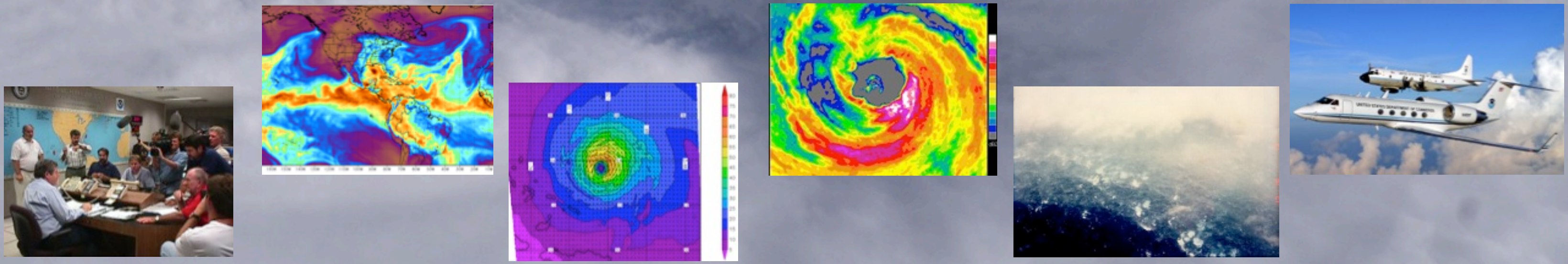
Using observations and models to better understand and predict hurricanes



Robert Rogers
AOML Program Review
4-6 March 2013

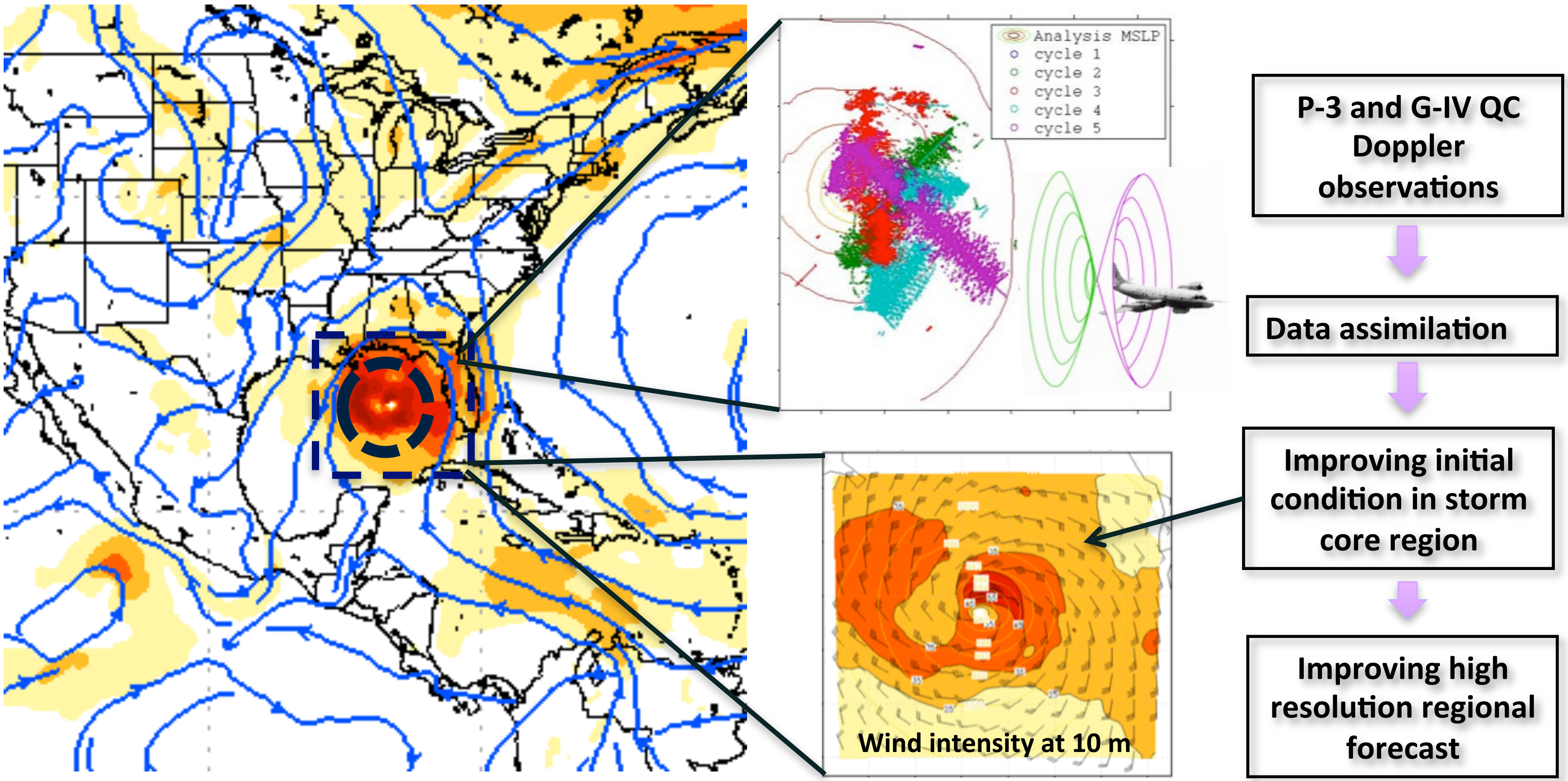
Overview

- TC intensity forecasting has shown less improvement than track forecasting
  - Intensity change involves multiscale processes
- Observations **key** component of a balanced approach toward advancing understanding and improving forecasts of TC intensity change
  - *HRD uniquely positioned to contribute to this effort through a combination of data collection and analysis and numerical model experiments*
- **IFEX**: Multi-year field campaign intended to improve TC intensity forecasts
  - Partnership among NOAA (NHC, EMC, AOC) and other government, academic agencies (NASA GRIP, HS3; NSF PREDICT)
  - **Goals**:
    1. collect observations that span TC life cycle in a variety of environments for model initialization and evaluation
    2. develop and refine measurement technologies that provide improved real-time monitoring of TC intensity, structure, and environment
    3. improve understanding of physical processes important in intensity change for a TC at all stages of its life cycle

What is the role of convective-scale processes in tropical cyclone intensity change?

