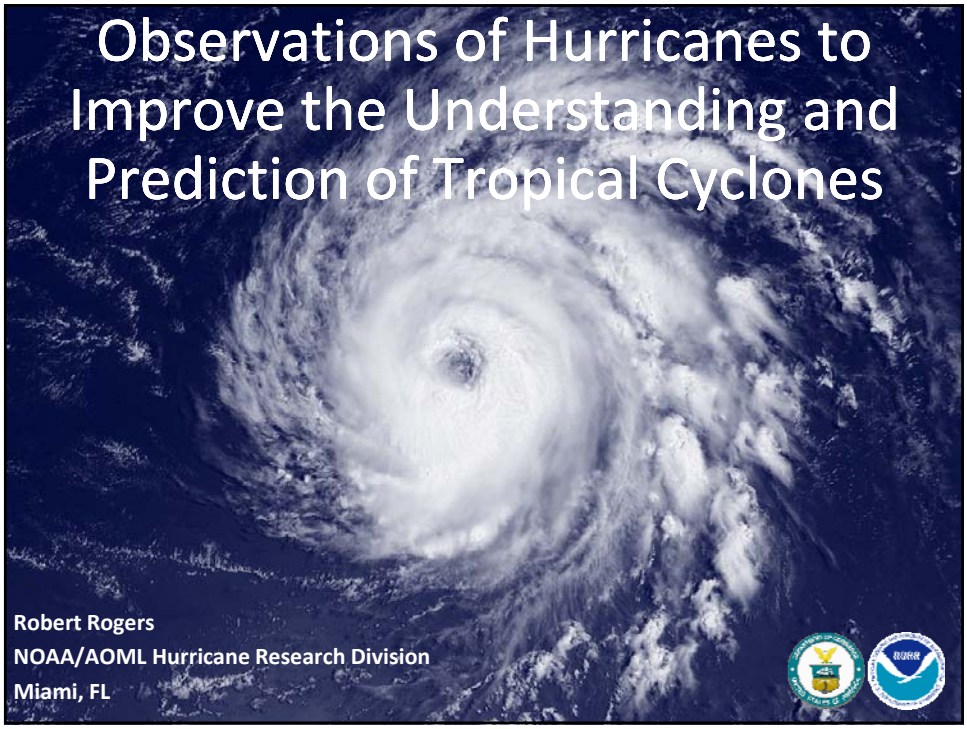
Observations of Hurricanes to Improve the Understanding and Prediction of Tropical Cyclones



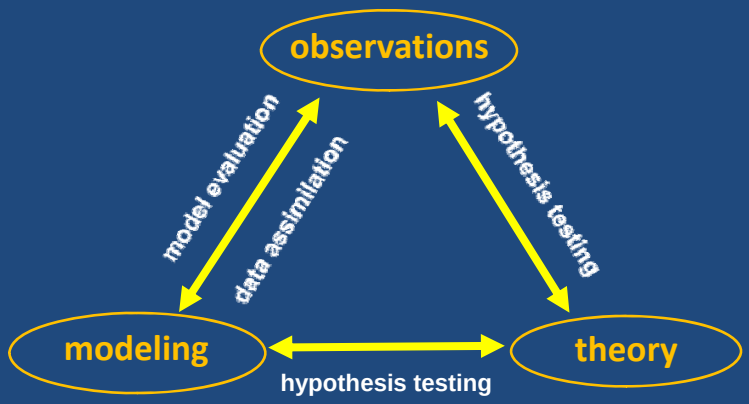
Robert Rogers
NOAA/AOML Hurricane Research Division
Miami, FL

Motivation

- Observations key component of balanced approach toward advancing understanding and improving forecasts (observations, modeling, theory)
- Many important physical processes within TCs occur over a multitude of spatial and temporal scales, from environmental to vortex to convective to turbulent to microphysical
- Three primary platforms for observations – airborne, spaceborne, and land-based – focus here on airborne and spaceborne
- For maximum impact on models, observations should be in a format compatible with models

2

Optimal interactions among observations, modeling, and theory



3

Types of Observations

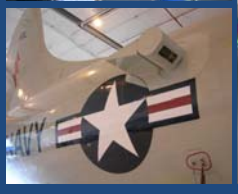
Airborne

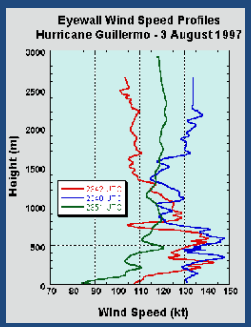
- **In-situ**
  - Wind, press., temp.

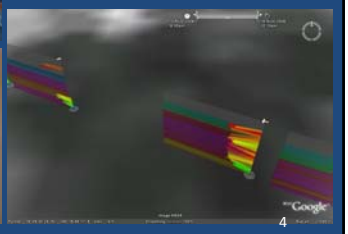
- **Expendables**
  - Dropsondes
  - AXBT, AXCP, buoy

- **Remote Sensors**
  - Doppler Radar
  - SFMR
  - DWL (ONR)
  - WSRA
  - Scatterometer/ profiler
  - UAS

Coyote UAS



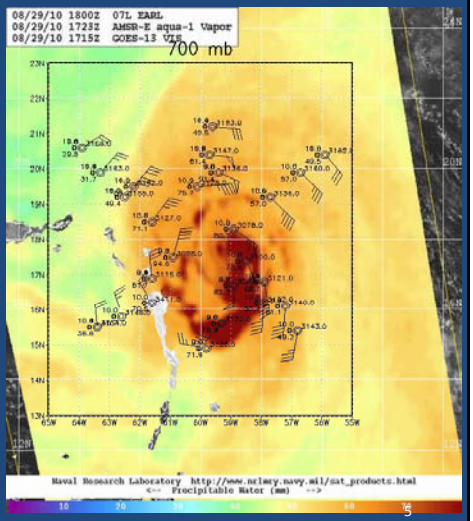




4

Types of Observations - Airborne
Environmental structure

- Synoptic-surveillance using dropsondes

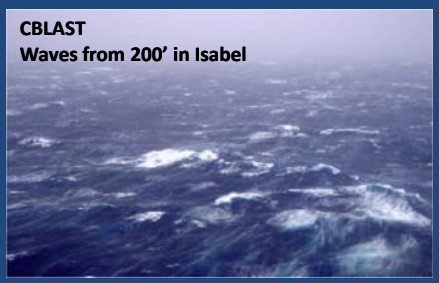


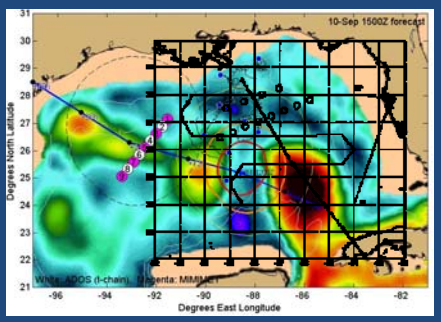
- Analytical & numerical studies.
- Ensemble track forecasting & targeted observations.

