PSU HFIP Annual Report
Real-time Convection-Permitting Ensemble Analysis and Prediction

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2012 PSU ARW-EnKF Configurations

**ARW** | **V3.4.1**
---|---
Cumulus | Grell-Devenyi ensemble (27 km domain only)
Microphysics | WSM 6-class graupel
PBL | YSU
Surface Layer | Monin-Obukov
Land Surface | thermal diffusion
Radiation | RRTM / Dudhia
Air-sea flux | Green and Zhang

- 60-member ensemble
- Gaspari & Cohn 99' covariance localization with varying RoI
- IC & BC: GFS using 3DVAR background uncertainty
- Hourly assimilation with TDR over all 3 domains

**ATCF ID:**
**APSU:** stream 1.5, ARW 3-km deterministic forecast initialized with TDR assimilation;
**ANPS:** stream 2.0, ARW 3-km deterministic forecast initialized with operational GFS Analysis.
APSU workflow

-12h

- wrf-3dvar produce 60 members from GFS analysis with 3 domains
- GFS forecast as BCs

SOs from 1st leg
- EnKF with radar Vr

SOs from legs
- EnKF with radar Vr

The last leg
- EnKF with radar Vr

Deterministic Forecast with moving nested domains by vortex

00h

The forecast will be available and verified since this time.

Usually there are about 2 to 5 legs for one NOAA P3 mission during -3h and 2h
APSU system updates before 2012 demo: from 30 to 60 ensemble members

Mean absolute forecast errors homogeneously averaged for 2008-2010 TDR cases.

**BASE**: HFIP baseline;
**A4PS**: 4.5-km EnKF with 30 members;
**A4P6**: 4.5-km EnKF with 60 members

$$\text{Bias}_{\text{corrected}} = \left( \text{Best} - \text{Forecast} \right)_{t=00h} \frac{30 - t_{t<30h}}{30} + \text{Forecast}$$
APSU system updates before 2012 demo: from 4.5 km/35 levels to 3.0 km/43 levels

Mean absolute forecast errors homogeneously averaged for 2008-2011 TDR cases

*APSU*: 3.0-km EnKF

*APSU*: 3.0-km EnKF
APSU system updates before 2012 demo: use of an ad hoc air-sea surface flux scheme

Mean absolute forecast errors homogeneously averaged for 2008-2011 TDR case.

A4PS-2011 system (yellow) : PSU 2011 stream-1.5 system, which has 4.5 km horizontal resolution and Charnock TC surface flux scheme.

APSU: PSU 2012 stream-1.5 system: Cd is half way between the Charnock and the updated Garratt schemes
APSU 2012 stream 1.5: deterministic forecast

2012 NOAA TDR cases: Alberto (1), Isaac (9), Leslie (3) and Sandy (7).

Due to NOAA Jet computing resource issue, we only operated 16 missions for hurricane Isaac and Sandy in real-time.

PSU ARW-EnKF 2012 demo system real-time forecasts for hurricane Isaac (up) and Sandy (down). ANPS is the ARW forecast without data assimilation, while APSU is the PSU ARW-EnKF forecast initialized with the EnKF analysis by assimilating NOAA airborne radar observations.
**APSU 2012 stream 1.5: deterministic forecast error**

*Track and Intensity forecast error for PSU 2012 stream 1.5 runs.*

APSU: PSU stream 1.5 with TDR
ANPS: PSU stream 2.0 with GFS analysis
OFCL, HWRF, GFDL and GFS are operational forecasts.
APSU Real-time ensemble track forecasts for hurricane Sandy with TDR assimilation.
APSU 2012 stream 1.5: ensemble intensity forecast

APSU Real-time ensemble intensity forecasts for hurricane Sandy with TDR assimilation.
ADCIRC Storm Surge Surge Forecasts for Sandy Driven by the APSU 2012 Stream 1.5 WRF Runs (Brian Colle, SUNYSB)

1. **Day 1**: 0000 Oct 24 to 0000 Oct 25. To get tides going, ran ADCIRC from rest with no winds from flat sea surface with tidal ramp only.
2. **Day 2**: 0000 Oct 25 to 0000 Oct 26. Ran ADCIRC with tides and linearly ramped PSU-WRF wind stress from zero to full strength (i.e., as of 0000 Oct 26, keeping wind direction constant).
3. **Days 3 - 8**: Ran ADCIRC with PSU-WRF winds from 0000 Oct 26 to 0000 Oct 31 (using 26/00z and 28/00z runs).
APSU deterministic forecast surface wind swatch and ensemble surface wind forecast probability for hurricane Sandy initialized at 00Z/26 Oct 2012.

