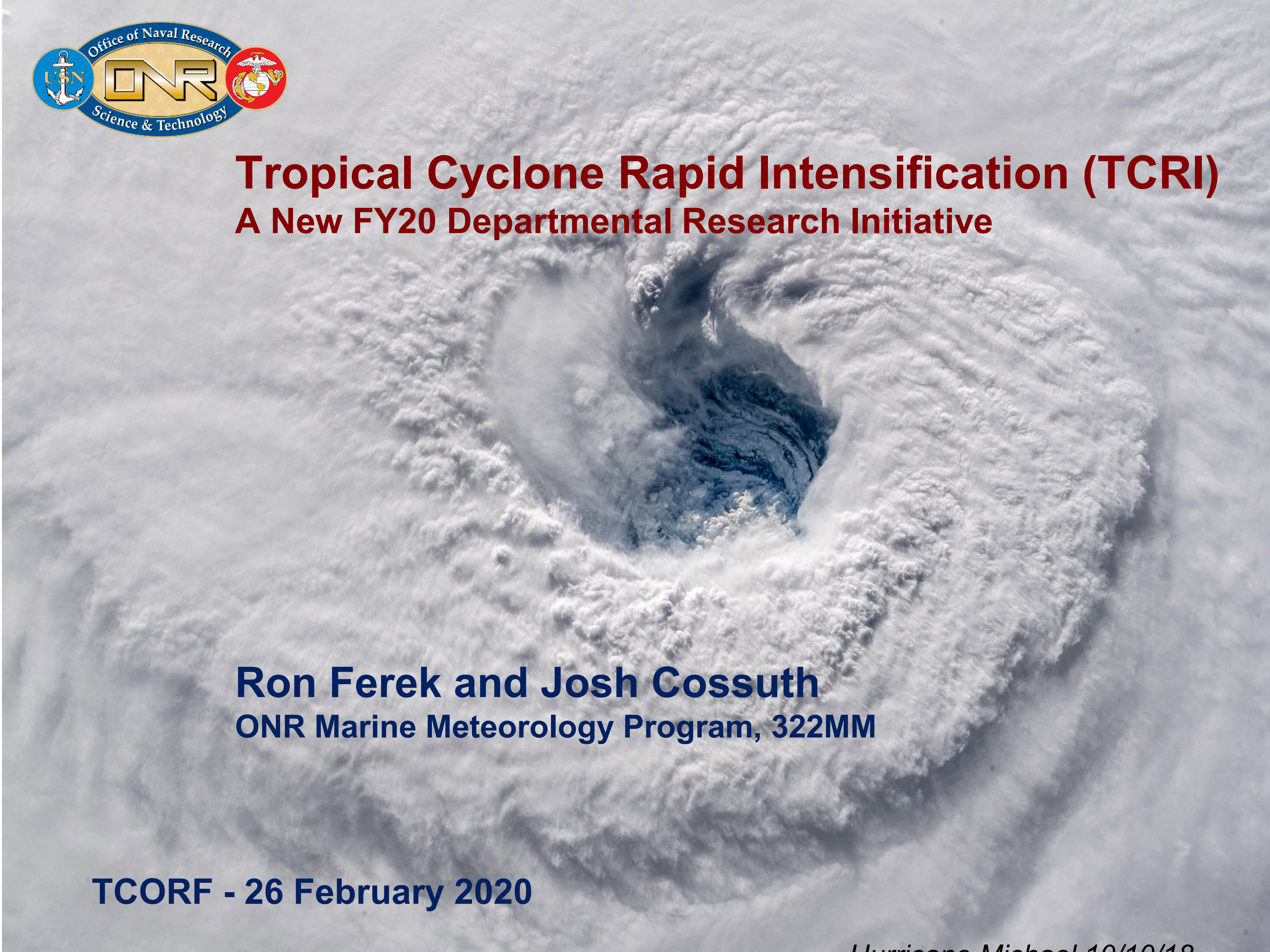
Tropical Cyclone Rapid Intensification (TCRI)

A New FY20 Departmental Research Initiative

Ron Ferek and Josh Cossuth

ONR Marine Meteorology Program, 322MM

TCORF - 26 February 2020



Hurricane Michael 10/10/18

BLUF

- ~2 decades of *basic* research investment has led to historic improvement in TC intensity prediction, mainly due to the development of <u>skillful mesoscale models</u>

- Despite steady progress, mesoscale models <u>perform worst</u> in cases of Rapid Intensification (RI); accounts for the largest source of the total intensity errors

- RI can be triggered with the ideal combination of favorable *environmental conditions*, *ocean forcing, internal dynamics* and *scale interactions*

- RI is the right problem to address now (highest JTWC and NHC priority), and can be addressed by building on CBLAST results through basic research focused on *internal dynamics* and *scale interactions,* and applied research focused on modeling