IFEX Goal 1: Observations for model initialization and evaluation

Synergy of high resolution forecast and airborne observations



P-3 and G-IV QC Doppler observations

Data assimilation

Improving initial condition in storm core region

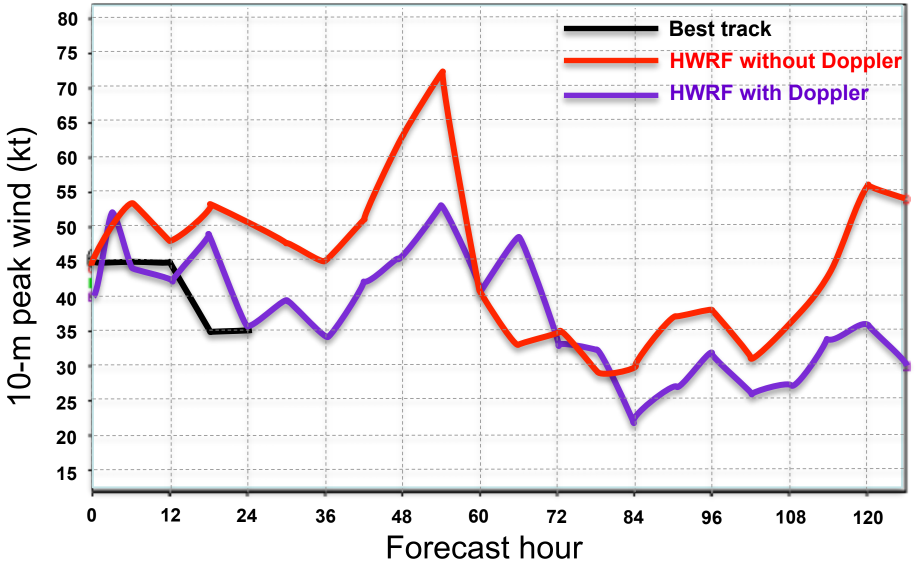
Improving high resolution regional forecast

Hurricane Isaac (2012)

IFEX Goal 1: Observations for model initialization and evaluation

Positive impact of Tail Doppler radar data on TS Karen intensity forecast

Intensity Forecast for Karen (2012)
Valid 12 UTC 4 October 2013



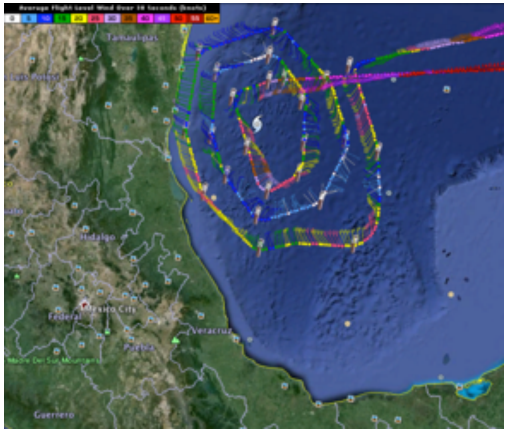
NHC Forecast Discussion on October 4, 5 PM:

"…THE 12Z HWRF RUN SHOWED CONSIDERABLY LESS INTENSIFICATION WITH KAREN COMPARED TO PREVIOUS RUNS AFTER ASSIMILATING DATA FROM THE FROM THE NOAA P-3 TAIL DOPPLER RADAR. THIS MARKS THE FIRST TIME DOPPLER RADAR DATA HAVE BEEN ASSIMILATIED INTO AN OPERATIONAL HURRICANE MODEL IN REAL TIME. .."

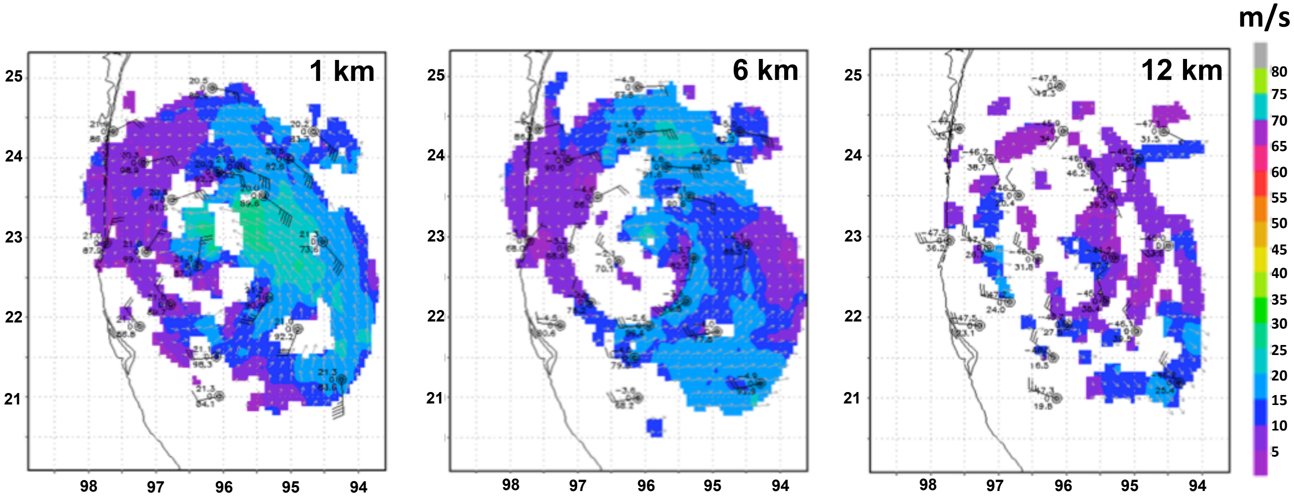
IFEX Goal 2: Techniques for real-time TC monitoring

Tail Doppler radar from the high-altitude NOAA G-IV aircraft

Flight track for the G-IV on 15 Sept 2013 in Hurricane Ingrid



Doppler-derived wind speed (shaded, m s^{-1}) and vectors and dropsonde measurements at 1, 6, 12-km altitude for Hurricane Ingrid (2013)

