Real-time Cloud-Permitting Hurricane Prediction with Assimilation of Inner-core Airborne Doppler Observations

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10-m surface wind forecast for Superstorm Sandy
Assimilate Airborne Doppler Winds with WRF-EnKF

Available for 20+ years but never used in operational models due to the lack of resolution and/or the lack of efficient data assimilation methods

Superobservations: 1. Separate forward and backward scans; 2. treat every 3 adjacent full scans as one fixed-space radar (translation<5km); 3. thinning ---one bin for 2 km in radial distance and 3 degree in scanning angle; 4. use medium as SO after additional QC checking

These SOs are generated on flight of NOAA P3’s; transmitted to ground in real-time

WRF-EnKF: 3 domains (40.5, 13.5&4.5km), 60-member ensemble

(Weng and Zhang 2012 MWR)
WRF-EnKF Performance with Airborne Vr for 2008-2010

(Zhang et al. 2011 GRL)
WRF-EnKF Performance Assimilating Airborne Vr
Mean absolute track (km) & intensity (kts) error for all 2008-2010 P3 missions

\[ WSP(t) = WSP(t) - \left( \frac{36h - t}{36h} \times Bias(6h) \right) \]

(Zhang et al. 2011 GRL)
PSU WRF-EnKF HFIP Stream1.5 Model and Filter Configurations for 2012

- WRF V3.3.1
- YSU PBL
- Monin-Obukov Surface Layer
- PSU Cd (Green & Zhang 2012)
- Garret Ck

- EnKF: 60 members
- Radius of Influence: SCL
- Covariance relaxation: 0.6

ICs & BCs: GFS analysis and its forecasts

Key differences from 2011: high resolution (4.5 → 3km), more vertical levels (30 → 43), surface flux (PSU Cd, Garret Ck)
Improvement of Wind-Pressure Relationship 2008-11 from 2011 to 2012 PSU WRF-EnKF Stream1.5 system
WRF-EnKF Performance Assimilating Airborne Vr
Mean track (km) & intensity (kts) error for all 93 P3 missions over 2008-2012

Abs Error of position (km) for 2008–2012

No-Bias Error of maxWSP (kts) for 2008–2012

OFCL
HWRF
GFDL
APSU
PSU WRF-EnKF Performance for Superstorm Sandy
60-member 3-km cloud-resolving ensemble analysis forecast from 00Z Oct 26
PSU WRF-EnKF Performance for Superstorm Sandy

EnKF analysis vs. independent observations from SFMR and flight-level obs
PSU WRF-EnKF Performance for Superstorm Sandy

EnKF analysis vs. independent observations from SFMR and flight-level obs

SFMR wind speed (m/s)

Flight-level q (k/kg)
PSU WRF-EnKF Performance for Superstorm Sandy

10-m maximum wind swath from the 3-km deterministic forecast
PSU WRF-EnKF Performance for Superstorm Sandy
60-member 3-km cloud-resolving ensemble analysis forecast from 00Z Oct 26

TS (>32kts) and Hurricane (>64kts) Strength Wind Probability
PSU WRF-EnKF Performance for Superstorm Sandy
60-member 3-km cloud-resolving ensemble analysis forecast from 00Z Oct 26

Forecasted Probability of 96h accumulated rainfall >25&100mm
PSU WRF-EnKF Performance for Superstorm Sandy

108-h 3-km cloud-resolving deterministic precipitation forecast from 00Z Oct 26

HPC Observation 12Z/26-30 Oct

PSU WRF-EnKF deterministic forecast
PSU WRF-EnKF Performance for Irene (2011)
3-km cloud-resolving deterministic hindcast of precipitation from 00Z Aug 24

120h accumulated rainfall observation  PSU WRF-EnKF 120h deterministic forecast
Concluding Remarks

• Hurricane intensity forecast can be greatly improved through using advanced DA techniques and a cloud resolving NWP model with assimilation of high-resolution inner-core observations

• Average over nearly 100 NOAA P3 Doppler missions, the PSU WRF-EnKF forecasts with assimilation of $V_r$ has the day 1 to 5 mean intensity forecast error 20-40% smaller than NHC official forecasts

• The PSU WRF-EnKF experimental system performed well for all landfalling hurricanes during 2008-2012. It also shows great promise in predicting hurricane-induced rainfalls, as well as uncertainties

• Future of hurricane prediction: better inner-core observations, better data assimilation, better forecast model, better computing resources
Our Ongoing EnKF Efforts not to be Reported Today

• Assimilation of satellite observations for hurricane prediction (satellite derived inner-core wind, cloudy radiance, GPS RO, etc.) (Jerry Zhang)

• Assimilation of Global Hawk observations: HAMSR, HIRAS, etc. (Scott Sieron)

• Fully cycled realtime WRF-EnKF hurricane prediction system for NOAA/HFIP in 2013 (Yonghui Weng)

• Multiscale regional ensemble reanalysis of radar and other observations of MJOS during DYNAMO (Michael Ying)

• Multiscale regional reanalysis for the Arctic and Tibetan Plateau regions (Hans Chen)

• Development of COAMPS-based EnKF system towards eventually for the fully coupled system that includes the ocean (Chris Melhauser)

• Development of CMA GRAPES-based EnKF system (Jidong Gao)

• Development of an WRF-EnKF based storm scale analysis and forecast system for China FAA (CAAC) for aviation safety (Aimin Liang)

• EnKF storm-scale verification (Dan Stern) and ensemble sensitivity (Erin Munsell)
2010 Atlantic Basin Best Track Average Uncertainty Estimates
Intensity (kt)

- Satellite Only
- Satellite and Aircraft
- U.S. Landfalling

Tropical Storms
Category 1 & 2 Hurricanes
Major Hurricanes

Average Best Track Intensity Uncertainty (kt)

1999

Courtesy of Chris Landsea and James Franklin
Sandy 20121026H2

Flt wind speed
- OBS
- GFS
- Prior
- Enkf

SFMR wind speed
- OBS
- GFS
- Prior
- Enkf

Flt t
- OBS
- GFS
- Prior
- Enkf

Flt q
- OBS
- GFS
- Prior
- Enkf
PSU WRF-EnKF Performance for Superstorm Sandy
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Hourly 10m wind composite