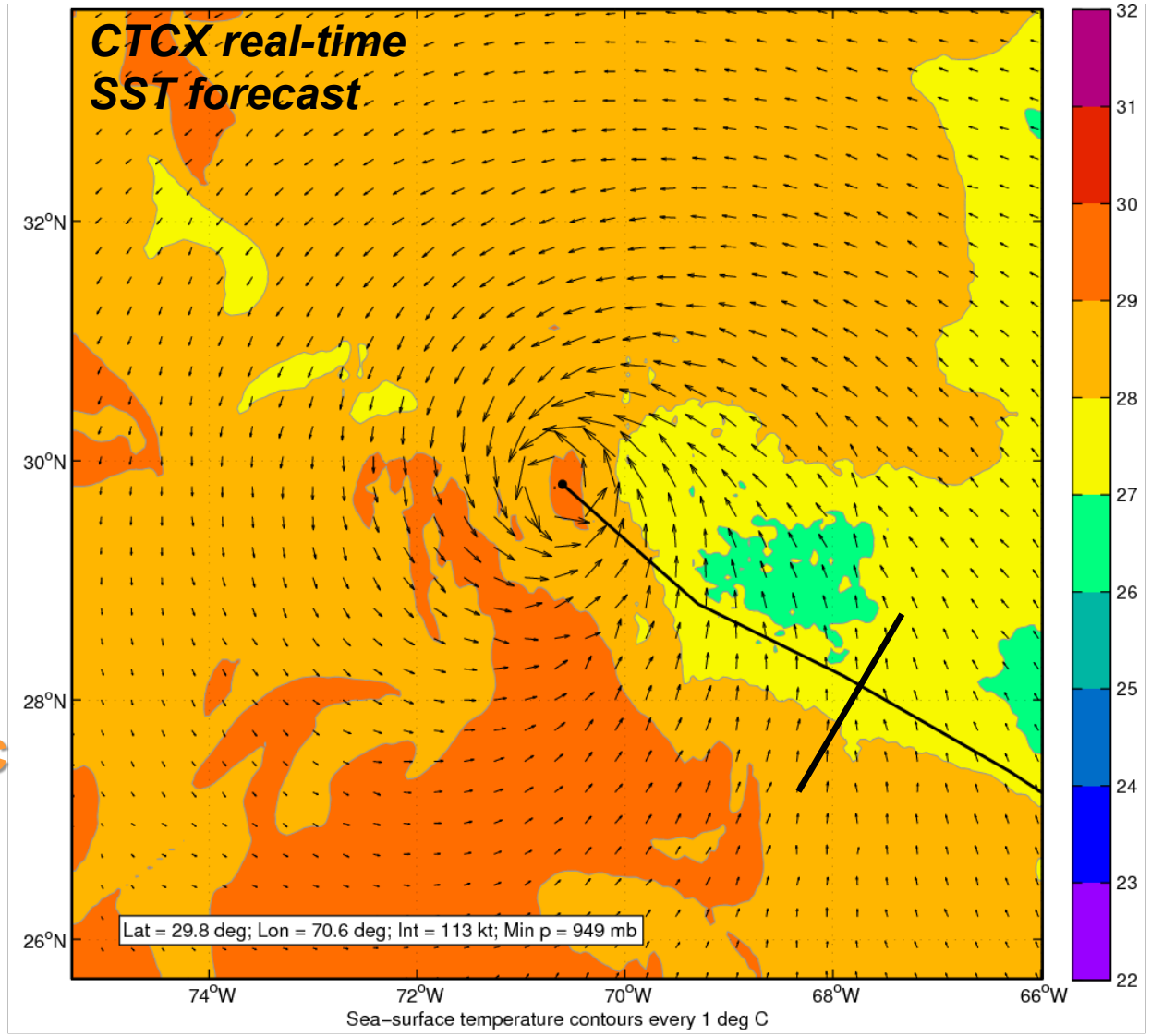
<u>Model validation opportunity</u>: 10 ALAMO floats were deployed in front of Florence by USNA (via USAF)