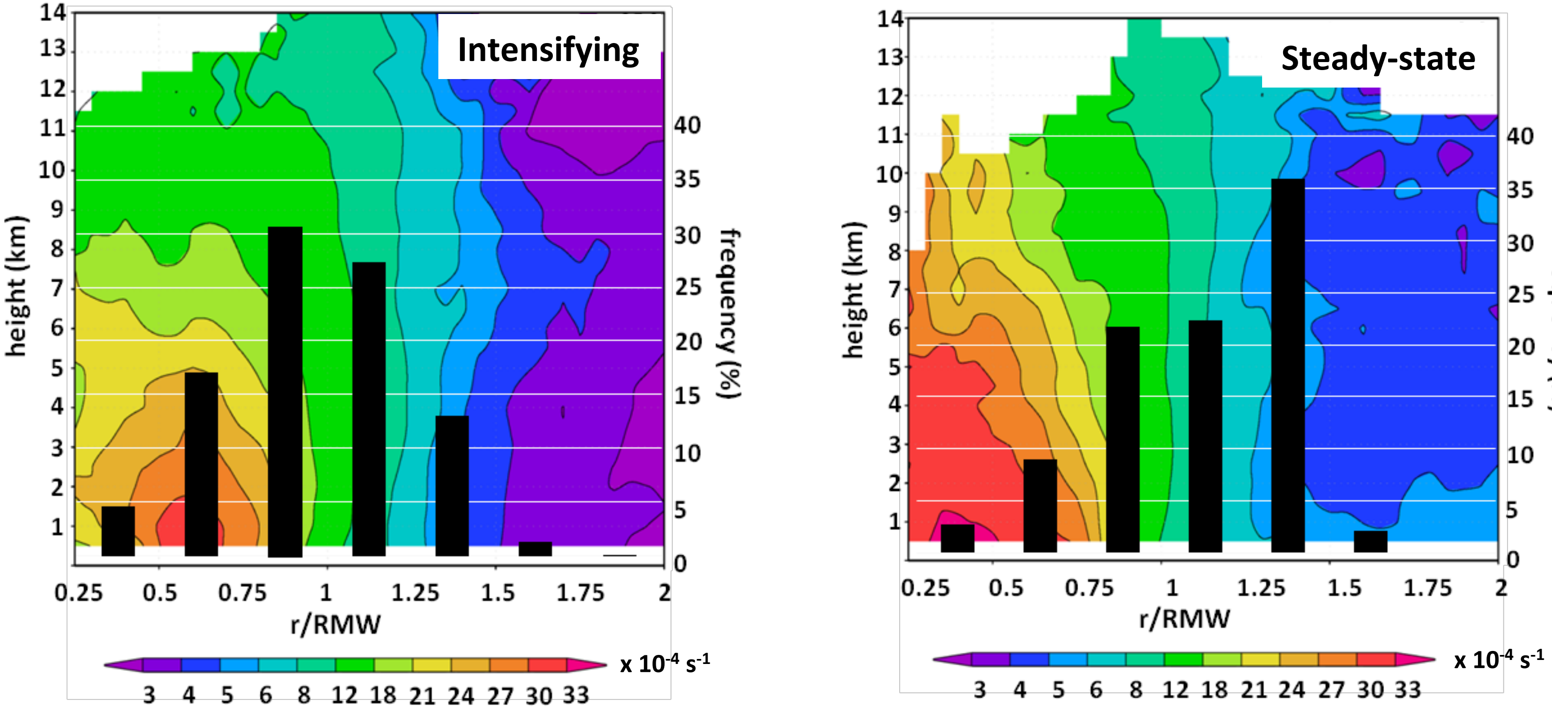


Doppler observations will be transmitted in real time this season

IFEX Goal 3: Improved understanding of TC processes: Role of convective-scale processes

What is the difference in the inner-core structure of intensifying and steady-state hurricanes?

Radial distribution of convective bursts (%) and axisymmetric vorticity (shaded, x 10^{-4} s^{-1})



- Analyses obtained from composites of multiple intensifying vs. steady-state hurricanes
- Convective bursts defined as top 1% of vertical velocity distribution at 8 km altitude (5.5 m/s)
- Intensifying cases have more bursts, more inside 2-km RMW compared with steady-state cases

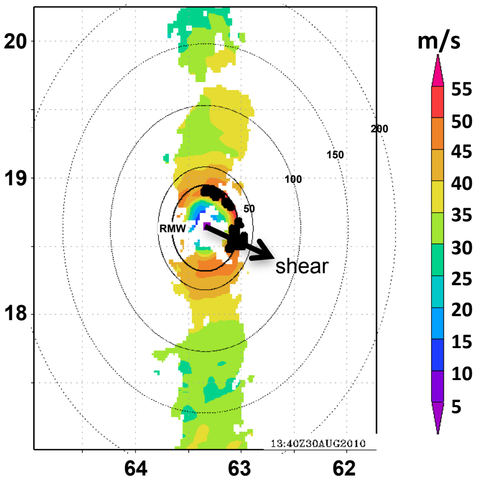
Rogers et al. (2013b)

IFEX Goal 3: Improved understanding of TC processes: Role of convective-scale processes

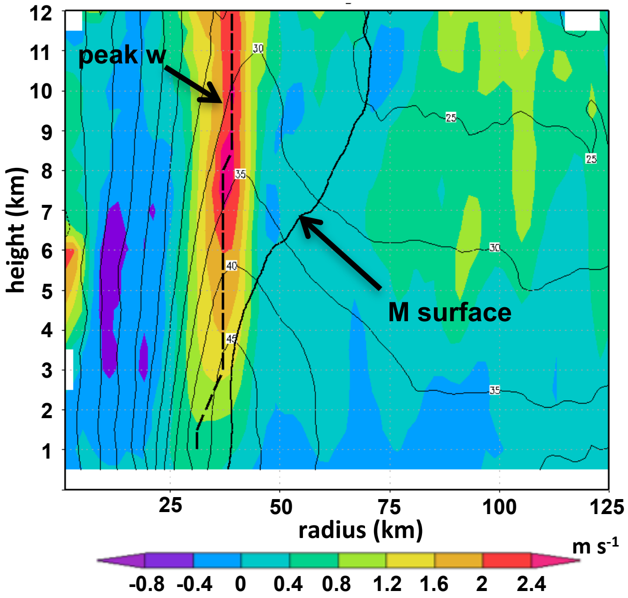
What is the inner-core convective structure of a rapidly-intensifying hurricane?