Navy Relevance: Requirements Documents

- Multiple long term requirements across the DoD/US Gov support the work this project provides to benefit operational missions:
  - USPACOM Ins. 5216 Ser: J33/#002, 23 Aug 09:
    - 15-20 yr operational objective: “Reduce uncertainty, provide projections *past the current five day forecast*… in a rolling, storm-following dynamic and probabilistic sense”
  - OPNAV N2N6E FY19 RDT&E Priorities, 19 Mar 18:
    - High priority processing objective P-1c, “Develop improved deterministic and *probabilistic* TC prediction tools with a focus on *decreasing the error*…. in intensification”
  - NOAA-OAR-OWAQ-2019-2005820 for JHT, list of priorities for improved tropical cyclone analysis and prediction at JTWC, NHC, and CPHC:
    - #3: “Improved tropical cyclone intensity guidance including the onset, duration, and magnitude of *rapid intensification* events…”

Past History of ONR's TC DRIs

- **CBLAST**
  - Improved understanding of drag at surface led to first realistic pressure/wind relationship in mesoscale models
  - Applied research developed and transitioned COAMPS-TC; first skillful operational mesoscale TC model

- **TCS-08**
  - Focused on storm scale processes
  - Increasingly reliable *intensity* and surface wind radii predictions (*structure*)

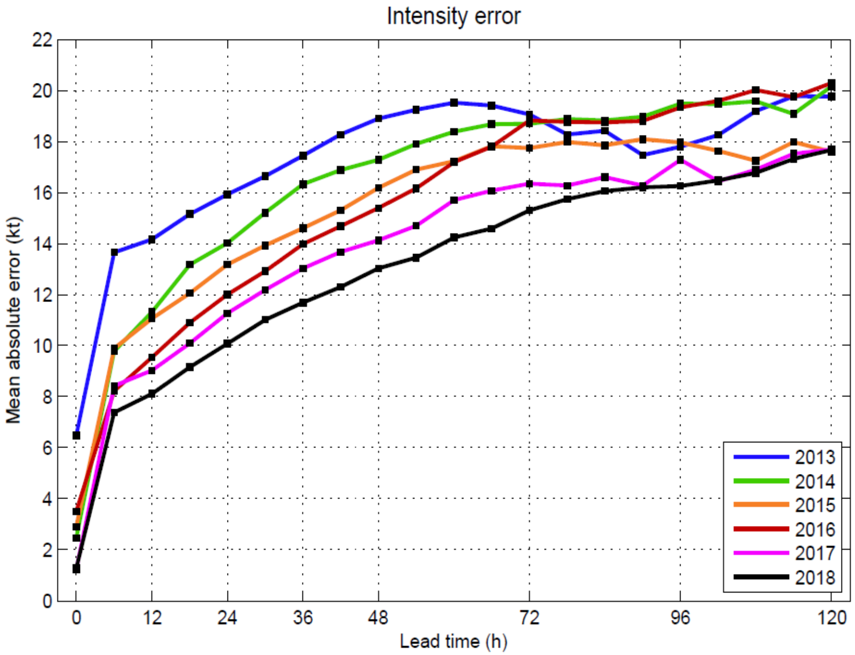
- **ITOP**
  - Improved ocean coupling (improves forecast *in some cases*)

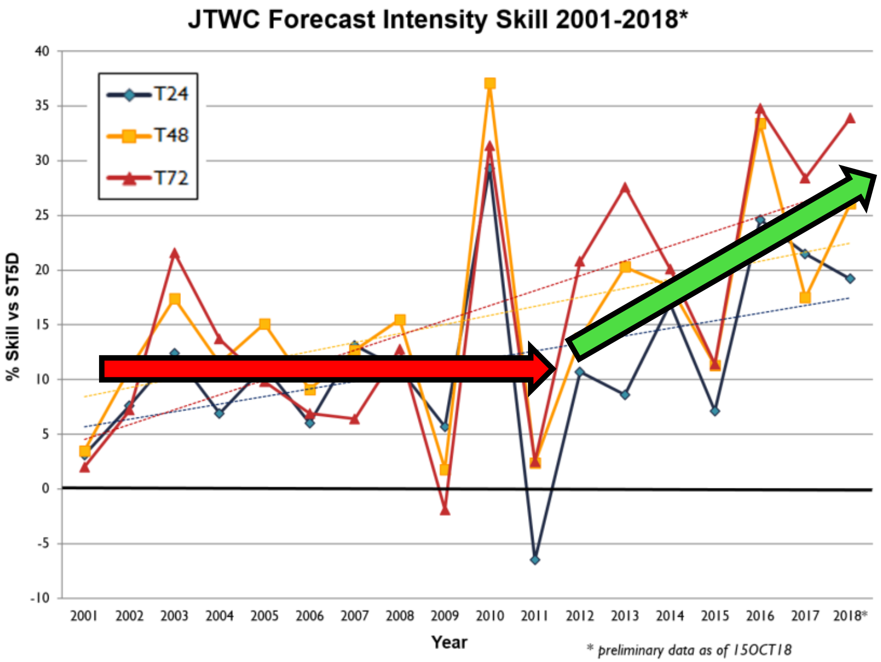
- **TCI-15**
  - Improved upper level physics and demonstrated value of in-situ observations for better model initialization and DA
  - Improved the ensemble through initial condition sensitivity