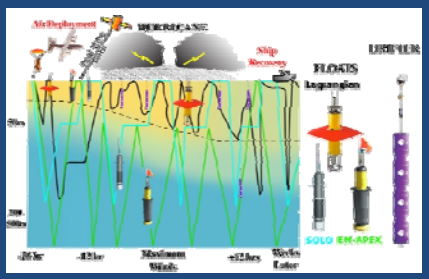
Types of Observations - Airborne
Environmental structure

Targeted upper ocean observations

TC impact on upper ocean effect of Hurricanes Gustav and Ike (2008)

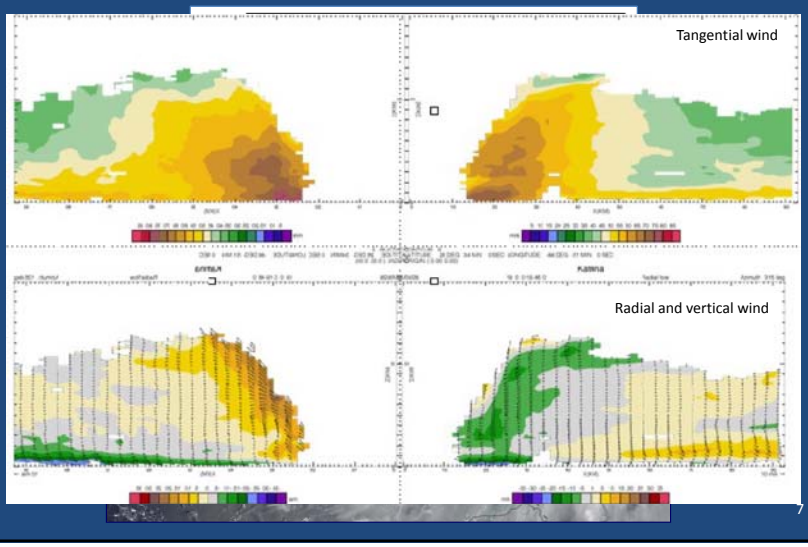






Types of Observations - Airborne
Vortex Structure

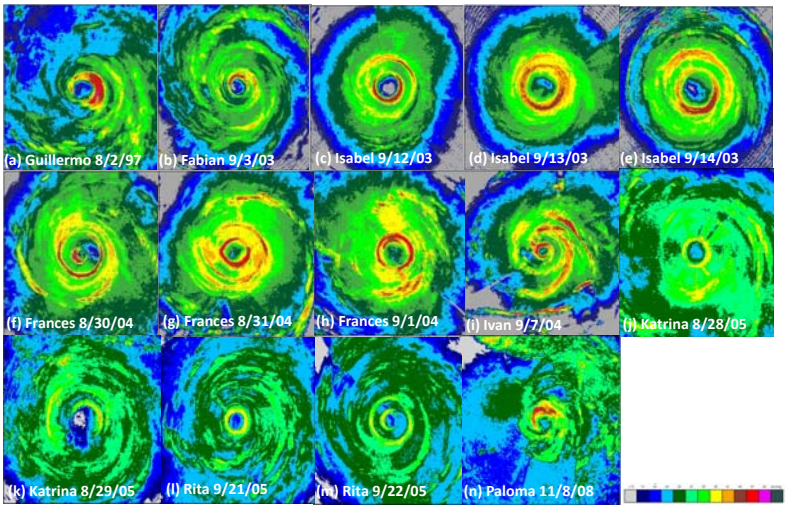
Vortex-scale measurements using Airborne Doppler radar



7

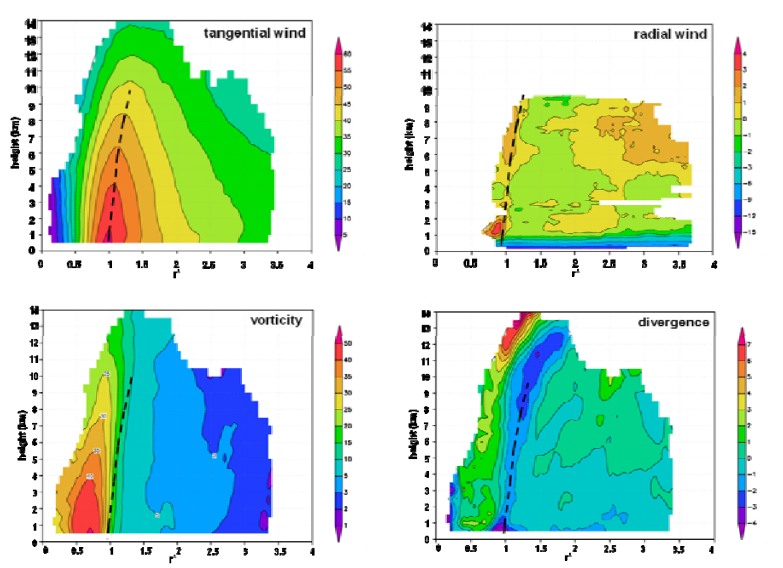
Types of Observations - Airborne
Vortex Structure

Lower fuselage images from storms used in airborne Doppler composite



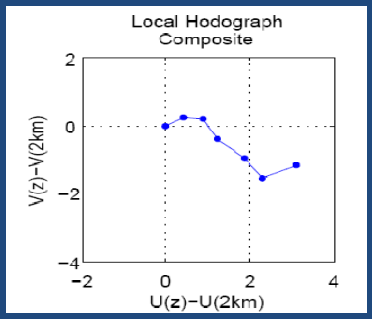
8

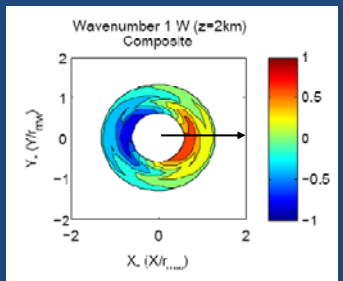
Types of Observations - Airborne
Vortex Structure
Composite axisymmetric vortex structure from mature hurricanes

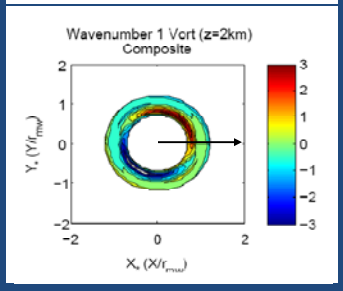


9

Types of Observations - Airborne
Vortex Structure
Composite asymmetric vortex structure from mature hurricanes