Airborne Doppler observations of the rapid intensification (RI) of Hurricane Earl (2010)

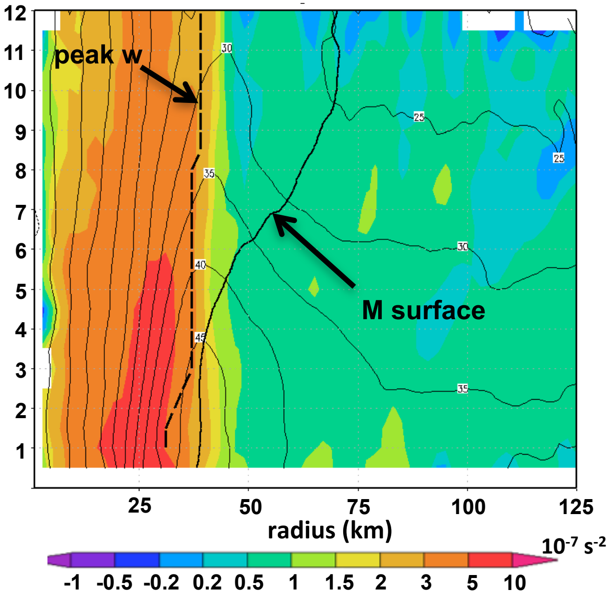
Storm-relative wind speed (shaded, m s^{-1}) at 2-km and CB locations (black dots) during RI



Vertical velocity (shaded, m s^{-1}) and tangential wind (contour, m s^{-1}) on downshear side during RI



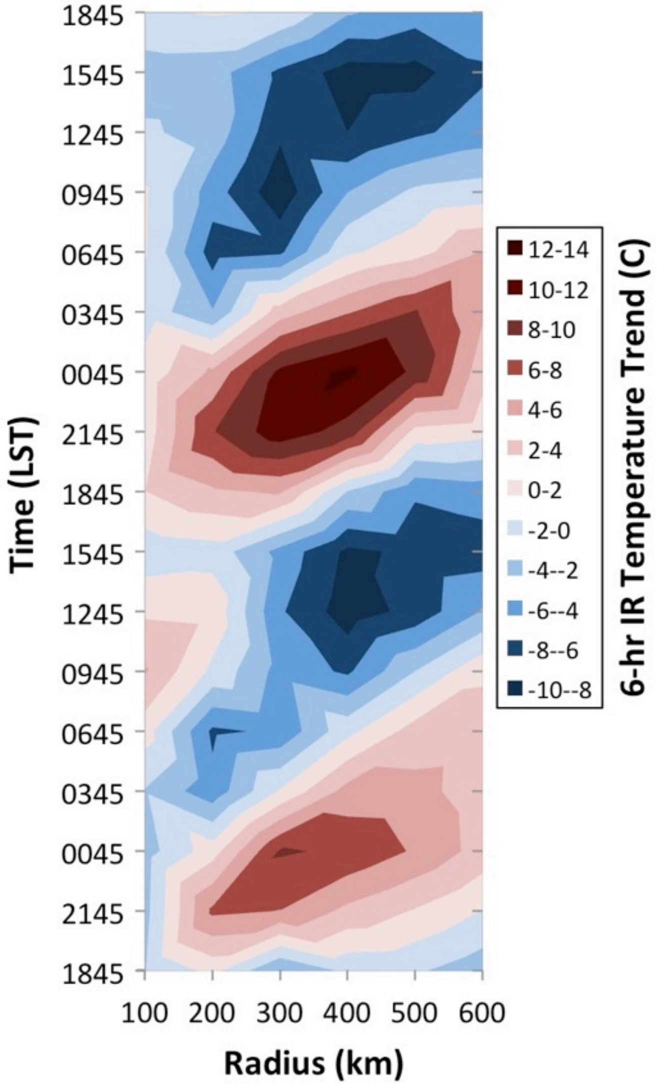
Inertial stability (shaded, 10^{-7} s^{-2}) and tangential wind (contour, m s^{-1}) on downshear side during RI



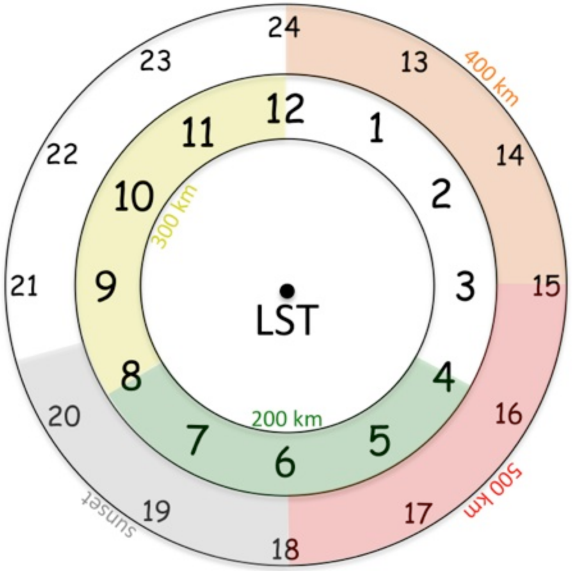
- Most convective bursts located inside 2-km RMW during this flight
- Updraft core originates from PBL inside RMW, nearly vertical ascent
- Slope of updraft core departs significantly from angular momentum (M) surface
- Peak updraft inside local RMW throughout ascent, in locally high inertial stability regime

IFEX Goal 3: Improved understanding of TC processes: The Tropical Cyclone Diurnal Cycle

Hovmoller:
Daily IR Temp Trends (10-yr MH Composite)



TC Diurnal Clock

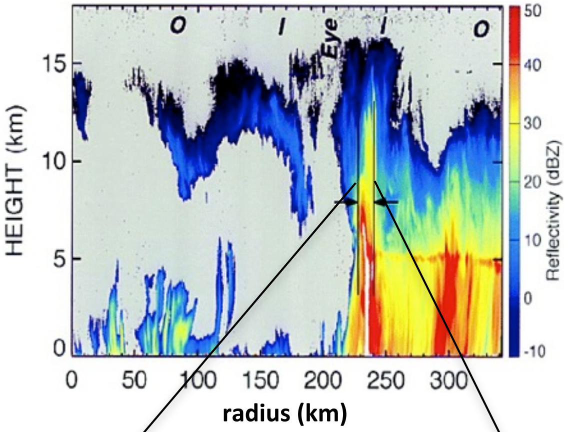


IFEX Goal 3: Improved understanding of TC processes: Role of convective-scale processes

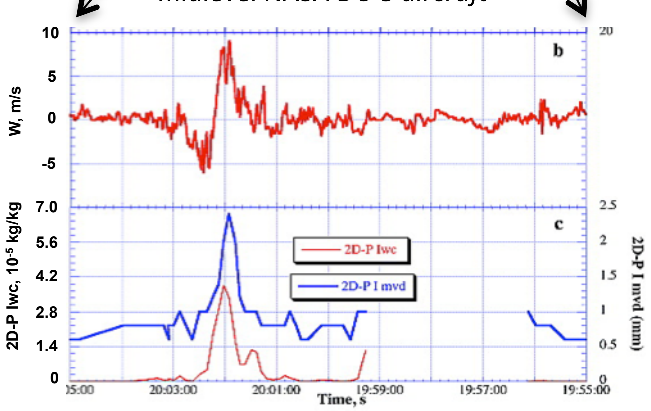
How well does HWRF produce microphysics fields in deep convection?