JTWC Official forecasts are improving

Yearly improvement gains by the operational COAMPS-TC

JTWC Forecast Improvement





Upgrades are transitioned once annually through the AMOP process

(Courtesy of Jim Doyle)

(Courtesy of JTWC)

“Rapid” Intensification

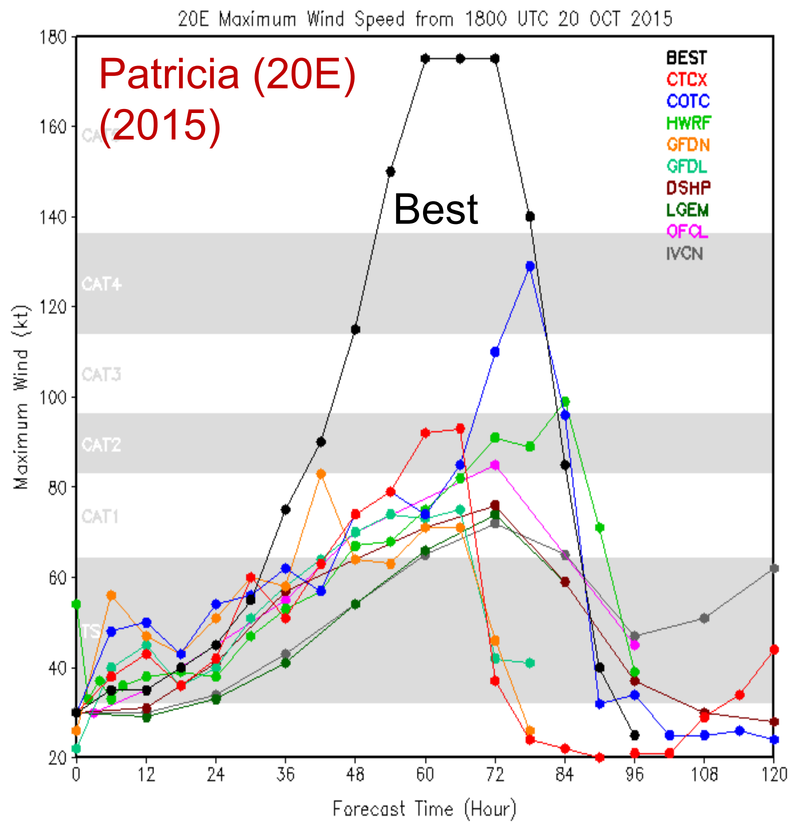
- ***Definition:*** **winds increasing by 30 knots or more in a 24-hour period**
  - **Patricia (2015)** +105 kts in 24 h (all-time record)
  - **Michael (2018)** + 65 kts in the 48 hours before landfall (70 to 135 kts)
  - NHC successfully predicted RI in only 5 of 36 cases in 2018

- **20-year summary of RI events:**
  - 66% of Atlantic hurricanes underwent RI
  - 75% of WestPac typhoons underwent RI

- For TCs reaching at least **Cat 3** (100kts):
  - 91% underwent RI in the Atlantic
  - 96% underwent RI in the WestPac

- For TCs reaching **Cat 5** (140kts):
  - 100% underwent RI in both basins (61 total)

- 50% of **Cat 5** TCs went through a “super-RI” of at least 60 kt in 24 h!



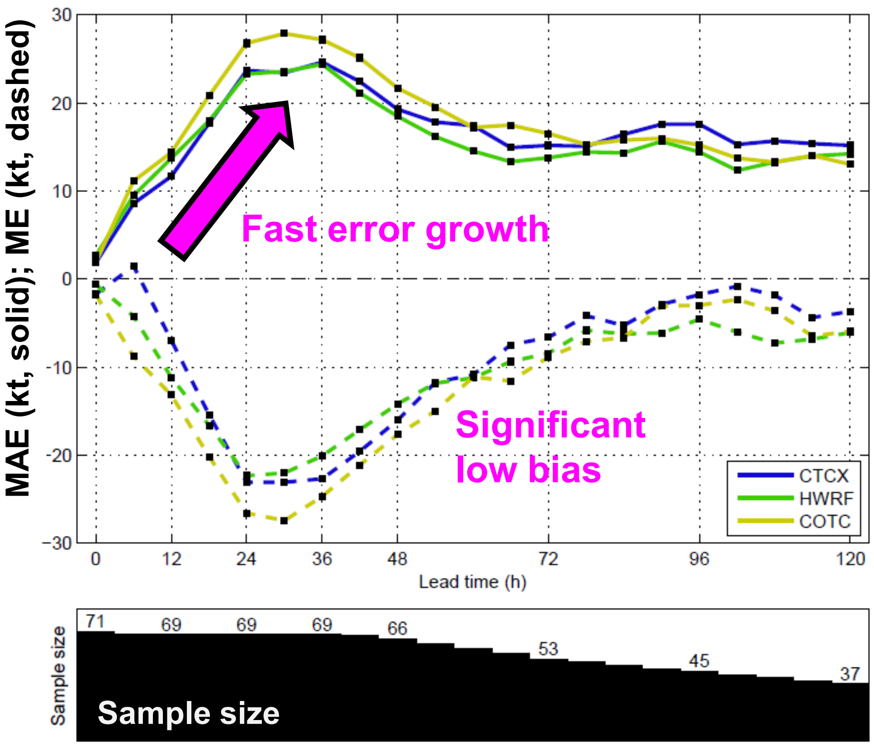
(Courtesy of Jon Moskitas)

