An Overview of the Tropical Cyclone Data Assimilation Activities at NOAA’s Hurricane Research Division

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7th Ensemble Kalman Filter Workshop – State College, PA
Hurricane Observing Platforms: NOAA P-3 and G-IV

The NOAA P-3 Typical Instrumentation

- Gust Probe
- In-situ Sensors
- Tail Doppler Radar
- Lower Fuselage Radar
- Stepped Frequency Microwave Radiometer
- Doppler Wind Lidar
- Dropsonde + Upper Ocean Sensors

Typical Purpose: Eye penetrations to observe the inner core structure
The NOAA G-IV Typical Instrumentation

Typical Purpose: Synoptic surveillance and hurricane outer structure

- Tail Doppler Radar
- In-situ Sensors
- Dropsonde
**Hurricane Observing Platforms: UAS – Coyote**

The NOAA P-3 Aircraft Typically Penetrates Tropical Cyclones and Collects Data with a Suite of Instruments.

The Dropsonde System is Designed to Measure the Vertical Variations in the Atmosphere.

The Coyote is a Small Aircraft that Uses the Dropsonde Deployment System and Sensor Suite and is Capable of Remaining Airborne for ~1 h or Longer.
Hurricane Observing Platforms: UAS – Global Hawk

- Flight Level: ~55-63,000 ft
- Duration: ~26 hr
- Range: 11,000 nm
- Payload: 1,500+ lbs
- Deployment Sites:
  - NASA Wallops Flight Facility (Wallops Island, VA)
  - NASA Armstrong Flight Research Center (Edwards AFB)

Courtesy: Gary Wick (NOAA)
Hurricane Observing Platforms: UAS – Global Hawk

**Environment Observations**
- Profiles of temperature, humidity, wind, and pressure (AVAPS - Dropsonde)
- Cloud top height (CPL)
- Cloud top temperature and profiles of temperature and humidity (S-HIS)

**Over-storm Observations**
- Doppler velocity, horizontal winds, and ocean surface winds (HIWRAP)
- Profiles of temperature and humidity and total precipitable water (HAMSR)
- Ocean surface winds and rain (HIRAD)

NOAA SHOUT Program Instrumentation: Dropsonde, HIWRAP, HAMSR

Courtesy: Gary Wick (NOAA)
Hurricane Observing Platforms: Satellites (CYGNSS)

- The CYclone Global Navigation Satellite System is a constellation of 8 micro-satellites scheduled for launch in late October 2016... a NASA Earth Venture Mission (Ruf et al. 2016)
- Utilizes signals from existing GPS satellites to retrieve ocean surface wind speed... surface roughness (mean square slope) affects forward-scattered signal

Receives GPS L-band signals at 19-cm wavelength | Low-Earth orbit covers 35S-35N | 25-km spatial resolution | Retrieved wind speed dynamic range 0-70 m/s | Median/mean revisit time is 2.8 h / 7.2 h

A hurricane over the western Atlantic Ocean is well-sampled in this simulation of orbits during a 6-hour time window. (Colors indicate wind speed.)

Basic geometry of bi-static quasi-specular scatterometry.
Hurricane Ensemble Data Assimilation System (HEDAS)
NOAA/AOML/HRD’s Vortex-Scale Data Assimilation System

HEDAS Characteristics
- Focus on tropical cyclone inner-core data assimilation for high-resolution vortex initialization
- Uses the ensemble square-root Kalman filter (Whitaker and Hamill 2002)
- Storm-relative observation processing capability (Aksoy 2013)
- Interfaced with NOAA’s HWRF model
- Deterministic HWRF forecasts initialized with the HEDAS mean vortex analysis

Aircraft/Platforms Processed:
- NOAA P-3
- NOAA G-IV
- Air Force Reserve C-130
- NASA Global Hawk
- Coyote
- Satellite AMVs
- AIRS & GPS-RO Retrievals

HEDAS Schematic
- Ensemble Spin-up
- DA Cycling With EnSRF
- Deterministic HWRF Forecast
- Ensemble Initialization from t-6h GFS-EnKF
- Real-time Observation Pre-Processing
- Mean of Final Analyses Valid at t
Storm-Relative Observation Processing

Assuming a Steady-State Tropical Cyclone:
- Allows observations to be randomly assigned to any number of DA cycles
- Provides homogeneous observation coverage in all DA cycles
- Allows for frequent “sub-cycling” to obtain a vortex-scale analysis with better balance
Where Are We Lacking Observations?
Example: All HEDAS Cases in 2013

Wind Observations

Observation Density: Azimuthally Averaged within 500-m Height x 25-km Radius Boxes
(Number of Cases: Upper Right in Parentheses)
Ongoing Projects: Global Hawk Dropsonde - HEDAS

Hurricane Edouard (2014) Sep. 15 vs 16 Case Study

All Edouard Missions

0000UTC September 15, 2014

GH: Main source of inner-core obs.