Evaluation of ice microphysics in HWRF simulations

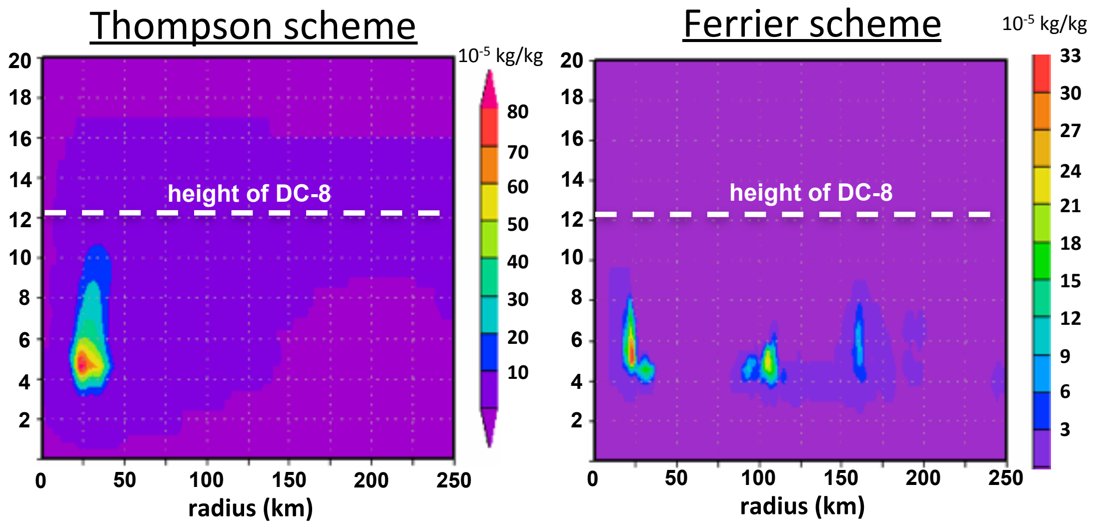
Radar reflectivity (shaded, dBZ) from ER-2 in Bonnie (1998)



Flight-level vertical velocity (top, m/s) and ice concentration (bottom red, x 10^{-5} kg/kg) from midlevel NASA DC-8 aircraft



Axisymmetric graupel concentration (shaded, x 10^{-5} kg/kg) at 54 h for idealized HWRF runs using Thompson (left) and operational Ferrier (right) scheme



- Thompson scheme produces graupel at high (12 km) altitudes, but may produce too much
- Ferrier does not produce any graupel at these heights, produces much less overall than Thompson
- Bonnie was an unusual storm; more research needed in a spectrum of cases

Black et al. (2003)

Summary

- HRD is advancing the IFEX goals of improving TC intensity forecasting through a combination of observations, modeling, and theory
    - *assimilation of airborne Doppler, new radar platforms, research on convection and its role in TC intensity change*

- HRD is uniquely positioned to combine these approaches

- Ongoing work will continue to develop and refine our observational and modeling capabilities, covering the spectrum of spatial and temporal scales important in TC intensity change
    - *new sampling strategies, model evaluation*

- These efforts advance NOAA's mission of building a Weather-Ready Nation

QUESTIONS?

Papers cited here

Black, R. A., G. M. Heymsfield, and J. Hallett, 2003: Extra large particle images at 12 km in a hurricane eyewall: Evidence of high-altitude supercooled water? Geophys. Res. Lett., **30**, 2124, doi:10.1029/2003GL017864, 21.

Dunion, J.P., C.D. Thorncroft, and C.S. Velden, 2014: The tropical cyclone diurnal cycle of mature hurricanes. *Mon. Wea. Rev.* (in press)