Capt. Sanabia, USNA

Pre-storm SST: **29-30°C**
Under-storm SST: **28-29°C**
Post-storm SST: **27-28°C**

Florence (06L) example: 2018091106, tau = 30 h

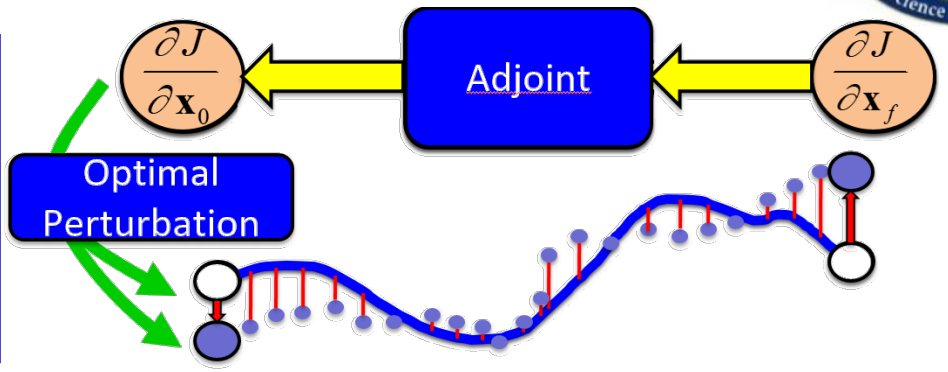


Summary and Key Gaps

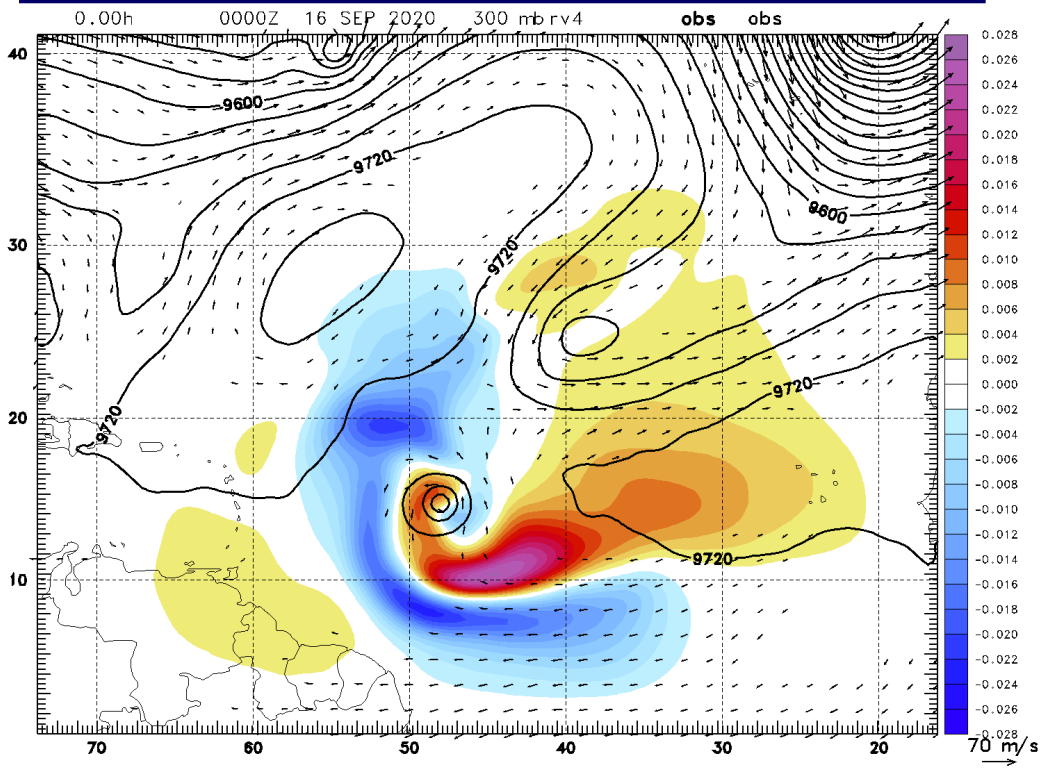
- COAMPS-TC much improved for track and intensity in 2019/20; RI improved too
  - Upgrades in the last two years: Microphysics-Radiation, PBL, Ocean DA, vortex initialization
  - RI challenges remain:
    - Onset, magnitude, timing, environmental shear, PBL and air-sea interaction, microphysics
    - Ensemble design for RI; Predictability horizon
- Gaps
  - Need observations during RI onset, RI in moderate shear, and cloud microphysics (focus of TCRI)
  - Improved data assimilation methods in TCs needed (all-sky radiance assimilation is promising)
  - Uncertainties in PBL and microphysics parameterizations
  - More emphasis on high-resolution ensembles (COAMPS-TC ensemble in ops in 2020)
  - Identify predictability sources and barriers for TC rapid intensification (adjoint, ensemble tools)
  - National high-resolution multi-model TC ensemble (COAMPS-TC, HWRF, HMON)