*Shear rotated to be pointing east

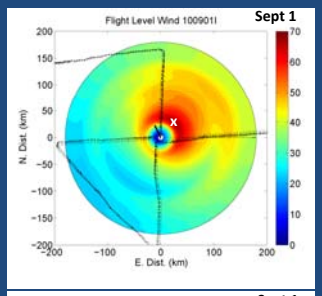
10

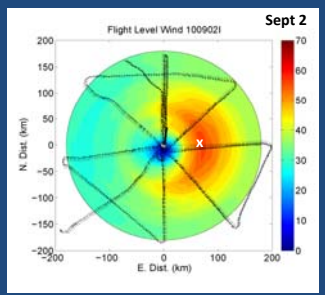
Types of Observations - Airborne
Vortex Structure

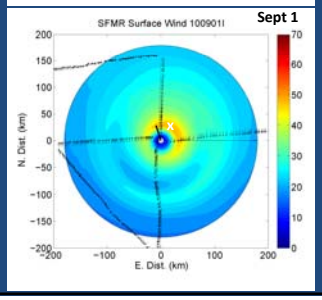
Surface and flight-level wind speed (shaded, m/s) during steady-state phase of Earl (2010)

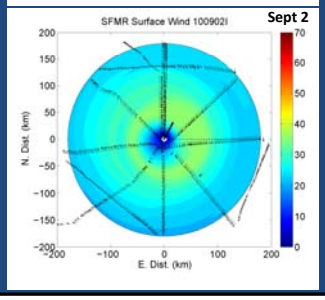
flight-level (~ 3.5 km)

surface





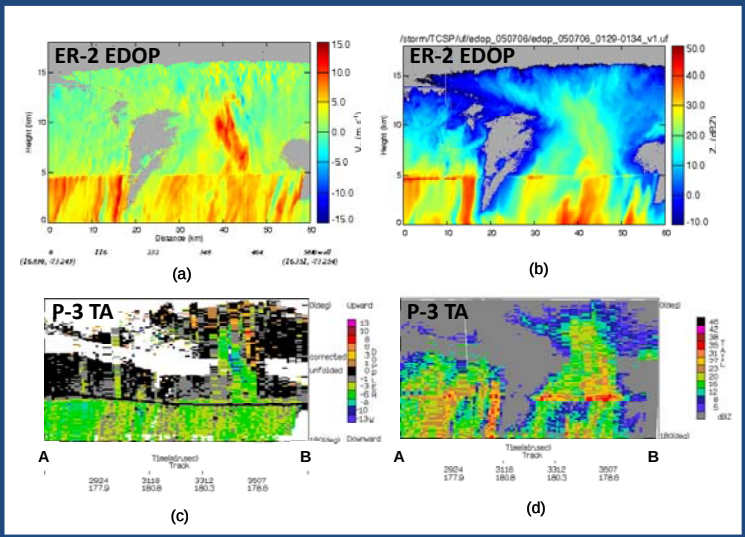




11

Types of Observations - Airborne
Convective Structure

Radar measurements in Hurricane Dennis (2005)



Doppler velocity (m/s)

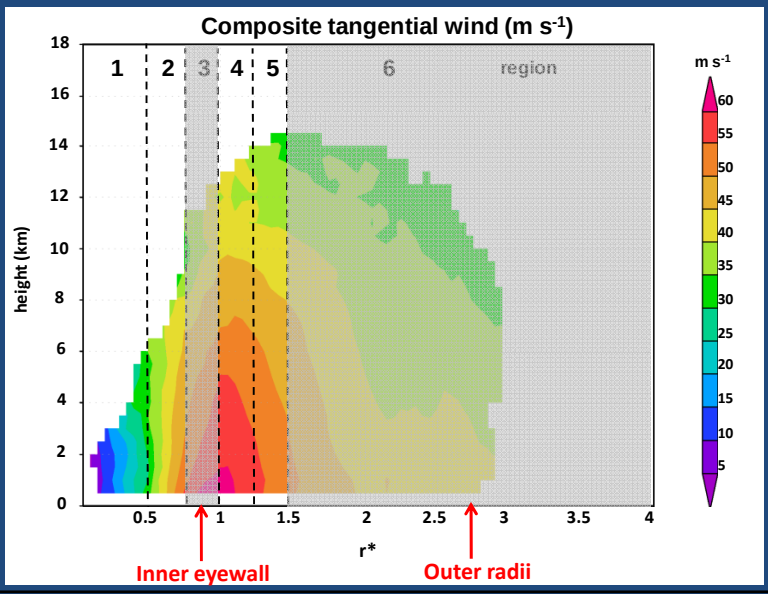
Reflectivity (dBZ)

12

Types of Observations - Airborne

Convective Structure

Partitioning into location relative to RMW

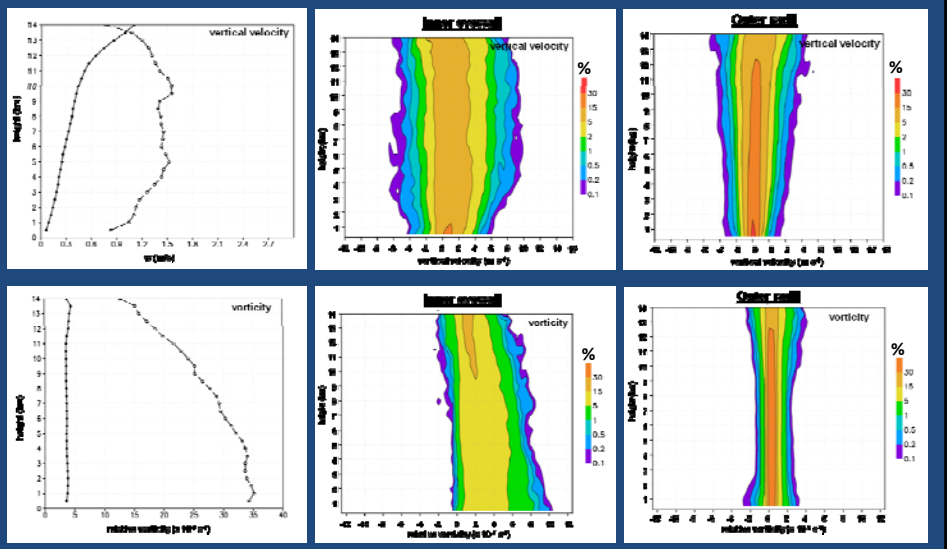


13

Types of Observations - Airborne

Convective Structure

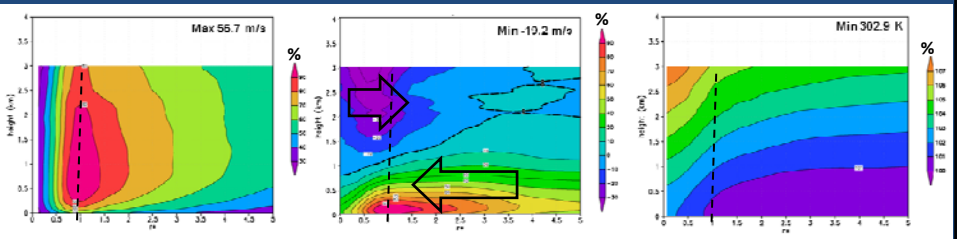
Statistical characteristics (means, CFADs) of convective-scale features