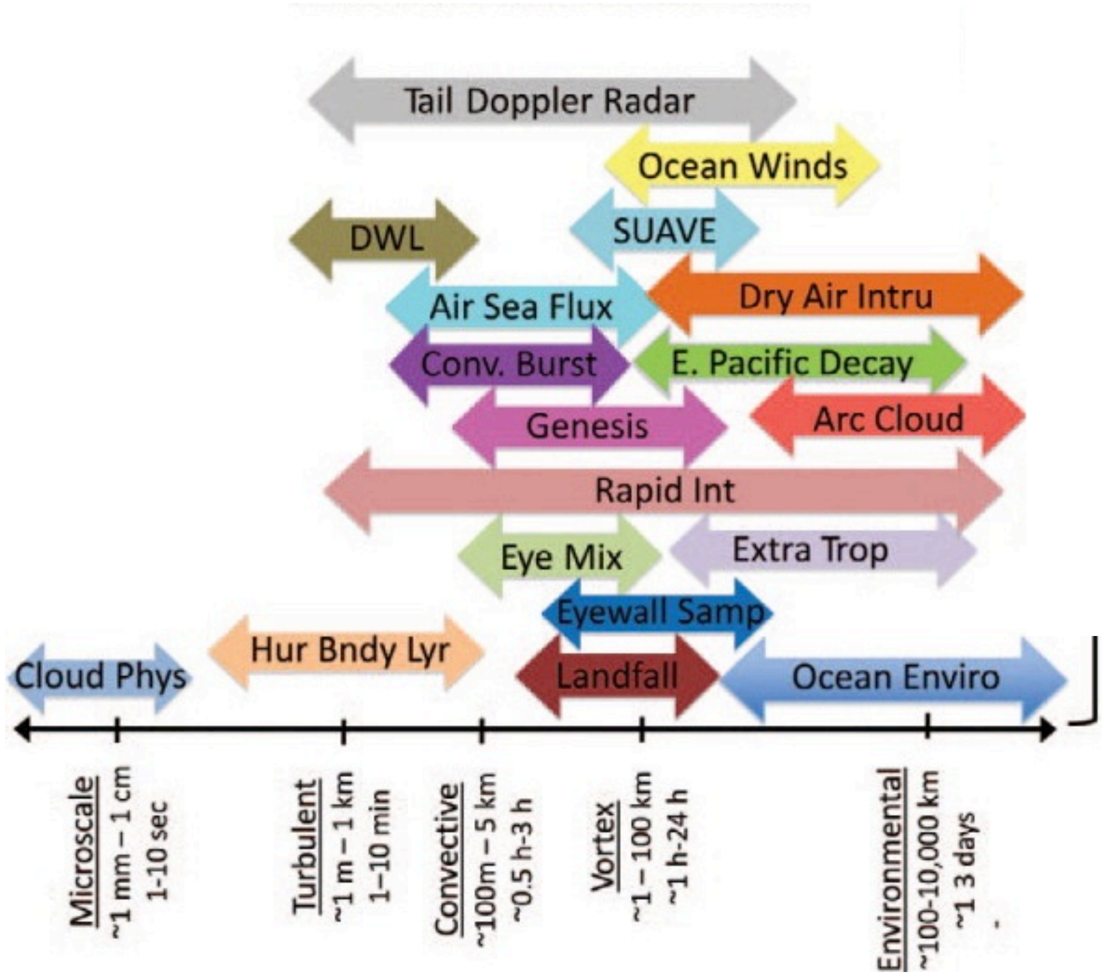
Rogers, R.F., S.Aberson, A. Aksoy, B. Annane, M. Black, J. Cione, N. Dorst, J. Dunion, J. Gamache, S. Goldenberg, S. Gopalakrishnan, J. Kaplan, B. Klotz, S. Lorsolo, F. Marks, S. Murillo, M. Powell, P. Reasor, K. Sellwood, E. Uhlhorn, T. Vukicevic, J. Zhang, and X. Zhang, 2013a: NOAA'S Hurricane Intensity Forecasting Experiment: A Progress Report. *Bull. Amer. Meteor. Soc*., **94**, 859–882.

Rogers, R.F., P. Reasor, and S. Lorsolo, 2013b: Airborne Doppler Observations of the Inner-core Structural Differences between Intensifying and Steady-State Tropical Cyclones. *Mon. Wea. Rev*., **141**, 2970-2991.

Extra slides

IFEX Goal 1: Observations for model initialization and evaluation

Spatio-temporal scales targeted by IFEX field experiments



Rogers et al. (2013a)

IFEX Goal 1: Observations for model initialization and evaluation

Percentage (%) of on-station aircraft flight hours

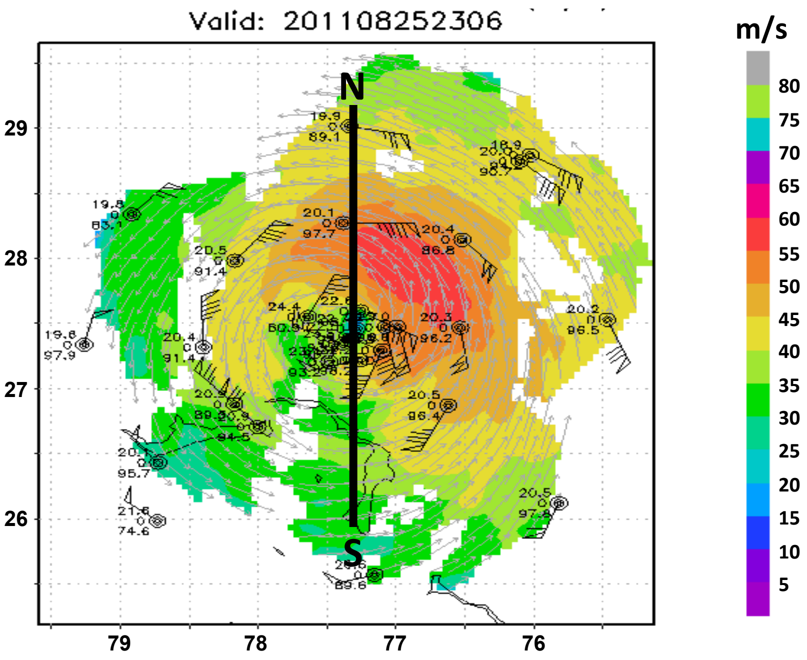
	Pre- IFEX 1956-2004	IFEX 2005-2011
Pre-TD	**4.3**	**9.9**
TD	**7.2**	**5.5**
TS	**26.8**	**37.1**
Cat 1-2	**31.6**	**24.8**
Cat 3-5	**30.0**	**22.7**

Rogers et al. (2013a)

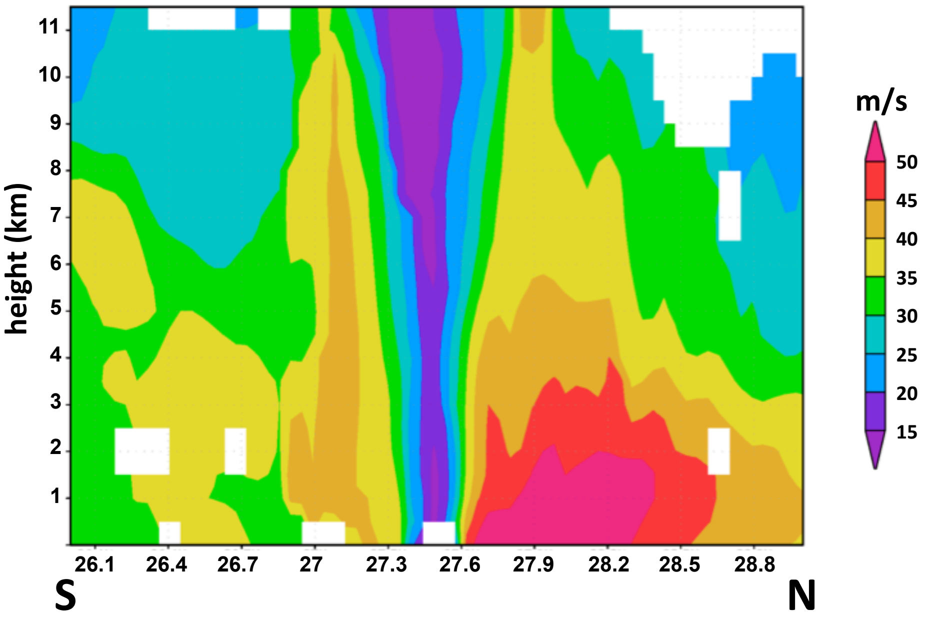
IFEX Goal 2: Techniques for real-time TC monitoring