COAMPS-TC Adjoint Sensitivity

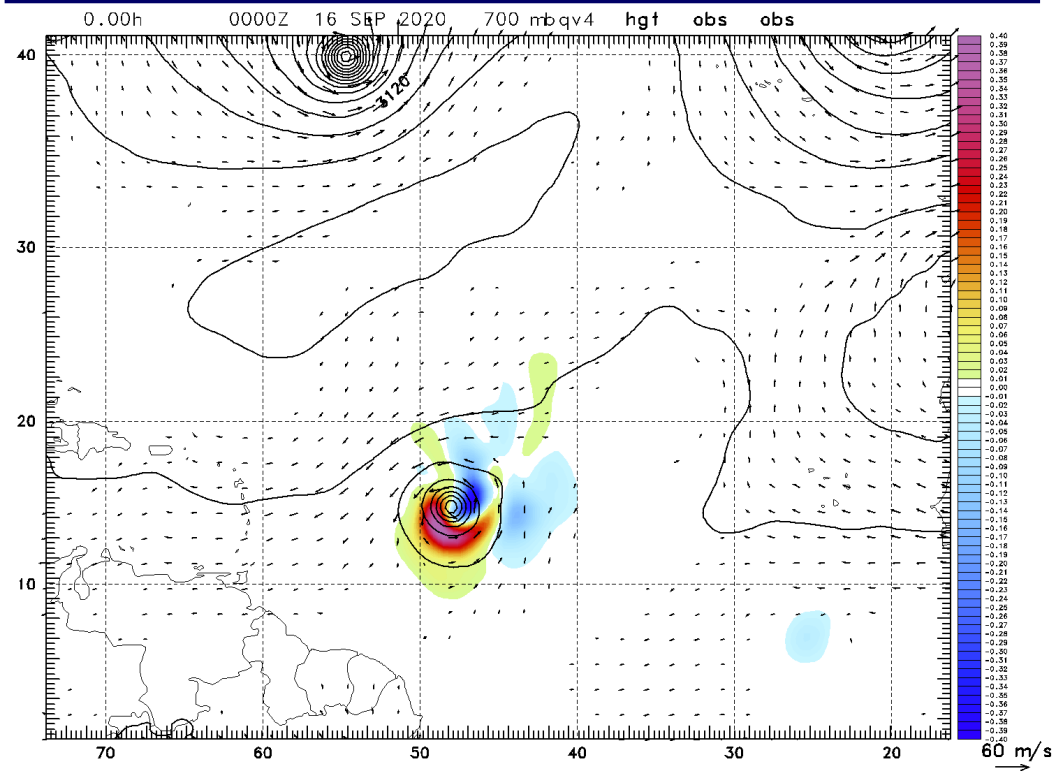
- Adjoint: Sensitivity of a forecast aspect to changes in initial state; highlights regions of large initial sensitivity.
- COAMPS-TC adjoint initialized from a GFS forecast for targeted observing (NOAA G-V during TCRI)
- Using the CTCX adjoint to help understand fcst "busts"



