NASA’S Exploration of Hurricanes
The Genesis and Rapid Intensification
Processes (GRIP) experiment

Ed Zipser, University of Utah, on behalf of
Scott Braun, NASA GSFC, and the GRIP Science Team
(similar to overview talk given at April 2012 AMS Hurricane Conference)

Funded by Dr. Ramesh Kakar, NASA HQ
What did we do during hurricane season 2010?

- NSF/NCAR PREDICT (PRE-Depression Investigation of Cloud Systems of the Tropics)
- NASA GRIP (Genesis and Rapid Intensification Processes)
- NOAA IFEX (Intensity Forecasting Experiment)

GOALS: Remarkably Similar.....*Not a coincidence!*
Mission and Science Overview: Summary of GRIP Science Objectives

- **Genesis:** Role of the larger-scale environment vs. meso-convective processes near the putative developing center. Is genesis predictable?

- **Rapid Intensification:** Relative role of environmental vs. inner core processes? Role of dust, aerosols, Saharan Air Layer? Is RI predictable?

- **Test-bed:** Evaluate candidate technologies for remote sensing from aircraft and from satellites. Wind lidar, high frequency passive microwave, dual-frequency radars, Global Hawk itself.
PREDICT/GRIP/IFEX Domains

Global Hawk
★ (Dryden)

ATLANTIC HURRICANE TRACKING CHART

WB-57

P-3

DC-8

NCAR
G-V

NOAA
P-3
This made all the planning worthwhile! Karl 2010: All Flight tracks (almost) Sept 11-17  Courtesy Scott Braun
GRIP

Global Hawk

55-65 kft, 30 h duration
Instruments: HIWRAP, HAMSR

WB-57: ~65 kft, 6 h duration
Instrument: HIRAD

DC8: Up to 40 kft, 8-10 h duration
DC8 Instruments include LASE, APR2, DAWN, and dropsondes
GRIP Accomplishments

• Major cases
  • Multi-day flights of covering the genesis of Karl, Matthew, and non re-genesis of Gaston
  • DC-8 flights for RI of Earl (from Cat1 to Cat4)
  • DC-8 & GH flights of RI of Karl (from Cat1 to Cat3)

• Technical Achievements
  • First GH flight over a hurricane
  • 20 GH eye crossings in one flight over Karl
Hurricane Karl Flights

Genesis Stage
DC-8 on Sept. 12-14
Global Hawk on Sept. 12

Rapid Intensification Stage
September 16
DC-8 (yellow), WB-57 (orange), Global Hawk (red), NOAA P-3 (black), NOAA G-IV (green)

September 17 (Karl’s Landfall)
DC-8 over ocean/land; WB-57 offshore
Karl’s Genesis

(see Jon Zawislak’s talk and poster, and several other talks, for details)

- Gradual intensification to TS
- Lightning primarily on NE side
- Rainfall episodic until increase late on Sept. 15

Upper panel:
Dropsonde wind barbs @ 600 hPa
Lightning flash locations:
  Blue: Sept. 12
  Green: Sept. 13
  Red: Sept. 14

Lower panel:
Dropsonde wind barbs @ 925 hPa
Matthew’s Genesis

- Gradual intensification to TS
- Lightning primarily west of disturbance
- Rainfall: Significant bursts on Sept 22 and 24

Upper panel:
Dropsonde wind barbs @ 600 hPa
Lightning flash locations:
  - Cyan: Sept 20
  - Violet: Sept 21
  - Blue: Sept. 22
  - Green: Sept. 23
  - Red: Sept. 24

Lower panel:
Dropsonde wind barbs @ 925 hPa
HIWRAP View of Intensification

3-km Wind Speed from HIWRAP

[Graph showing wind speed patterns with color bars and time intervals]
Warm anomaly propagated to lower levels as the storm intensified with the peak warm anomaly increasing by \(~2-3\)C

Decreasing RH in upper troposphere while air below the inversion layer remained near saturation

Courtesy of S. Brown, B. Lambrigtsen, JPL
Hurricane Earl Flights

Rapid Intensification Stage
DC-8 on August 29-30

Aug 29:
Cat1-Cat2

Aug 30:
Cat3-Cat4

Mature Stage
September 1: DC-8 (orange) and WB-57 (yellow)
September 2: DC-8 (red) and Global Hawk (black)
Background: AIRS 700-600 Relative Humidity, AMSR-E precipitation structure
The Interaction of Earl With the SAL

Valid: Thu 00z 2010–08–26 (τ= 0)
TS Earl just prior to rapid intensification

Pre-Fiona

Cat 1 Danielle

Valid: Sun 12z 2010-08-29 (τ=0)
Interaction of Earl with the SAL

- GFS 700 hPa storm-relative streamlines suggest **slow** pathway for dry SAL air to get into Earl (too slow to have effect?)

- Dust and low RH observed in near environment of Earl

- Dry tongue of air in LASE data between SAL layers—suggests non-SAL source of dry air
Microphysical Impacts of Dust?