Types of Observations - Airborne
Boundary Layer Structure

Radial variation of mean PBL structures from GPS dropsonde composites

tangential wind | radial wind | virtual potential temperature

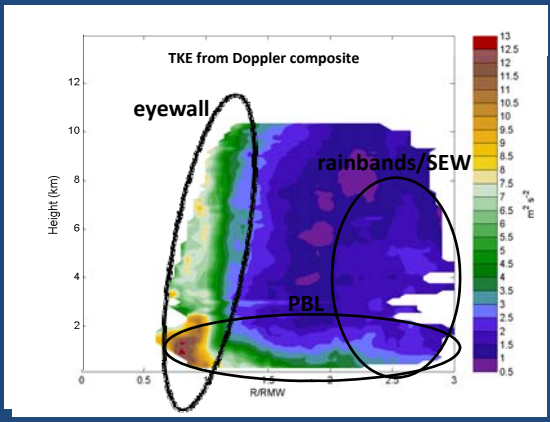


- 794 dropsondes in 13 different storms
- normalized by RMW and peak value within composite

15

Types of Observations - Airborne
Turbulent Structure

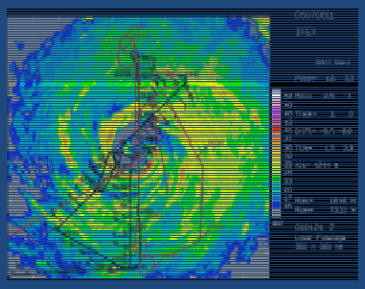
Turbulent kinetic energy inferred from airborne Doppler

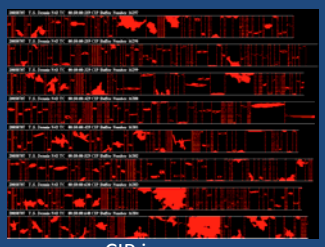


16

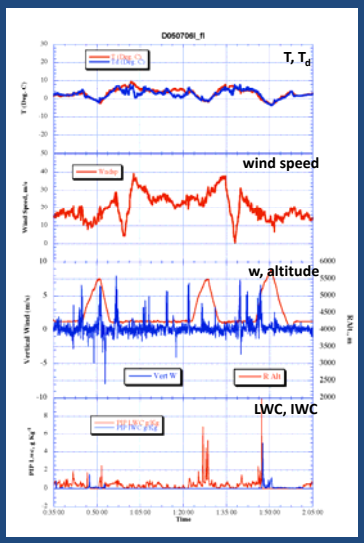
Types of Observations - Airborne
Microphysical Structure

Flight-level parameters during north-south leg on July 6 for Dennis (2005)





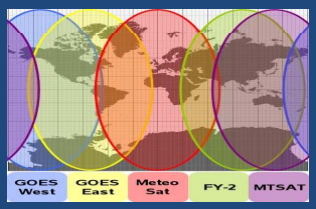
CIP images



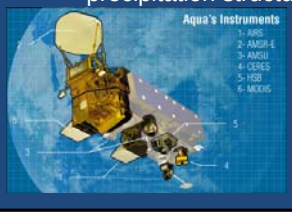
17

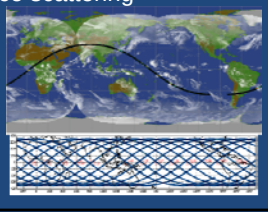
Types of Observations
Spaceborne

- Geostationary
  - visible, infrared, water vapor channels
  - cloud structure, cloud-drift winds

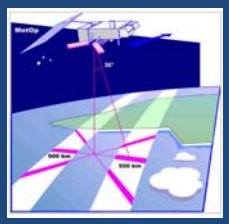


- Polar-orbiting
  - passive microwave channels
  - precipitation structure, ice scattering





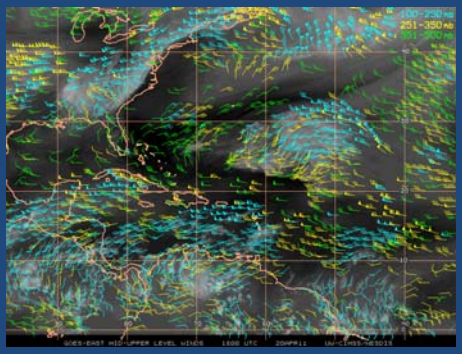
- Polar-orbiting
  - active scatterometer
  - surface wind speed and direction