Hurricane Teddy (00Z 16 Sep 2020)
Track Sensitivity (300-hPa ζ sensitivity)



Hurricane Teddy (00Z 16 Sep 2020)
Intensity Sensitivity (700-hPa q_v sensitivity)



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1) Increasing accuracy and run-to-run consistency of track and intensity forecasts for developing TCs (particularly when intensity is below the tropical storm threshold)

2) Improving model initialization and forecasts for non-classical TC genesis cases (particularly for multi-vortex disturbances such as monsoon depressions and Central America Gyres)

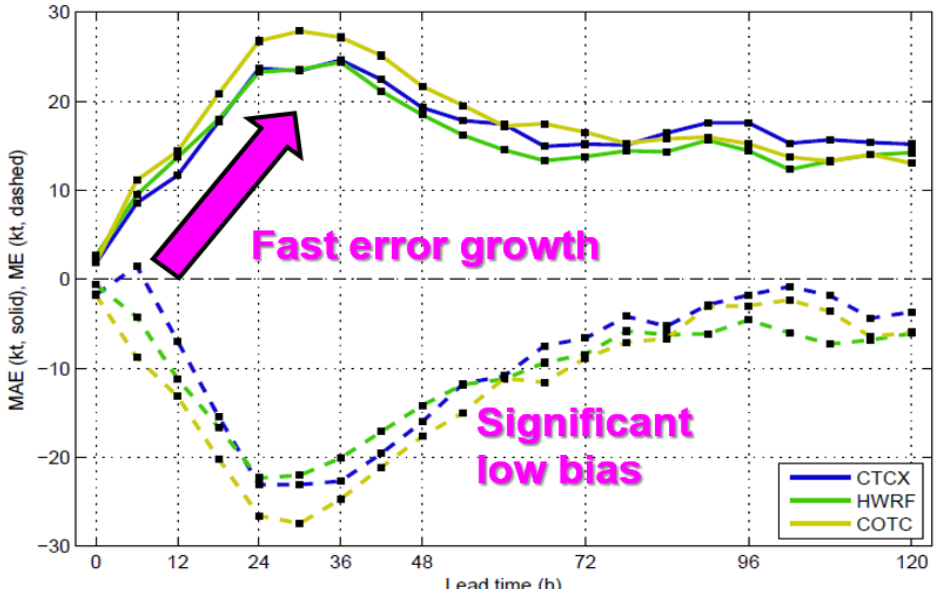
Important aspects of the operational models with emphasis on the successes and challenges in predicting TC tracks and intensity, especially the rapid intensification of TCs in 2020.

How ensemble or adjoint based operational model guidance is used for objective sampling strategies for aircraft based hurricane reconnaissance.

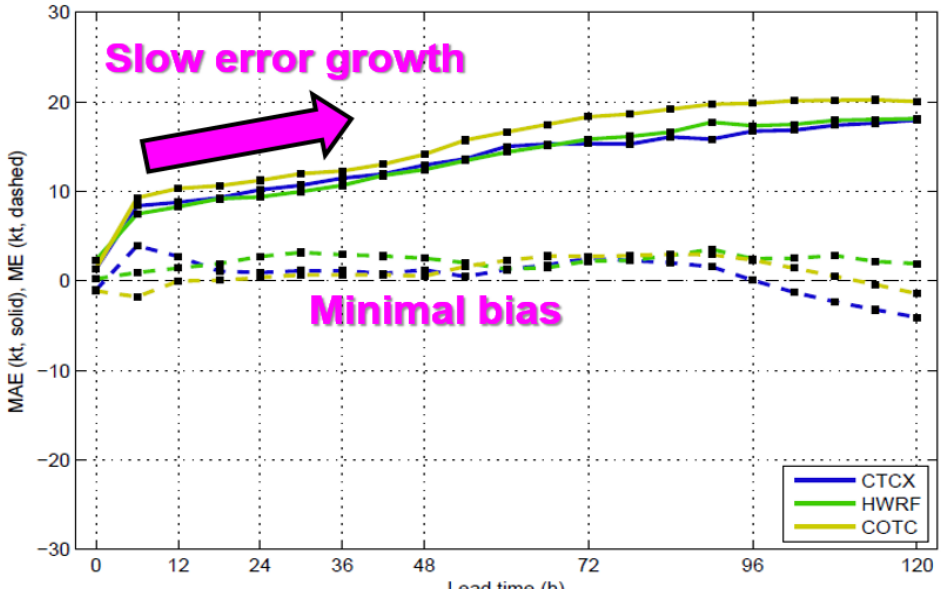
Future plans for model and data assimilation upgrades related to TC predictions, with emphasis on addressing specific issues identified with storms in the 2020 hurricane season.