- Microphysical impact of dust should be seen in CDP data as high concentration of small (3-10 microns) drops
- Shown here is one of the 5 passes during an east-to-west (left-to-right in figure) pass
- But bottom line: There is much work that we GRIP PIs need to get together and accomplish to extract the best information from these outstanding missions.

(see pointed finger)

Red dashed line: $\theta$-320K
Blue dotted line: LWC*100
Potential Opportunities for in situ microphysics data from the NASA DC-8, coincident with NOAA P-3 radar coverage and data from other aircraft

Karl, Sept. 16: Beginning rapid intensification
  DC-8: SW-NE through the eye, 2020 – 2038 (all times UTC)
  NOAA 42: W-E through the eye, 2020 – 2100

Earl, Sept. 02: Strong but weakening, possible double eyewall
  DC-8: NE-SW through the eye, 2132-2200
  NOAA 43: SW-NE through the eye, 2139-2220

Earl, Aug 30: Rapidly intensifying
  DC-8: N-S through the eye, 2113-2132; E-W through the eye, 2156-2218
  NOAA 43: SE-NW through the eye, 2100-2140; SW-NE through the eye, 2200-2250

Earl, Aug 29: Beginning rapid intensification
  DC-8: N-S through the eye, 2055-2114
  NOAA 43: SE-NW through the eye, 2040-2120
Microphysics/dynamics interactions: Why do we care?

• Retrievals require knowledge of particle phase, habit, density, size distribution
• Evolution of convection depends to first order on the difference between particle fall speed and updraft speed
• To know particle fall speed: (See first bullet!)
Short and very incomplete list of interesting unanswered questions

- If aerosols are suspected in the eye or eyewall of Earl, what is the pathway for them to reach DC-8 altitudes? Do they somehow survive passage through the rain area outside the eyewall? Are they products of evaporation in the mid-upper troposphere?

- High concentrations of cloud droplets in the 3-10 micrometer range are observed on occasion by the DC-8 microphysics package at temperatures of -30 to -40 C in the eyewall. What is the pathway for their appearance in this location? If they first form in the low troposphere, how do they avoid growing to larger drops?

- (Add several dozen others here – see next 2 days of talks!)

- We have much to look forward to! Let’s get to it.
Summary of GRIP

• The GH was demonstrated to be a unique and valuable tool for long-duration, high-altitude observations of the hurricane inner core

• GRIP will provide valuable information on the formation and rapid intensification of hurricanes

• The 2010 season included three storms that underwent rapid intensification while surrounded by, or adjacent to, dusty Saharan air
Upper Warm Core Intensification and Clear-Eye Formation

- HAMSR data monitored warm core intensification

- 7-km warming steadily increasing with drop in SLP

- 12-km warming increases suddenly after formation of clear eye in IR
Eastern Eyewall Cross Sections During Repeated Passes on Aug 30
Coordination of NASA and NOAA aircraft in Hurricane Karl
A new record: 6 aircraft simultaneously

NASA: DC8, WB57, GH
NOAA: P3, G-IV
Air Force: C130
HIRAD Measurements in Karl

- HIRAD measures surface wind & rain—similar to SFMR, but with cross-track scanning
- HIRAD captures the key structures of the eyewall and rainbands
- Will fly on the GH during the Hurricane and Severe Storm Sentinel (HS3) EV-1 project
Radar Structure in TS Matthew

- NCEP storm-relative 700 hPa streamlines, AMSR-E rainfall show strong asymmetry of precipitation on SW side

- HIWRAP cross sections of radar reflectivity
• Microphysical impact of dust should be seen in CDP data as high concentration of small (3-10 microns) drops

• 3 of 4 passes on 9/1 and 4 of 5 on 9/2 do show enhanced concentrations of small drops

• Shown here is one of the passes with enhanced drops during an west-to-east (left-to-right in figure) pass

• Eastern eyewall echo only at upper levels, and has very large concentration of small drops, 5 m/s vertical velocity

Red dashed line: $\theta$-320K
Blue dotted line: LWC*100
Earl Flights—September 1 & 2

- Earl underwent eyewall replacement cycle on Aug 31 and weakened

- Earl reintensified Sept 1, then weakened Sept 2 due to increasing westerly shear

- LASE cross sections show plentiful dust on western side of storm on both Sept 1 and 2
Tilt of the Hurricane Eyewall
(courtesy JPL’s APR-2 team)

Modest vertical wind shear (NNW @ 6 m s⁻¹) produces southward tilt of Cat 4 hurricane

Radar reflectivity (dBZ)

Estimated vertical velocity (m s⁻¹)
Tilt of the Hurricane Eyewall

Shear (NNW @ 6 m s\(^{-1}\)) produces little tilt in E-W direction

Radar reflectivity (dBZ)

Estimated vertical velocity (m s\(^{-1}\))