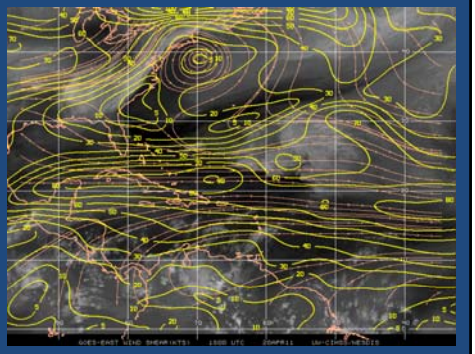


18

Types of Observations - Spaceborne
Environmental structure

Upper-level winds and vertical shear derived from cloud drift winds

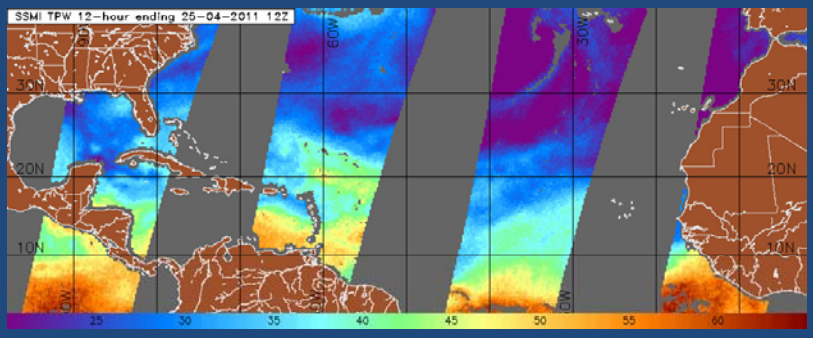




19

Types of Observations - Spaceborne
Environmental structure

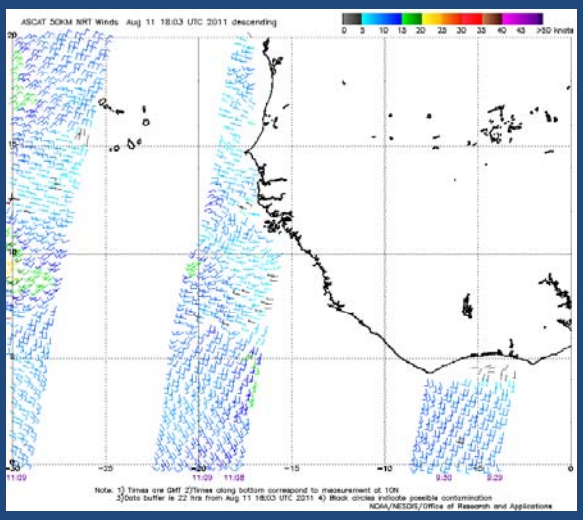
Mosaic of total precipitable water from SSMI polar orbiter



20

Types of Observations - Spaceborne
Environmental and Vortex structure

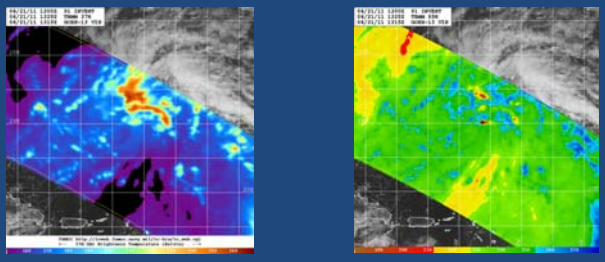
ASCAT surface winds for Invest 93 (1803 UTC August 11, 2011)



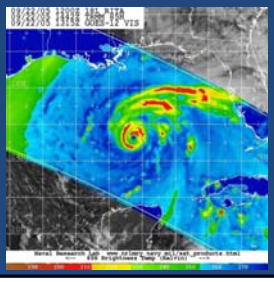
21

Types of Observations - Spaceborne
Vortex and convective structure

37 and 85 GHz microwave brightness temperatures for Invest 91 (2011)



85 GHz microwave brightness temperatures for Rita (2005)

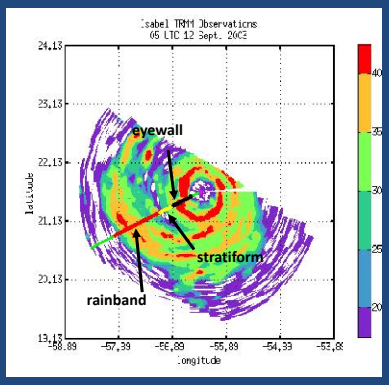


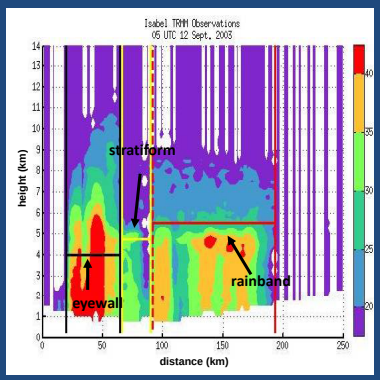
22

Types of Observations - Spaceborne

Vortex and convective structure

Eyewall/rainband/stratiform partitioning from TRMM Precipitation Radar

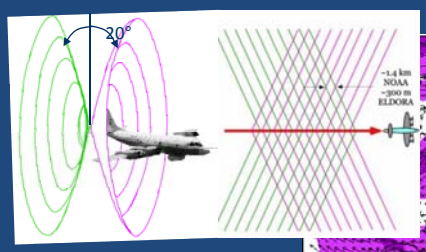


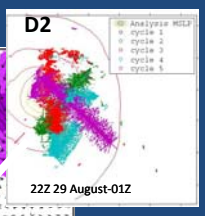


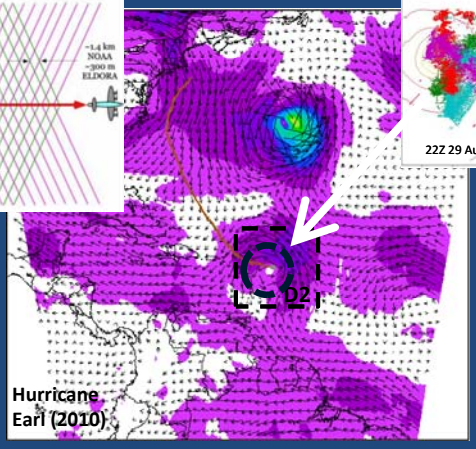
23

Use of Observations – Data assimilation

EnKF data assimilation of inner core observations







Real-time SOs transmitted during P-3 mission and assimilated into HWRFx using HEDAS

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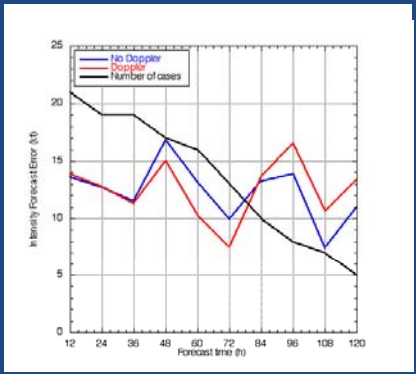
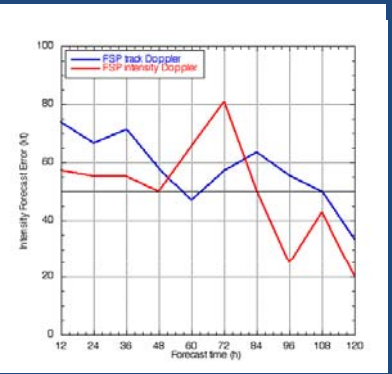
Use of Observations – Data assimilation