COAMPS-TC (CTCX) Intensity Forecast Errors

Intensity MAE and ME: Observed RI 0-24 h

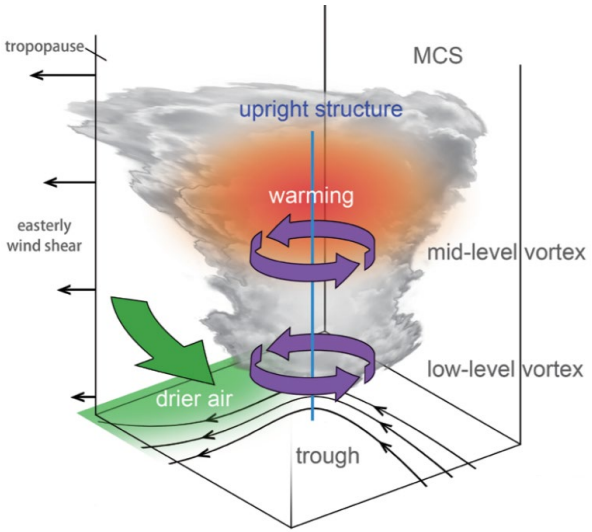


Intensity MAE & ME: No observed RI 0-24 h

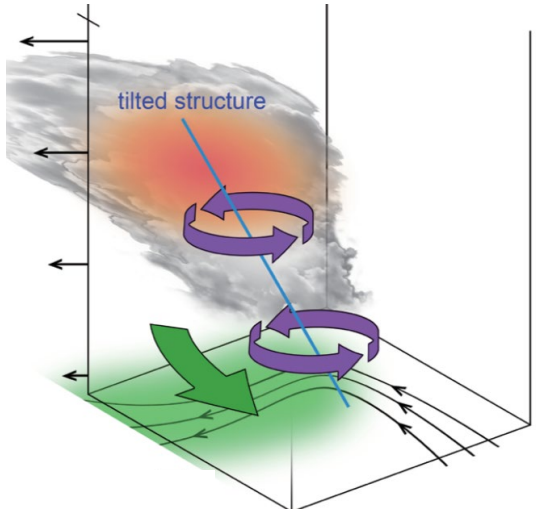


- Intensity forecasts have much faster error growth and much larger biases for RI (30 kt/24h) cases. (Resolution is only part of the limitations)
- RI remains a major challenge for forecasters. NHC correctly forecasted 5 of 39 RI events (2019)
- Some major RI challenges:
  - RI onset
  - RI that occurs in moderately sheared TCs
  - RI magnitude (Eta, Goni) (next frontier)