Accurate prediction of RI is essential to provide adequate warning for impacts associated with Cat 3-5 TCs

RI vs. non-RI cases

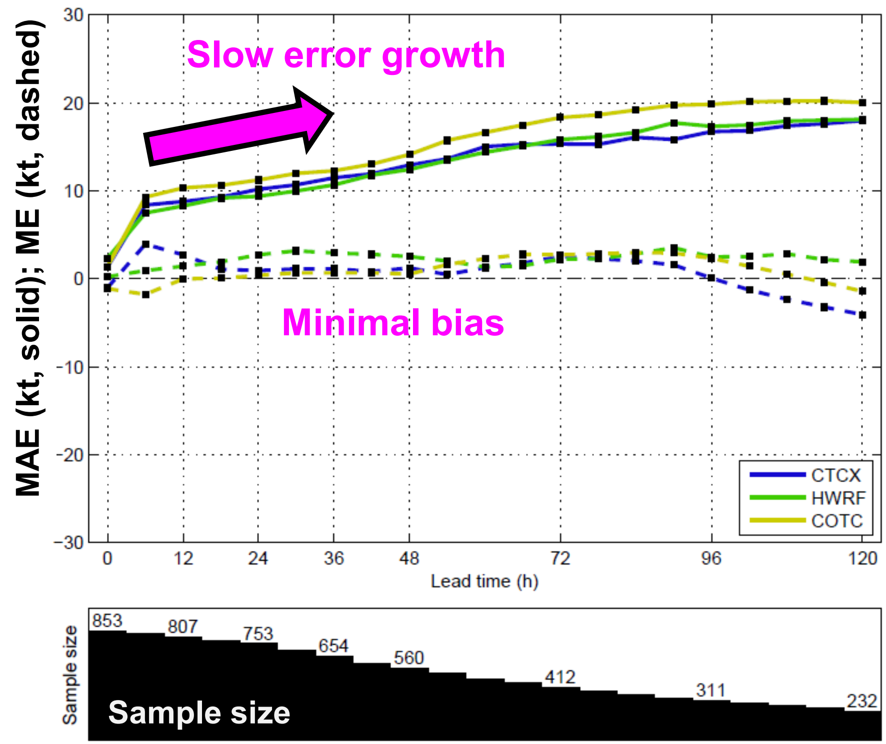
errors are fundamentally different

Intensity MAE and ME: Observed RI 0-24 h



Lead time

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



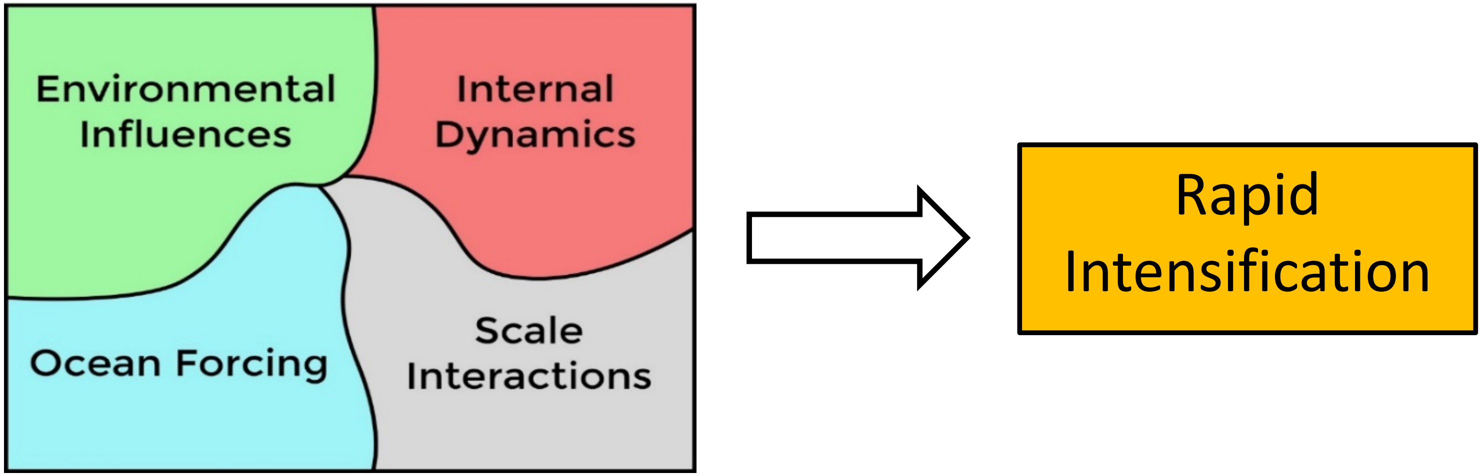
Lead time

Intensity mean absolute error (solid) and mean error (dashed) for 2017 real-time cases with RI observed during the 0-24 h lead time window (left panel) and with no RI observed during the 0-24 h (right panel).