Assessing impact of assimilating inner-core observations into HWRF using HEDAS

Intensity error



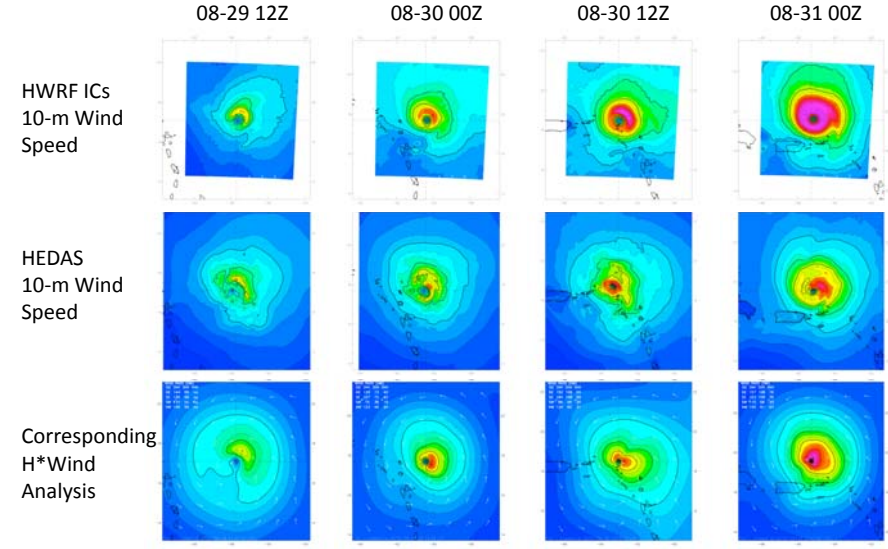
Frequency of superior performance for intensity forecast



25

Use of Observations – Data assimilation

Assessing impact of assimilating inner-core observations into HWRF using HEDAS

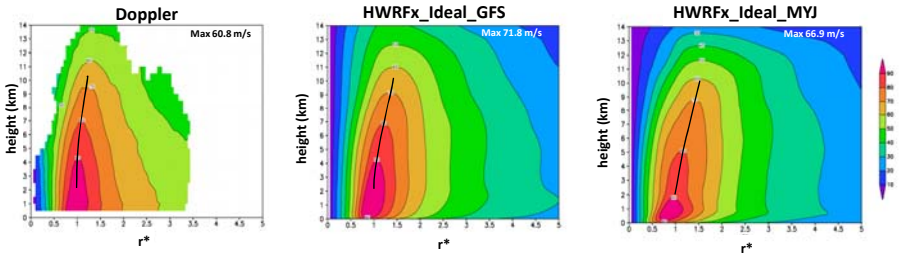


26

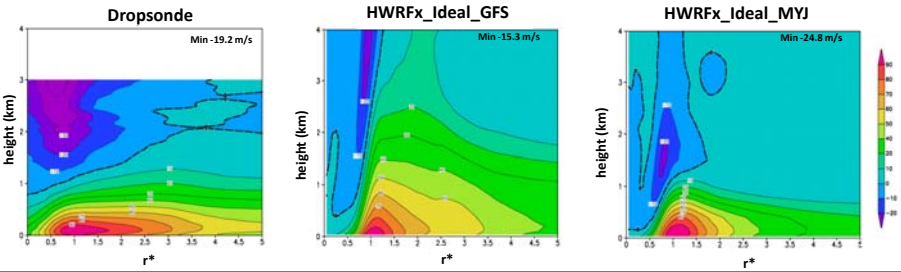
Use of Observations - Model evaluation

Evaluating impact of different PBL parameterizations on HWRF simulations of TC structure

Normalized tangential wind

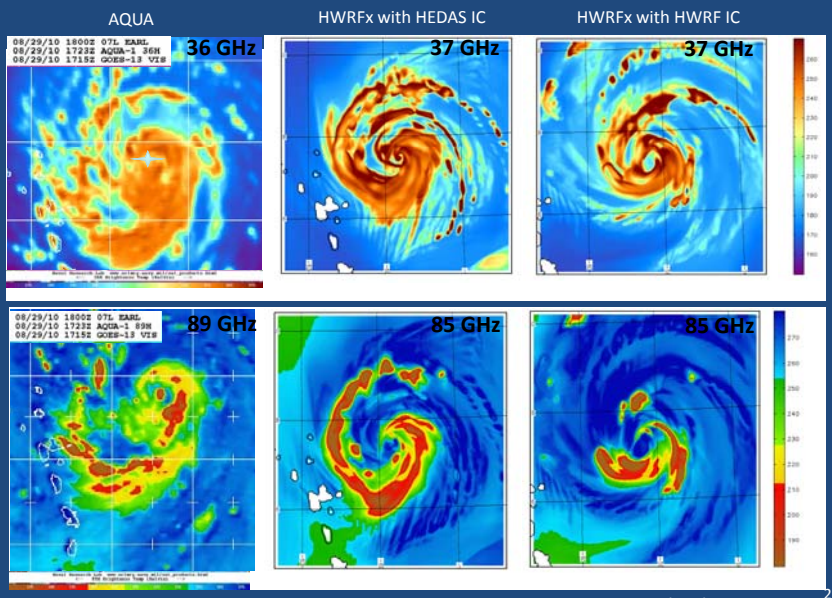


Normalized radial wind in PBL



Use of Observations - Model evaluation

Comparison of observed and forecast images for Earl (2010) from HEDAS and HWRF ICs



Forecast initial time 12:00Z, 08/29/2010

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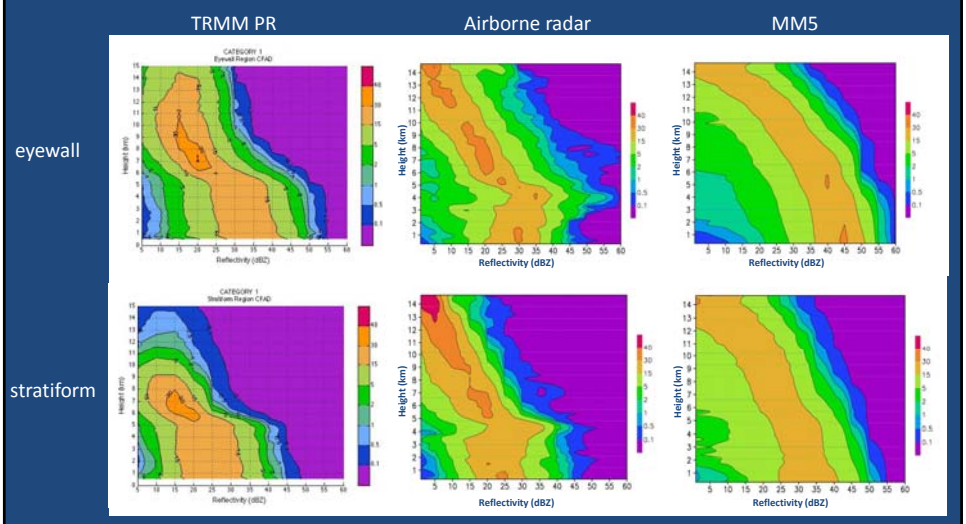
Use of Observations - Model evaluation

