Ensemble-based Data Assimilation for Tropical Cyclones: Current Status and Future Prospects

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University at Albany, SUNY

Frontiers in Ensemble Data Assimilation Workshop
5 August 2015
Boulder, CO
Outline

• Tropical Cyclone Overview
• Unique TC Observations
• Challenges with TCs
• Future prospects
TC Intensity Errors

NHC Official Intensity Error Trend
Atlantic Basin

Forecast error (kt)

Year

National Hurricane Center
Intensity Factors

TC Environment

Surface Boundary

Internal Processes

Courtesy National Hurricane Center
TC Observations

• One hypothesis for how to improve TC intensity forecasts is to assimilate more observations in their vicinity

• TCs have some unique datasets
  – TC “Vitals”
  – Aircraft Data
  – Satellite-derived wind vectors
TC “Vitals”

Hurricane Isaac (2012)

NHC 09L ISAAC 20120828 1200 278N 0882W 305 031 0976 1012 0556 31
Position Assimilation

a) Center positions, $\sigma_f = 20$ km

b) Ens. mean vort. incr. ($10^{-4}$s$^{-1}$)

c) Center positions, $\sigma_f = 80$ km

d) Ens. mean vort. incr. ($10^{-4}$s$^{-1}$)

MSLP Assimilation

Chen and Snyder (2007) MWR
HURRICANE SANDY FORECAST/ADVISORY NUMBER 17
NWS NATIONAL HURRICANE CENTER MIAMI FL AL182012
1500 UTC FRI OCT 26 2012

CHANGES IN WATCHES AND WARNINGS WITH THIS ADVISORY...

THE GOVERNMENT OF THE BAHAMAS HAS DISCONTINUED THE TROPICAL STORM WARNING FOR THE CENTRAL BAHAMAS...AND REPLACED THE HURRICANE WARNING WITH A TROPICAL STORM WARNING FOR THE NORTHWEST BAHAMAS EXCEPT FOR GREAT ABACO AND GRAND BAHAMA ISLANDS.

THE TROPICAL STORM WATCH FOR THE FLORIDA KEYS SOUTH OF OCEAN REEF TO CRAIG KEY AND FOR FLORIDA BAY HAS BEEN DISCONTINUED.

HURRICANE CENTER LOCATED NEAR 26.7N 76.9W AT 26/1500Z
POSITION ACCURATE WITHIN 25 NM

PRESENT MOVEMENT TOWARD THE NORTH OR 360 DEGREES AT 5 KT
Aircraft Platforms

- Flight-level wind, temperature, moisture
- Dropsondes
- Tail-mounted Doppler Radar
- Stepped-Frequency Microwave Radiometer (SFMR; P3)

- Flight-level wind, temperature, moisture
- Dropsondes
- Stepped-Frequency Microwave Radiometer (SFMR)
Hurricane Sandy
0000 UTC 28 October 2012
Radar Assimilation

• Dropsonde and flight-level data assimilation is fairly straightforward to assimilate and is more complete.

• Radar velocity assimilation considered potentially more valuable due to greater spatial coverage.
Zhang et al. (2009) MWR
Figure 1: Time series of sea surface temperature (SST) anomalies (°C) for different sections of the Pacific Ocean. The sections are labeled (a) 1401-1441, (b) 1513-1553, (c) 1558-1638, (d) 1658-1738, (e) 1827-1907, and (f) 1940-2040. The anomalies are compared against the SFMR, NoDA, Prior, and Post models.

Wang and Zhang (2012), MWR
Comprehensive Recon. Tests

101 cases over 5 different seasons
3 Different groups, two different models
- NCEP Environmental Modeling Center (HW*)
- Penn State University (AP*)
- NOAA Hurricane Research Division (HE*)

Nance et al. (2013) Report

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Nance et al. (2013) Report
Atmospheric Motion Vectors

Wu et al. (2014), MWR
Challenges

- TC data assimilation has a number of challenges, some of which are unique to the application
  - Modes of variability
  - Impact of sampling errors
  - Representativeness
  - Variable observation densities
  - Model biases
  - Domain sizes
Tropical Cyclone Variability

Torn & Hakim (2009), MWR
Storm-centered Assimilation

Regression Between TC sea-level pressure and 950 hPa wind

u-wind

v-wind
Storm-relative Obs.

Aksoy (2013) MWR
Covariances

Temperature

Mixing Ratio

U-Wind
Poterjoy et al. (2014), MWR

Poterjoy and Zhang (2011), MWR
Representativeness

Hence & Houze (2008), MWR

Hurricane Hugo (1989)

Marks et al. (2008)
Observation Variability

1800 UTC 10 September 2010
Observation Variability

Observation Distribution valid 2010091100

eta = 0.926 U inflation

0000 UTC 11 September 2010
Model Biases

Vucevick et al. (2013), MWR
New Directions

- Most of the above issues can be addressed with more development & computing
- New observation platforms are becoming available that will provide better coverage
- New methods of determining where to direct scarce observation resources
Unmanned Vehicles

NASA Global Hawk
- Has similar observation capability to manned aircraft (including radar)
- Long duration flights (> 20 h)
- Used in Hurricane Sentinel (HS3) project
HIWRAP Assimilation

Sippel et al. (2013) and Sippel et al. (2014), MWR
Satellite Data
SHOUT

Possible Modified AV-6 Flight Pattern with approaching trough to the west

Extra Drops

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Dropsonde impact at 2014091312 (F024)

- 25N
- 20N
- 15N
- 10N
- 5N
- 0N
- 5S
- 10S
- 15S
- 20S
- 25S

- 45W
- 50W
- 55W
- 60W

Colors represent different wind speeds:
- < 3
- 5 <= x < 8
- 10 <= x < 15
- 23 <= x < 30
- > 40
- 3 <= x < 5
- 8 <= x < 10
- 15 <= x < 23
- 30 <= x < 40

SHOUT TECHNOLOGY

SENSING HAZARDS WITH OPERATIONAL UNMANNED
Summary

• Greatest challenges in TC data assimilation due to multi-scale nature
  – Needs more intelligent methods of dealing with sampling errors
  – Must remove position variability
• Aircraft data is useful for assimilation, but impact has been limited. Likely that UAVs will provide better coverage in next 10-20 years
• Satellites hold promise to provide frequent coverage, but forward operators are problem
• Biggest improvement to assimilation likely to come from model itself. DA systems are too stressed by bias and representativeness problems
• Need to focus forecast metrics away from wind
  – Storm surge & Precipitation