Intensity forecasts have much faster error growth and much larger biases for RI cases relative to non-RI cases.

(Courtesy of Jon Moskitas)

RI: Approaching the Problem

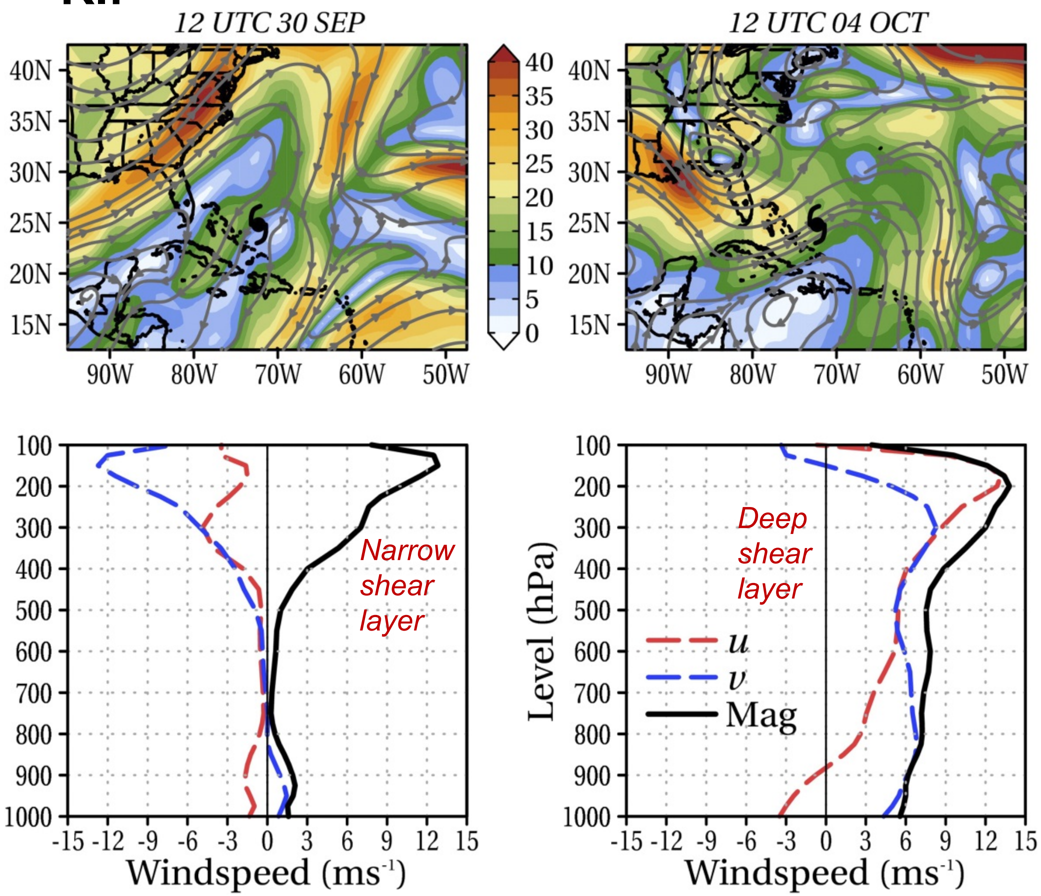


RI occurs when a TC crosses the threshold of internal conditions (thermodynamic and dynamic state) supported by favorable atmospheric and oceanic conditions

- In priority order: *Scale Interactions, Internal Dynamics, Ocean Forcing, Environmental Influences*