Weak Wind Shear



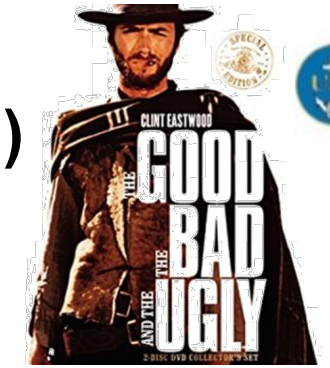
Moderate Wind Shear

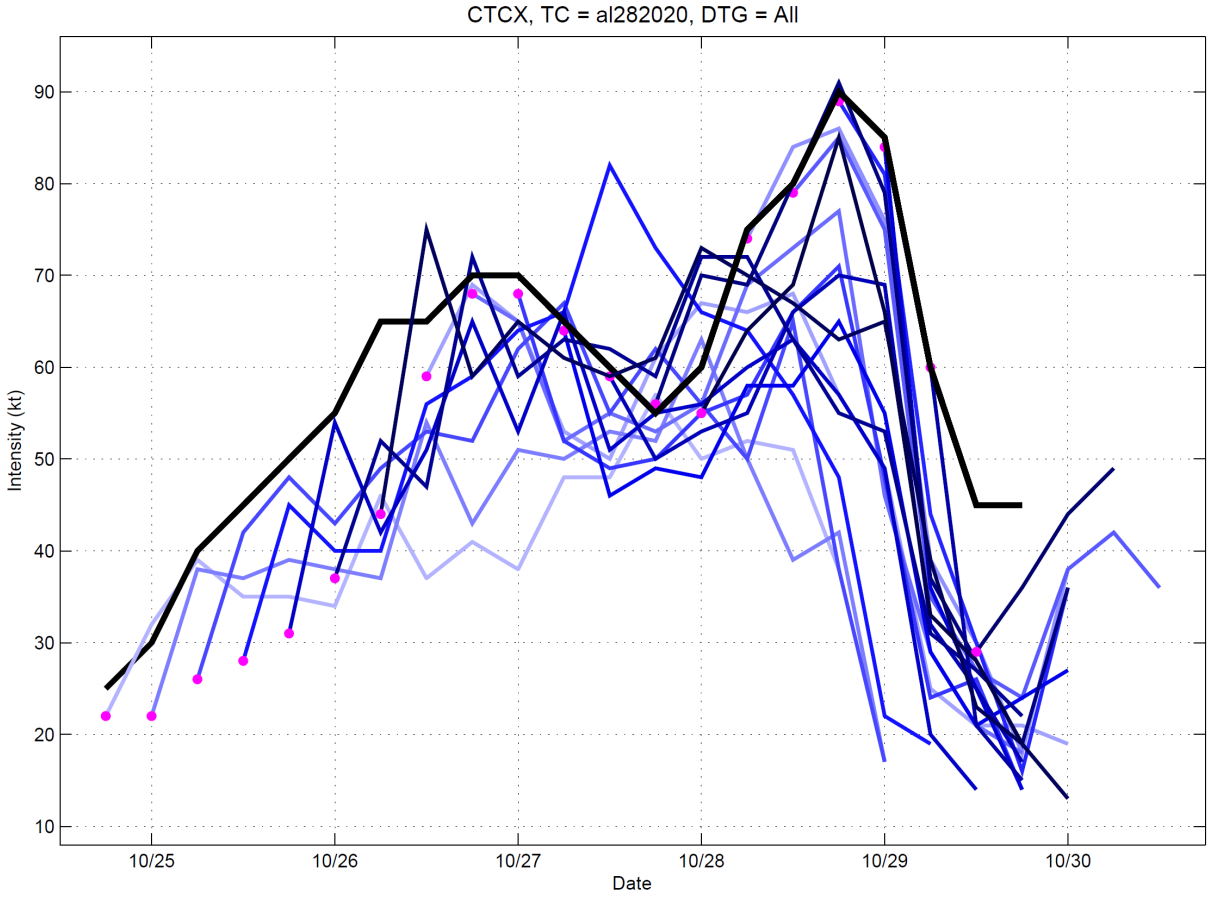


