Performance of WRF-EnKF for Cloud-resolving TC Ensemble Analysis and Forecasting System during 2008-2010

Yonghui Weng and Fuqing Zhang

Penn State University

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Experimental Design for PSU ARW-EnKF w/ Assimilation of NOAA P3 Doppler Vr

-18hr

- Ensemble Forecast

- SOs from 1st leg
  - wrf-3dvar produce 30 members from GFS analysis with 3 domains
  - GFS forecast as BCs

- SOs from legs
  - EnKF with radar Vr

- The last leg
  - EnKF with radar Vr

00hr

- Deterministic Forecast with fixed domains
- Deterministic Forecast with moving nested domains by vortex

Usually there are about 2 to 5 legs for one NOAA P3 mission during -12hr and -5hr

The forecast will be available and verified since this time.
PSU ARW-EnKF Real-time Configurations

- 35 vertical levels;
- WSM 6-class microphysics;
- YSU PBL;
- Grell-Devenyi CPS
- 30-member ensemble;
- Gaspari&Cohn 99' covariance localization with varying RoI
- IC & BC: GFS using 3DVAR background uncertainty
- Assimilation is performed over D1-3. D4 is used only for high-res forecast.

The inner domains are centered with the storm’s center.
AL2010: 23 Missions/Cases Total

<table>
<thead>
<tr>
<th>Storms</th>
<th>P3 Missions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alex</td>
<td>1</td>
</tr>
<tr>
<td>Two</td>
<td>3</td>
</tr>
<tr>
<td>Earl</td>
<td>11</td>
</tr>
<tr>
<td>Karl</td>
<td>4</td>
</tr>
<tr>
<td>Richard</td>
<td>1</td>
</tr>
<tr>
<td>Tomas</td>
<td>3</td>
</tr>
</tbody>
</table>

NOAA P3 Airborne Doppler Missions for the 2010 Atlantic Hurricane Season
AL2009: 10 Missions/Cases Total

NOAA P3 Airborne Doppler Missions for the 2009 Atlantic Hurricane Season

<table>
<thead>
<tr>
<th>Storms</th>
<th>P3 Missions</th>
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</thead>
<tbody>
<tr>
<td>Ana</td>
<td>1</td>
</tr>
<tr>
<td>Bill</td>
<td>4</td>
</tr>
<tr>
<td>Danny</td>
<td>5</td>
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</table>
AL2008: 26 Missions/Cases Total

<table>
<thead>
<tr>
<th>Storms</th>
<th>P3 Missions</th>
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</thead>
<tbody>
<tr>
<td>Dolly</td>
<td>6</td>
</tr>
<tr>
<td>Fay</td>
<td>6</td>
</tr>
<tr>
<td>Gustav</td>
<td>6</td>
</tr>
<tr>
<td>Ike</td>
<td>5</td>
</tr>
<tr>
<td>Paloma</td>
<td>3</td>
</tr>
</tbody>
</table>

NOAA P3 Airborne Doppler Missions for the 2008 Atlantic Hurricane Season
Hurricane Earl (2010): Forecast from 18Z 2 Sept

*EnKF assimilation of airborne Doppler winds*
PSU ARW-EnKF Assimilating Airborne Radar OBS
Mean Absolute Error and Ensemble Spread for all 59 cases 2008-2010

ABS Error of position (km) for all 2008–2010AL

ABS Error of maxWSP (kt) for all 2008–2010AL

A1PS: PSU 1.5km single forecast initialized with EnKF analyses
A4PS: PSU 4.5km single forecast initialized with EnKF analyses
P400: ensemble forecast mean of 30 members in 4.5km resolution
PSTD: averaged ensemble spread of P400
Consistency between Ensemble Spread and Error

Mean Absolute Error and Ensemble Spread for all 59 cases 2008-2010
PSU ARW-EnKF Assimilating Airborne Radar OBS

Mean Absolute Error and Mean Bias for all 59 cases 2008-2010

ABS Error and Bias of maxWSP (m/s) for all 2008–2010
Performance with Simple Bias Correction

Mean Absolute Error and Mean Bias for all 59 cases 2008-2010

Corrected WSP = WSP - \left( \frac{30h - t}{30h} \times \text{Bias at initial time} \right)
ABS Error of maxWSP (kts) for 2008–2010

No-init–bias Error of maxWSP (kts) for 2008–2010

Numbers on top: cases

HFIP BASE: dark line

20% reduction from BASE: dark dash line

P400: PSU-EnKF 4.5km ensemble forecast mean, purple line

HWRF: cyan line

After initial bias corrected
Numbers on top: cases

HFIP BASE: dark line

NoDA: The same as A4PS from GFS but without assimilation of airborne radar Vr observations
Remarks on WRF-EnKF Performance 2008-2010

- All 59 cases with P3 Vr missions for 2008-2010; these are the cases that are usually near land with biggest impacts to US

- Forecasts is available at the 00h verification time (as in OFCL)

- Ensemble spread is broadly consistent with mean forecast error

- With some bias correction, 15-40% less error than OFCL to 96hr

- No ocean model is used; the same ARW setup is used; no tuning whatsoever yet; 4.5-km runs similar to 1.5-km runs

- Only 30 members are used in the EnKF analyses; further improvement is also expected with 60-90 members

- Plans: assimilating more obs besides Vr and hybrid with 3DVar