Environmental Influences

RI: **RW:**



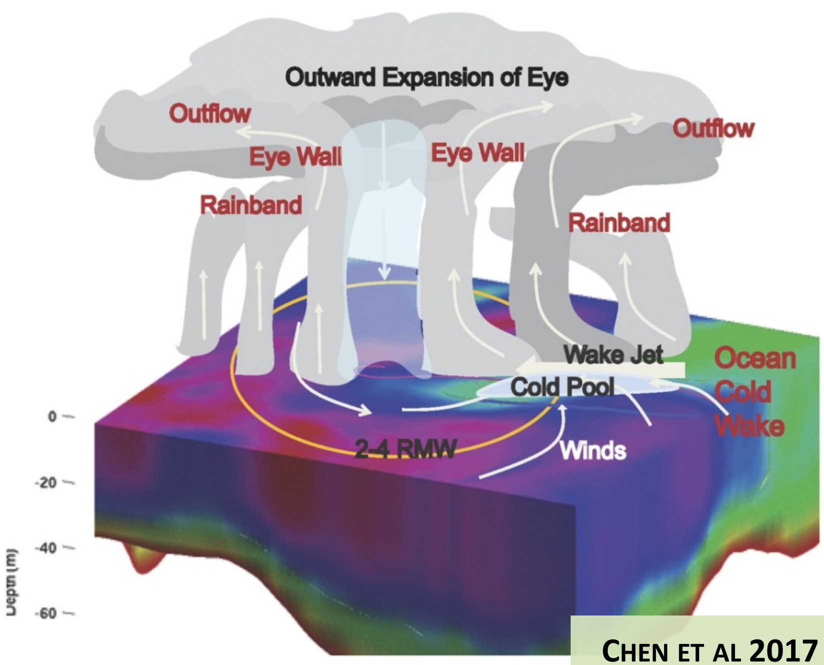
RYGLICKI ET AL 2018

- Hurricane **Joaquin** underwent rapid intensification (and RW)
  - Upper-level winds and wind profiles (shear) were well predicted, but the storm response was not
- Mesoscale model failed to capture storm response to change in winds and shear profile
- Need to better represent details of *internal dynamics* on the mesoscale and their response to the background environment

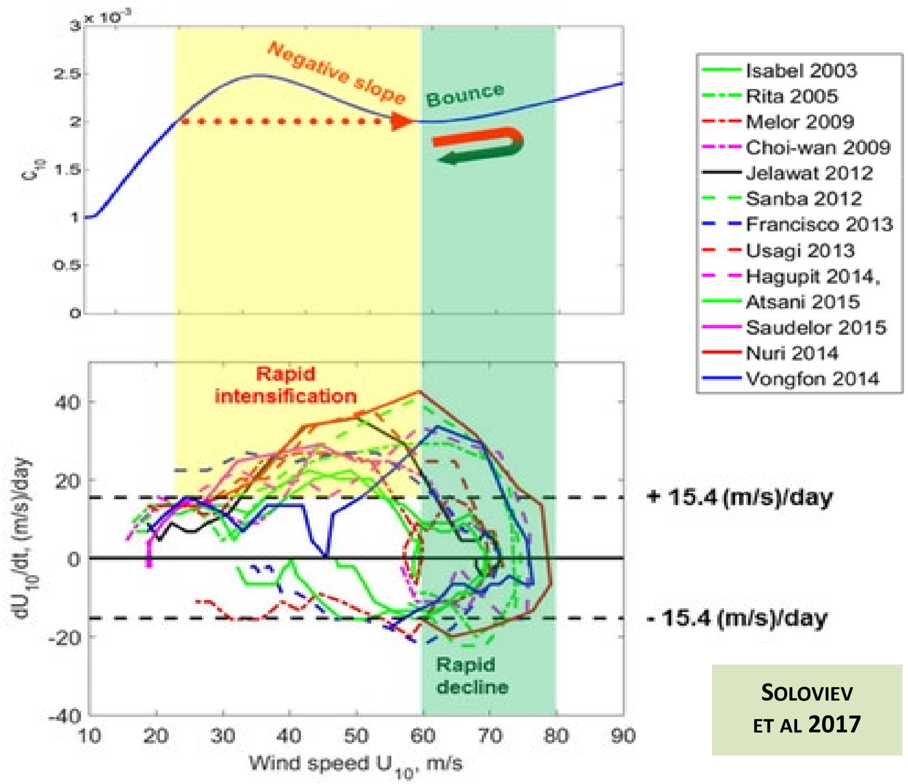
<u>UNDERSTOOD</u>: GLOBAL MODEL ADEQUATELY PREDICTS THE ENVIRONMENT

Ocean Forcing

- Lessons learned from CBLAST (2003) still being applied
- Air-sea enthalpy fluxes (left) and drag coefficients (right) need some additional refinement, testing/V&V to push into operational model