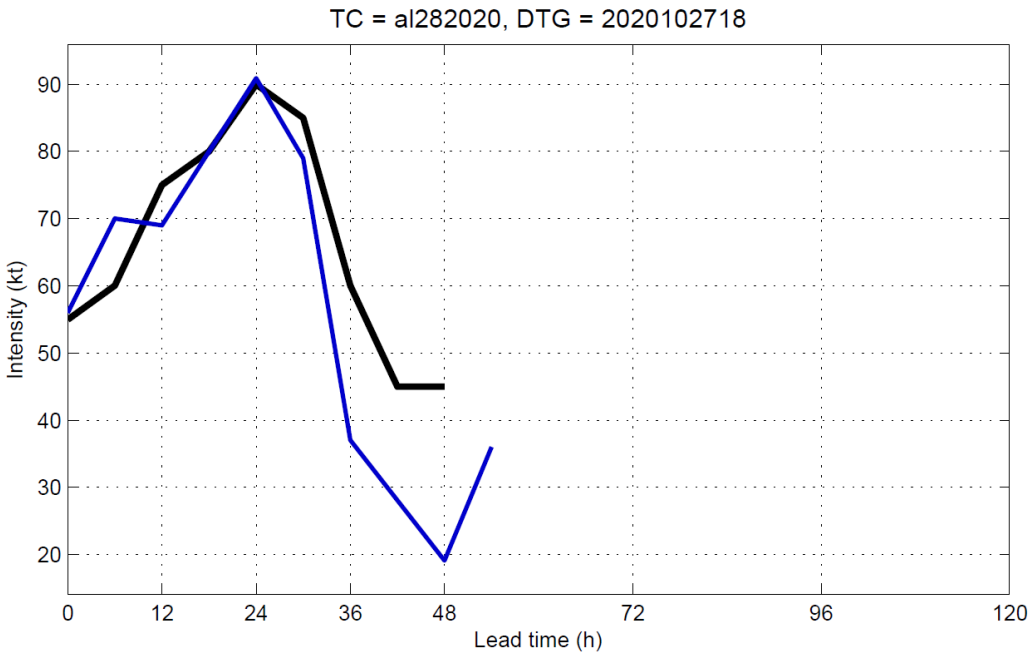
Yoshida et al. (2017)

COAMPS-TC RI Performance

Hurricane Zeta (28L) ('The Bad or Not so Bad')