CFADs of reflectivity from TRMM, airborne radars and high-resolution models



118 TRMM PR swaths
64 TCs

233 aircraft radial legs
9 TCs

96 output times Δx 1.67 km
2 TCs

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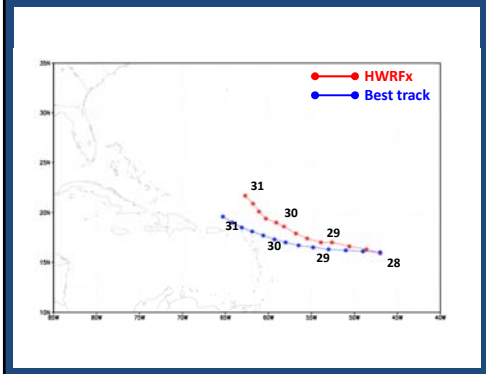
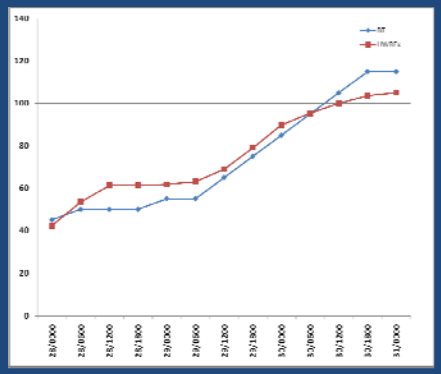
Use of Observations - Model evaluation

Rapid intensification of Hurricane Earl (2010)

Track forecast for HWRFx simulation



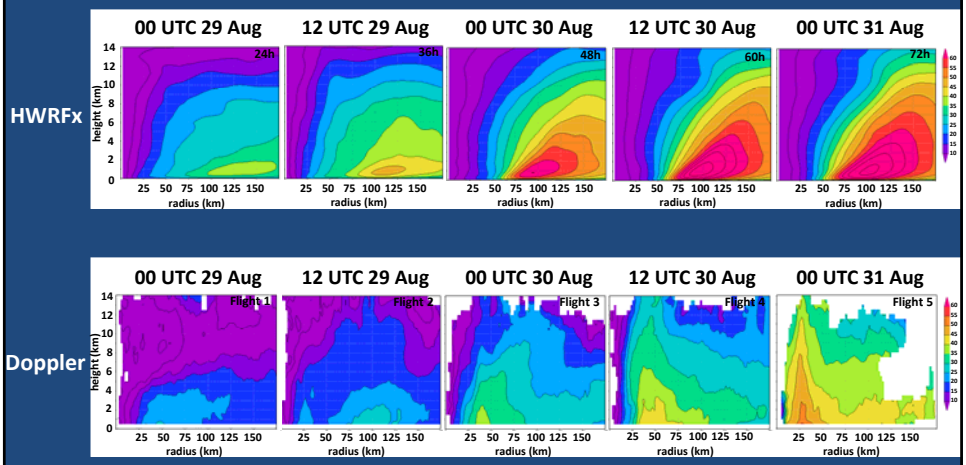
Intensity forecast for HWRFx simulation



Use of Observations - Model evaluation

Rapid intensification of Hurricane Earl (2010)

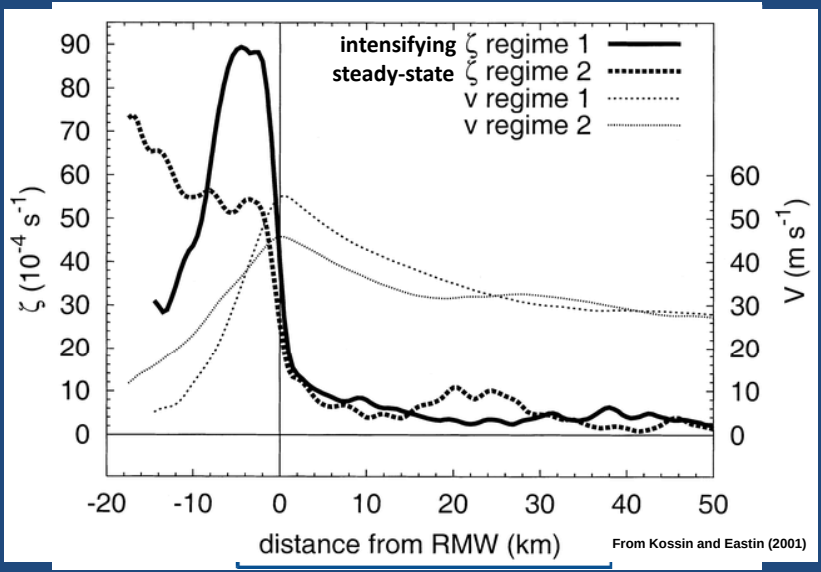
Axisymmetric tangential wind speed (shaded, m/s)



Use of Observations – Hypothesis testing

Symmetric vortex structure for rapidly-intensifying vs. steady state TCs

- Using Doppler composite dataset



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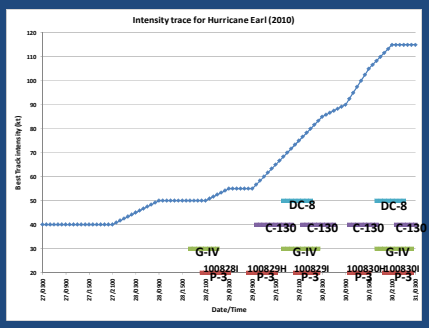
Use of Observations – Hypothesis testing

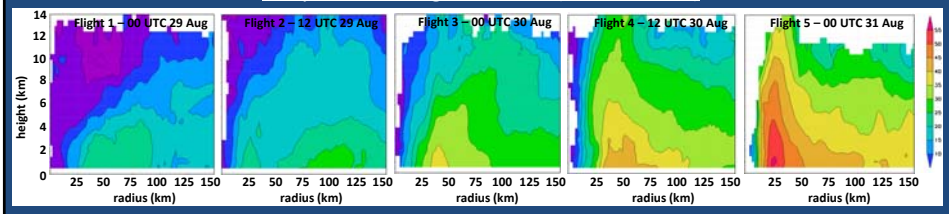
Vortex alignment and Earl's Rapid Intensification