Real-time analyses of TC inner-core structure from airborne radar

Doppler-derived wind speed (shaded, m s^{-1}) and vectors and dropsonde measurements at 1-km altitude for Hurricane Irene (2011)



South-north cross section of Doppler-derived wind speed (shaded, m s^{-1}) through Hurricane Irene (2011)

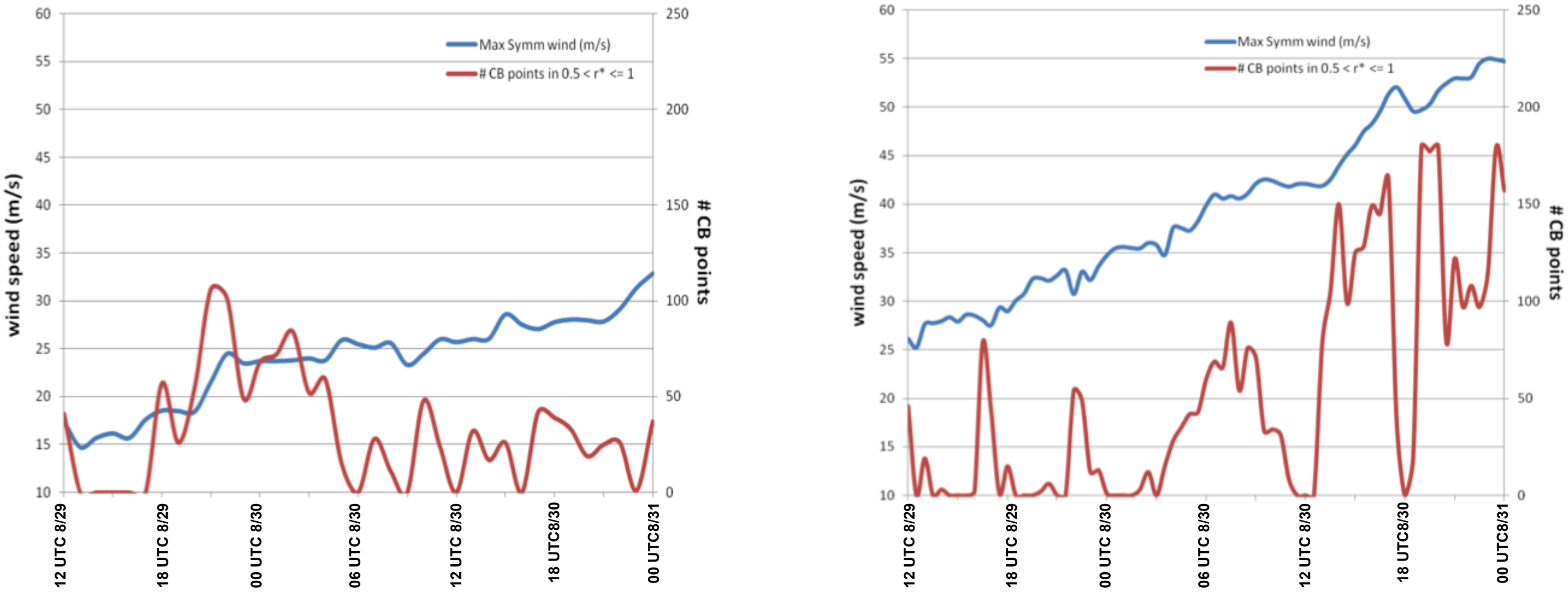


- Analyses are available within 1-2 h after aircraft lands

IFEX Goal 3: Improved understanding of TC processes: Convective-scale processes

HWRF simulations of the rapid intensification of Hurricane Earl (2010)

2-km axisymmetric wind maximum and coverage of convective bursts between r = 0.5 and 1*



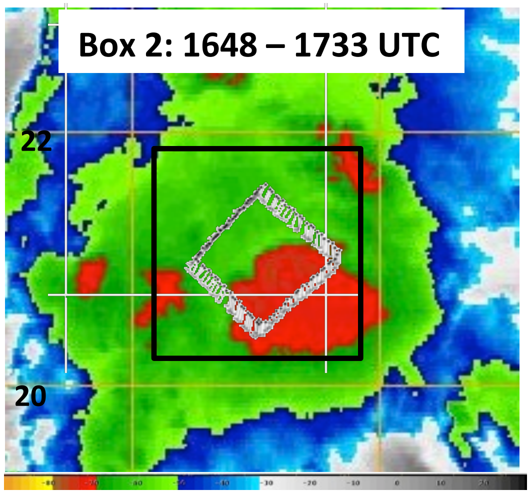
Exp. 1226 HWRF

Exp. 1826 HWRF

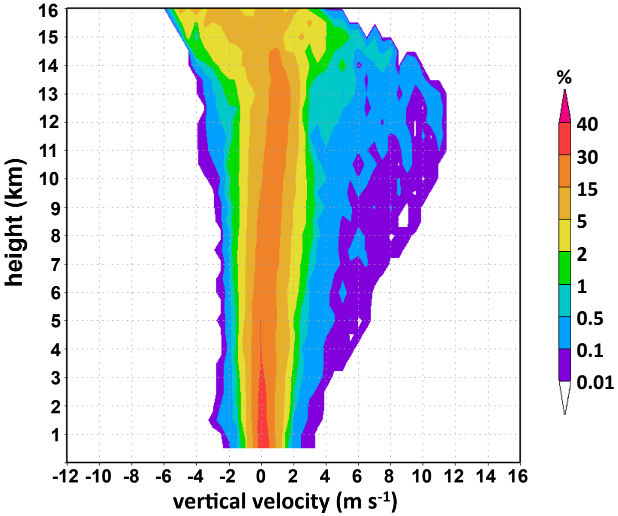
- After bifurcation period, coverage of bursts for Exp. 1826 increases markedly
- Enhanced coverage occurs prior to significant increase in symmetric wind speed
- Transient, limited coverage of bursts for Exp. 1226