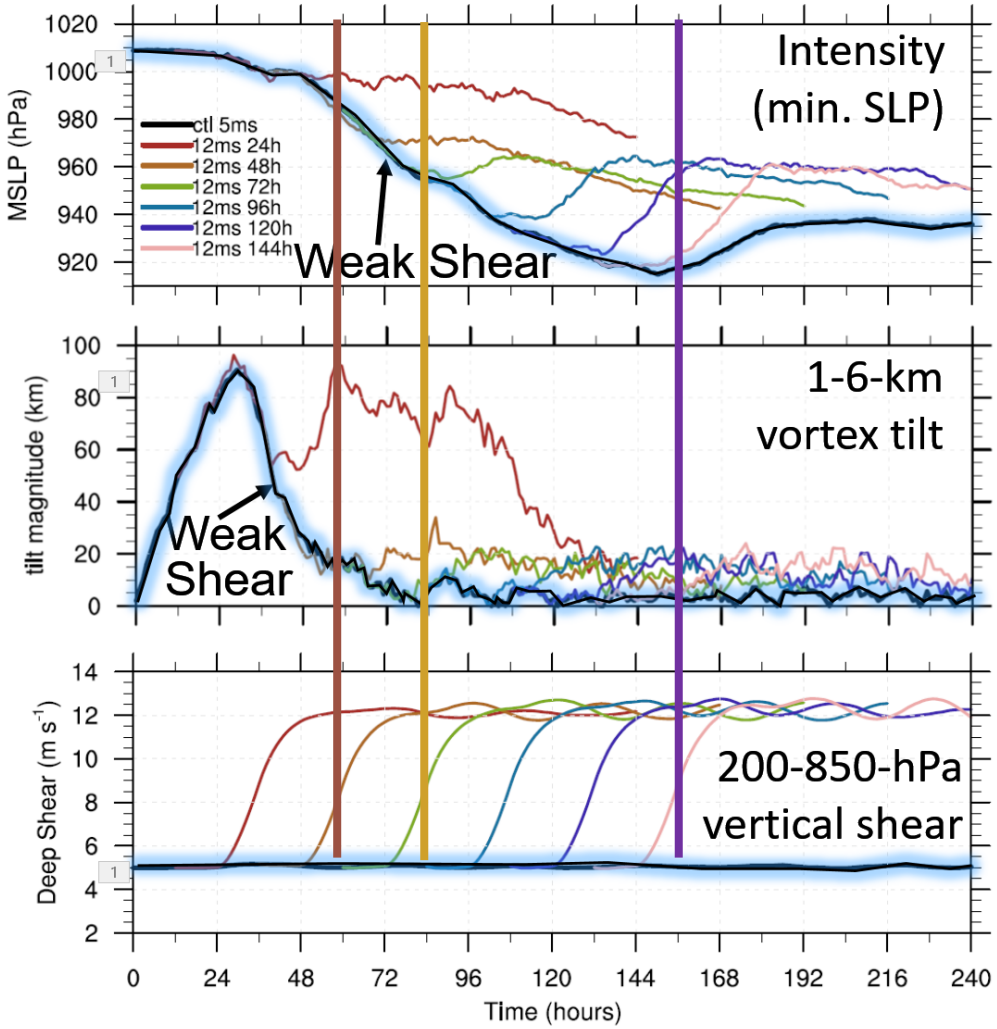






- CTCX had the right idea for the 26/12z forecast through 27/12z forecast, it just didn't have enough intensification.
- CTCX got the RI at the last possible chance, the 27/18z forecast (it got a hit with the one time it predicted RI)

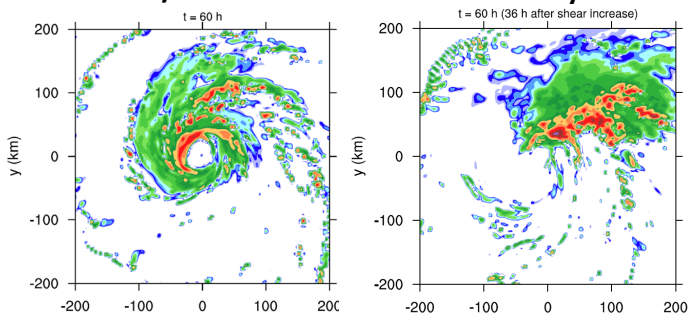
Intensity-Dependent TC Response to Vertical Wind Shear



Simulated radar reflectivity at z=1km

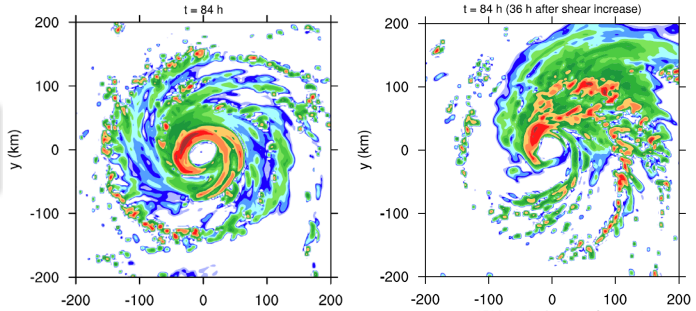
5 m/s shear | 5 to 12 m/s shear

Pre-RI



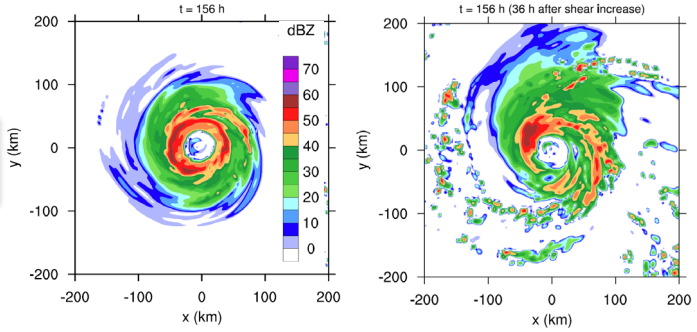
Increasing shear prevents RI of weak initial TC by maintaining large down-shear tilt.

Mid-RI



Increasing shear during RI slows intensification. The vortex tilt response is less extreme.

Post-RI



Weakening of strong initial TC results in large eyewall precipitation asymmetries instead of large tilt.

Finocchio and Rios-Berrios (to be submitted)