CHEN ET AL 2017

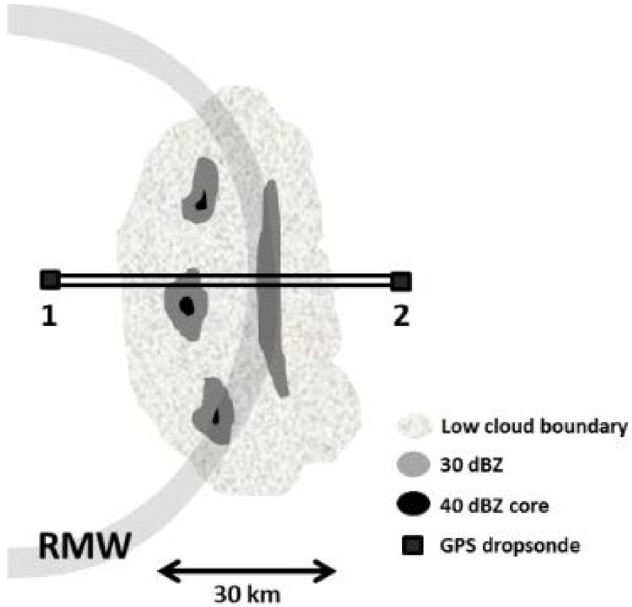


SOLOVIEV ET AL 2017

UNDERSTOOD: APPLIED RESEARCH TO PUSH INTO NUMERICAL MODELS

Internal Dynamics

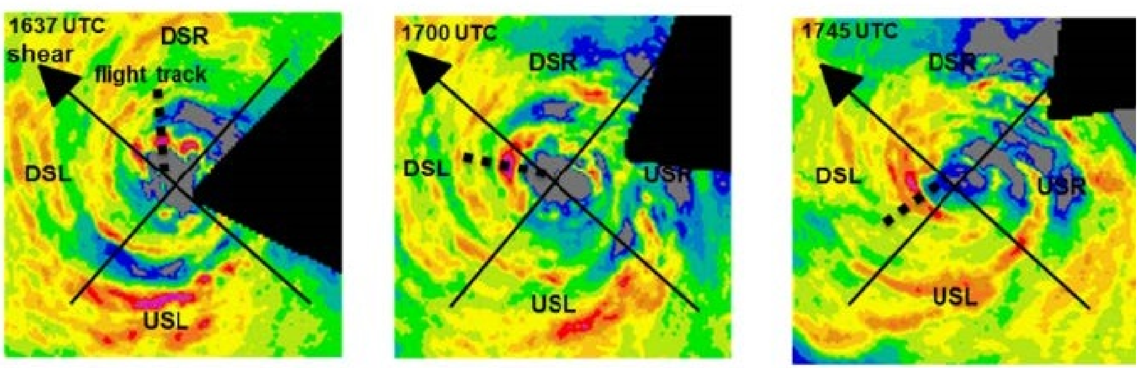
- Need radial penetrations that *sample core storm cells*
- *Repeated sampling* of developing cells to understand evolution of convective bursts
- Changes in fluxes and microphysics affect structure and intensity tendencies



OBJECTIVES:

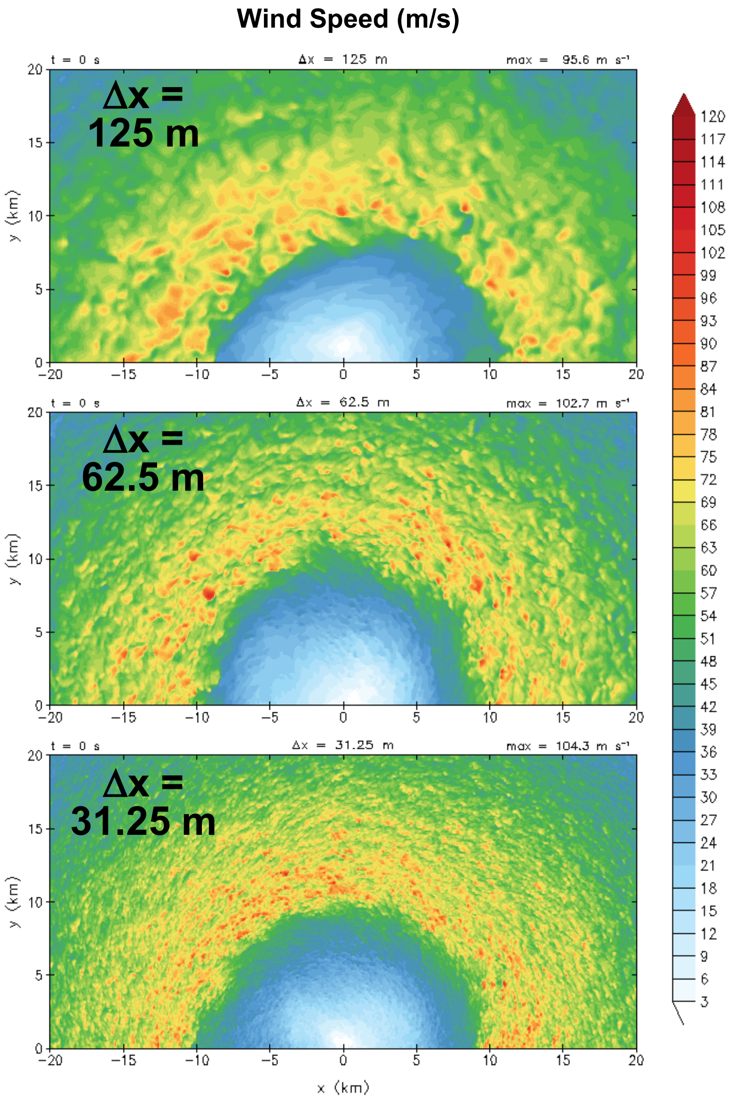
- RI is diagnosed by increased liquid and ice hydrometeors, latent heating by stratiform and shallow convection, and increasing symmetry of precipitation about center and upshear
- Need to understand conditions that foster symmetric storm development and differentiate from null events that do not RI