IFEX Goal 3: Improved understanding of TC processes: Role of convective-scale processes

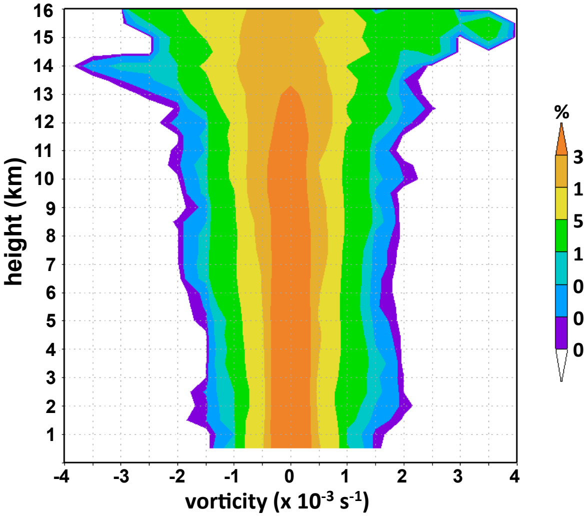
Convective burst module in Tropical Storm Gabrielle (2013)



Infrared satellite image and flight track showing 2nd of 3 box patterns flown around convective burst



Contoured frequency by altitude diagram (CFAD) of vertical velocity (shaded, %) for 2nd box pattern



Contoured frequency by altitude diagram (CFAD) of vertical vorticity (shaded, %) for 2nd box pattern

Convective burst module:

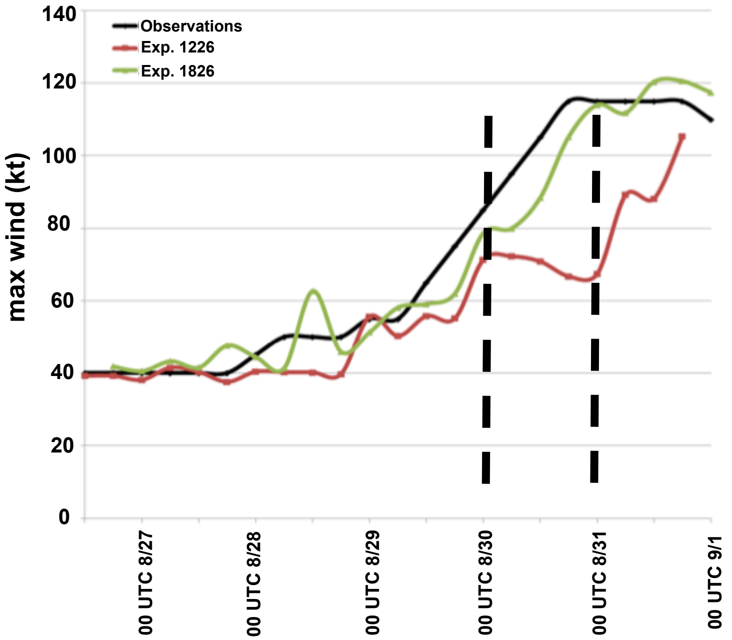
- Collect Doppler and dropsonde data in vicinity of a convective burst at high time frequency (~30-45 minutes)
- Document structure and evolution of convective-scale properties, e.g., statistics of reflectivity, vertical velocity, vorticity, mass flux over convective/mesoscale time scales
- Quantify impact of convective-scale processes on parent system
- Evaluate and improve HWRF microphysics parameterization

IFEX Goal 3: Improved understanding of TC processes: Role of convective-scale processes

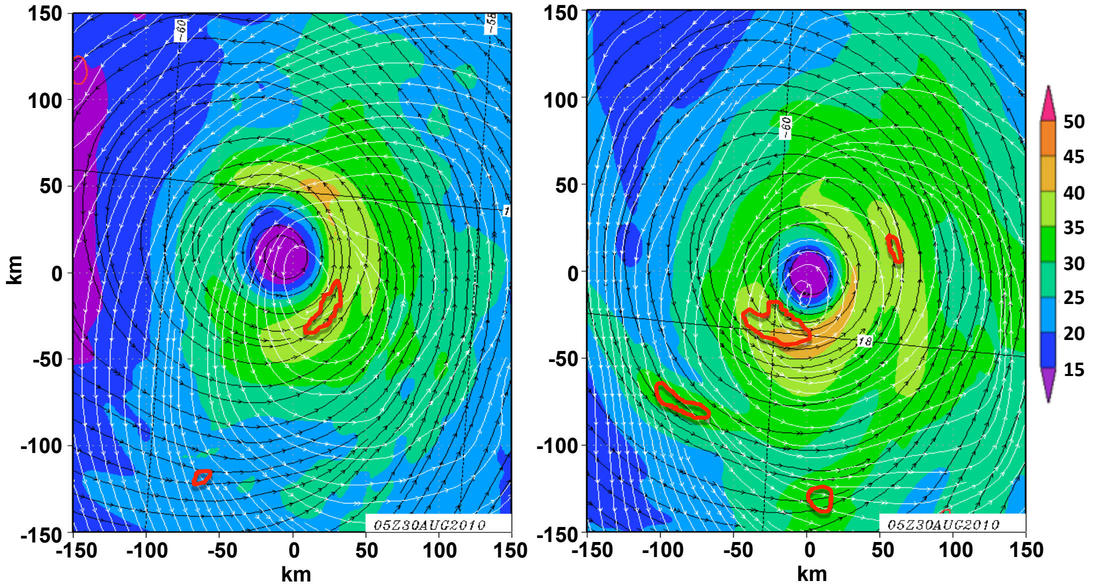
Can high-resolution numerical models capture structural features of RI?

HWRF 3-km simulations of the rapid intensification of Hurricane Earl (2010)

Intensity traces for Hurricane Earl (2010)



Wind speed at 2 km(shaded, m s^{-1})
Streamlines at 2 km(black), 8 km(white) during bifurcation period
Convective burst locations (red contours)



Exp. 1226 HWRF (no RI)

Exp. 1826 HWRF (RI)

- Two HWRF runs: initialized at 12 UTC 26 August (Exp. 1226) and 18 UTC 26 August (Exp. 1826)
- Both runs capture early intensity evolution well
- Bifurcation period at 00 UTC 8/30 – RI aborted in Exp. 1226 for 24 h
- More convective bursts inside 2-km RMW in Exp. 1826 during bifurcation period