1800UTC September 16, 2014

GH: Competes w/other aircraft in inner core

With GH

No GH

Diff

0000UTC September 15, 2014

1800UTC September 16, 2014

Positive Impact on Track Forecast

Positive Impact on Intensity Forecast

Courtesy: Hui Christophersen (HRD)
Ongoing Projects: Global Hawk T/Q vs AIRS - HEDAS

Hurricane Edouard (2014) Sep. 12 Case Study

SHIS Assimilation Verifies Well Against Dropsondes

GH & AIRS Had the Complimentary Impact on Frst Quality

Consider Sat in GH Track Design?

Availability of High-Res SHIS Thermo Obs. Competed with GH+AIRS

Forecast Errors

Forecast lead time (hour)

Forecast Errors

Forecast lead time (hour)

GH & AIRS Had the Complimentary Impact on Frst Quality

Consider Sat in GH Track Design?

Availability of High-Res SHIS Thermo Obs. Competed with GH+AIRS

Courtesy: Hui Christophersen (HRD)
Ongoing Projects: Impact of Coyote Observations

16 September 2014 1432Z: First of Only Two Successful Missions of Coyote
Eye/Eyewall Sampling | 28-minute Mission | Min. Altitude 896 m | Max. Wind Speed 100 kt

- Edouard Best-Track Intensity and Aircraft Missions
- Ocean surveys
- Coyote deployments

- Observed Variable
- Observed-Analysis Difference

- Edouard Wind and Temperature Difference

- Track (km)
- Min. Pressure (mb)
- Intensity (kt)

- Mean Error

- Impact from Coyote
Ongoing Projects: Impact Doppler Wind Lidar

Lidar Data Had Significant Impact on Wind and Thermodynamic Analysis of the Vortex Structure

Courtesy: Lisa Bucci (HRD)
HRD’s Hurricane OSSE Framework

• **Nature Runs**
  - **Global**: ECMWF: low-resolution (~40 km) “Joint OSSE Nature Run”
  - **Regional (North Atlantic)**: WRF-ARW: high-resolution (27 km) regional domain, 9/3/1-km nests (v3.2.1)

• **Data Assimilation Scheme**
  - **GSI**: Gridpoint Statistical Interpolation... standard 3D variational assimilation scheme (v3.3). Analyses performed on 9-km grid.

• **Forecast Model**
  - **HWRF**: the 2014 ‘operational’ Hurricane-WRF model (v3.5). Parent domain has 9-km resolution, single storm-following nest has 3-km resolution.

Courtesy: Brian McNoldy & Bachir Annane (U. Miami)
Ongoing Projects: Impact of CYGNSS Wind Speed

Control
51.6 kts, 986.62 mb

Control + CYGNSS
77.1 kts, 987.7 mb

Nature
79.1KTS, 968.9 MB

PEAK 10m WIND SPEED

MINIMUM CENTRAL PRESSURE

RADIUS OF MAXIMUM WIND

AVE WIND SPEED AT RMW

AVE RADIUS OF 34kt WIND

AVE RADIUS OF 50kt WIND

 Courtesy: Brian McNoldy & Bachir Annane (U. Miami)
Ongoing Projects: Canonical Correlation Vectors

Satellites have good spatial and temporal coverage but remain underutilized in data assimilation especially in cloudy areas. Satellites make up around 90% of the available observations but currently more than 75% are thrown away due to issues with “cloud contamination.”

As part of the HFIP, JPL/UCLA collaborates with HRD to implement a novel observation operator based on the statistical extraction of maximally certain information from satellite observations. This information is especially amenable to data assimilation. This is potentially a way to recover massive amounts of useful data for hurricane DA.

Below: the CCV obs/model vectors.

Above: CCV Observations of Earl during eyewall replacement from TRMM/TMI, giving uncorrelated “views” of the storm. only the first 3 have a high enough $R^2$ enough to warrant inclusion.

Right: Track before and after DA with these observations v/ best track (left: no obs). More testing is needed.

Please See Jeff Steward’s Poster

Courtesy: Jeff Steward (NASA/JPL)
Thank You!

For HRD data, please visit:
http://www.aoml.noaa.gov/hrd/data_sub/hurr.html

Flying in a Hurricane -- Hurricane Patricia 23 Oct 2015 NOAA P-3 Flight
(Experienced ~2000 ft / 650 m drop flying through the eye)
Ongoing Projects

OSEs
- Tail Doppler Radar
- Doppler Wind Lidar
- Coyote
- Global Hawk Dropsondes
- Global Hawk S-HIS
- Atmospheric Motion Vectors
- AIRS Retrievals

OSSEs
- G-IV Dropsonde Impact
- Coyote Impact
- Global Hawk Impact
- CYGNSS

New/Improved DA Methods
- Parallel EnKF Methods
- Canonical Correlation Vectors
- EnKF Optimization for New Datasets
- Background QC Methods