Onboard radar will direct A/C to developing features of interest:



DRI FOCUS: OBSERVE PROCESSES WITH FIELD CAMPAIGN

Scale Interactions



- As resolution of LES increases, modeling enables:
  - More detailed and realistic structures to be resolved
  - Updrafts tend to get stronger
  - The inner core tends to get smaller
  - The eyewall decreases in width and the area of strong winds decreases
- Conclusion: system scale energetic organization is dominated by upscale cascade of smaller internal convective/turbulent processes
  - (Fierro et al. 2009, Gentry and Lackmann 2010, Stern et al. 2018)
- Use LES alongside COAMPS-TC and field campaign observations to understand features important to eyewall boundary layer evolution and improve sub-grid parameterization

DRI FOCUS: UNDERSTAND ENERGY SCALES VIA MODELING

Observing Capabilities and Platforms

- **Research Aircraft**: NOAA P-3 and G-IV
  - AVAPS (and HDSS?) dropsondes
  - Tail Doppler Radar (TDR)
  - Stepped Frequency Microwave Radiometer (SFMR) for surface winds
  - Others (TBD):
    - Doppler Wind LIDAR (DWL)
    - Compact rotational Raman LIDAR (CRL, below) for water vapor, temp, aerosols
    - Full suite of cloud microphysics probes
  - Ideal platforms for flight through and around TCs to obtain obs. of temperature, water vapor, cloud properties, etc.
  - Obtain measurements for (1) data assimilation/ model testing, and (2) to help improve turbulence and microphysical parameterizations in numerical models
- **Field Experiment**
  - Multiple opportunities w/ NOAA in 2020-2022
  - Possibly NASA WB-57 in year 3
    - HDSS dropsondes and HIRAD

Summary

- TCRI will build on key findings from previous ONR field campaigns at the air-sea interface (CBLAST), at the tropopause (TCI-15), and through the atmospheric column (TCS-08, ITOP)

- Addressees the missing pieces of the RI puzzle: to understand processes and model structures that create RI
  - ✓ Small scale internal processes that tie together air-sea flux to outflow
  - ✓ Focus on boundary layer, convection and microphysics processes

- Unprecedented opportunities during 2020-2022 to obtain the necessary in-situ observations at sufficient detail
  - ✓ Partnership with NOAA for aircraft observations
  - ✓ Fly every interesting Atlantic case in Years 1-3
  - ✓ Deploy NASA WB-57 in year 3 if needed

- Past experience (and *steady improvement in Operations*) has shown that this *methodology is robust*
  - ✓ Understand processes (theory and field expts)
  - ✓ Represent new understanding in models (State-of-the-art DA and quantitative RS)
  - ✓ Transition innovations into prediction systems

TCRI DRI Awards (as of 2/20)

PIs	Institution	Title
Jason Dunion, Rob Rogers, Jon Zawislak, Joe Cione	NOAA/OAML CIMAS/UM	Investigating interactions between the TC inner core and near environment and their impacts on intensity change
Jim Doyle	NRL	Dynamics and Predictability of Tropical Cyclone Rapid Intensification
Michael Bell	CSU	Heating, Cooling, and Rapid Intensity Change in TCs
Brian Tang, George Bryan, Jun Zhang	U Albany NCAR CIMAS/UM	Boundary-Layer Processes Associated with Rapid Intensification in TCs
Anthony Wimmers Chris Velden	University of Wisconsin	A Deep Learning Approach to Examining and Predicting Tropical Cyclone Rapid Intensification
David Richter	Notre Dame	Boundary layer structure and large eddy simulation of intensifying TCs
Sharanya Majumdar David Nolan	RSMAS/UM	Multi-scale interactions and predictability of TC intensification
Chun-Chieh Wu	National Taiwan University	Rapid Intensification in TCs: Dynamics, Thermodynamics and Predictability
David Raymond Zeljka Fuchs	New Mexico Tech	Convection in TC Intensification
Chanh Kieu Louis Fan	Indiana University	On the Dynamics and Predictability of Tropical Cyclone Rapid Intensification
Ralph Foster	U Washington	High-Resolution Hurricane Boundary Layer Structure From Satellite Synthetic Aperture Radar and Aircraft Observations