Geographic coverage of P-3 RI flights

Intensity coverage of P-3 RI flights



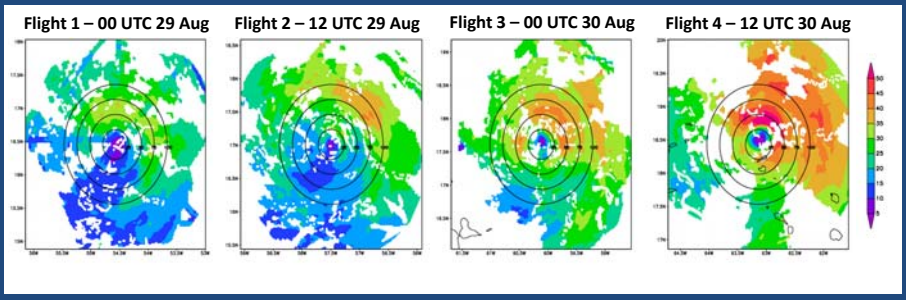
Axisymmetric tangential wind (shaded, m s^{-1})



Use of Observations – Hypothesis testing

Vortex alignment and Earl's Rapid Intensification

Wind speed (m/s) at 2-km altitude



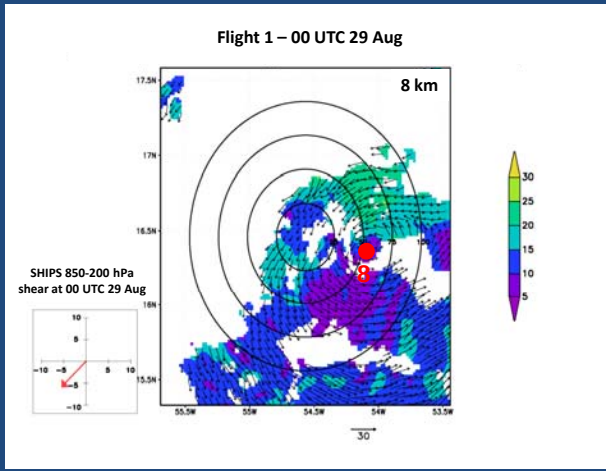
- RI begins during flight 2
- time period of focus is between flight 1 and 2

Use of Observations – Hypothesis testing

Vortex alignment and Earl's Rapid Intensification

Vertical structure of vortex 12 h before onset of RI

Wind speed and vectors (m/s) at 2- and 8-km altitude



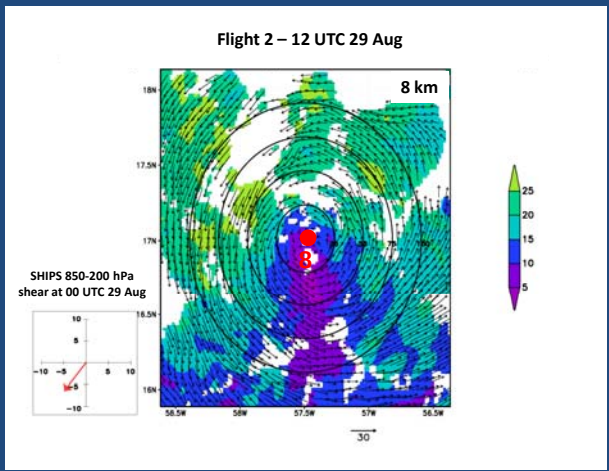
Red dots denote approximate location of circulation center

Use of Observations – Hypothesis testing

Vortex alignment and Earl's Rapid Intensification

Vertical structure of vortex at onset of RI

Wind speed and vectors (m/s) at 2- and 8-km altitude



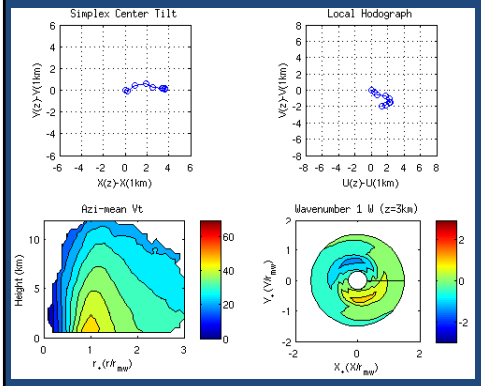
Red dots denote approximate location of circulation center

Use of Observations – Hypothesis testing

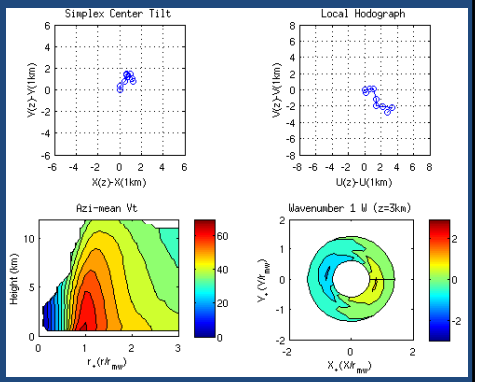
Asymmetric vortex structure in vertical shear as a function of vortex strength

- Using Doppler composite dataset

Weak vortex



Strong vortex



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Summary

- Wealth of observations across multiple scales collected over many years, continue to be collected in real time
- New tools being developed to analyze observations
  - TKE fields
  - Composites of Doppler and dropsonde measurements
- These observations serve a variety of purposes
  - Model evaluation
  - Data assimilation
  - Hypothesis testing
- Partnerships among government, academic institutions needed to help digest and analyze observational data
  - Testbeds (e.g., JHT, DTC, JCSDA)
  - Hurricane Forecast Improvement Project (HFIP)

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Observational databases used in composites

Doppler database

40 radar analyses in 8 different storms

Storm name	Date (mm/dd/yyyy)	Number of analyses	best track intensity (kt)	t+24 h intensity change (kt)
Guillermo	8/2/1997	4	105	25
Fabian	9/3/2003	3	110	0
Isabel	9/12/2003	2	140	0
Isabel	9/13/2003	1	140	0
Isabel	9/14/2003	4	140	-25
Frances	8/30/2004	3	110	15
Frances	8/31/2004	2	125	-5
Frances	9/1/2004	3	120	-5
Ivan	9/7/2004	4	105	15
Katrina	8/28/2005	1	150	-70
Katrina	8/29/2005	3	110	-80
Rita	9/21/2005	3	145	-20
Rita	9/22/2005	3	125	-15
Paloma	11/8/2008	4	125	-100

Rogers et al., MWR, 2011 (in review)

GPS dropsonde database

794 dropsondes in 13 different storms

Storm name	Year	Storm Intensity range (kt)	Number of sondes
Erika	1997	83 – 110	40
Bonnie	1998	68 - 93	76
Georges	1998	66 - 78	39
Mitch	1999	145 - 155	28
Bret	1999	75 - 90	33
Dennis	1999	65 - 70	7
Floyd	1999	80 - 110	40
Fabian	2003	68 - 120	131
Isabel	2003	85 - 140	162
Frances	2004	68 - 83	62
Ivan	2004	65 - 135	123
Dennis	2005	65 - 70	7
Katrina	2005	68 - 100	46

Zhang et al., MWR, 2011 (in press)

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