Probability = forecasted members / total members
Spatial distribution of the 96-h (12Z26 to 12Z 30) accumulated rainfall (up) and the ensemble-derived probability of accumulated precipitation exceeding 100 mm (left) for hurricane Sandy initialized at 00Z/26 Oct 2012.
Composite Analysis: Mean Tracks (by Erin Munsell)

Time 5: 10/27/12 at 00Z
Time 9: 10/28/12 at 00Z

Black: Best Track
Blue: 10 Best Members (Good)
Red: 10 Worst Members (Bad)
Magenta: 10 Members that were furthest off the coast but still made landfall (Fair)
10/26/12 – 00Z, SLP and dBZ

Top Left: 10 good members
Bottom Left: 10 fair members whose tracks were furthest off shore before curving back towards land
Bottom Right: 10 bad members
10/28/12 – 00Z, SLP and dBZ

Top Left: 10 good members
Bottom Left: 10 fair members whose tracks were furthest off shore before curving back towards land
Bottom Right: 10 bad members
10/30/12 – 00Z, SLP and dBZ

Top Left: 10 good members
Bottom Left: 10 fair members whose tracks were furthest off shore before curving back towards land
Bottom Right: 10 bad members
Time 1: 10/26/12 – 00Z

dBZ, 500 mb Geopotential Height and Surface Winds differences

Top Left: Good – Bad
Bottom Left: Good – Fair
Bottom Right: Fair – Bad
Time 5: 10/27/12 – 00Z

dBZ, 500 mb Geopotential Height and Surface Winds differences

Top Left: Good – Bad
Bottom Left: Good – Fair
Bottom Right: Fair – Bad
Differences in Environmental Steering Flow – Zonal

- Good composite track separates by Time 5

![Graphs showing differences in mean U-component for different times](image-url)
Time 9: 10/28/12 – 00Z

dBZ, 500 mb Geopotential Height and Surface Winds differences

Top Left: Good – Bad
Bottom Left: Good – Fair
Bottom Right: Fair – Bad
Differences in Environmental Steering Flow – Meridional

- Bad composite track separates by Time 9

Time 7

Time 8

Time 9
Composite Cumulative Rainfall between 10/26/12 at 00Z – 10/31/12 at 06Z

Domain 2 – Mask over Ocean

Top Left: Good
Bottom Left: Fair
Bottom Right: Bad
Composite Cumulative Rainfall between 10/26/12 at 00Z – 10/31/12 at 06Z

Domain 1 – No Mask

Top Left: Good
Bottom Left: Fair
Bottom Right: Bad
Evolution of Total Rainfall Across Domain 1

Blue: Good
Magenta: Fair
Red: Bad
Cyan: Other

5% Difference in Total Rainfall
ANPS 2012 stream 2.0 system real-time forecasts for Atlantic storms.

Total 762 forecasts were made in 2012 for storms and Invests.
ANPS cases: intensity forecast

2012a109 ISAAC ANPS Vmax

2012a12 Leslie ANPS Vmax

2012a14 NADINE ANPS Vmax

2012a18 Sandy ANPS Vmax

Isaac

Leslie

Nadine

Sandy
APSU for 2008-2012 TDR cases

<table>
<thead>
<tr>
<th>Year</th>
<th>Cases</th>
<th>Storm (cases)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>35</td>
<td>Dolly (6),  Fay (6), Gustav (6), Ike (6), Kyle (8), Paloma (3)</td>
</tr>
<tr>
<td>2009</td>
<td>10</td>
<td>Ana (1), Claudette (4), Danny (5)</td>
</tr>
<tr>
<td>2010</td>
<td>25</td>
<td>Alex (1), Two (3), Earl (11), Karl (4), Gaston (1), Tomas (5)</td>
</tr>
<tr>
<td>2011</td>
<td>13</td>
<td>Irene (7), Lee (1), Ophelia (1), Rina (4)</td>
</tr>
<tr>
<td>2012</td>
<td>19</td>
<td>Isaac (9), Leslie (3), Sandy (7)</td>
</tr>
<tr>
<td>Total</td>
<td>102</td>
<td>22 storms</td>
</tr>
</tbody>
</table>
2008-2012 APSU Errors

APSU forecast error for 102 TDR cases during 2008-2012.

Abs Error of position (km) for AL2008–2012–APSU–OFCL–homo

No-Bias Error of maxWSP (kts) for AL2008–2012–APSU–OFCL–homo

\[ \text{Bias\_corrected} = (\text{Best} - \text{Forecast}) \left( \frac{30 - t_{\leq 30\,\text{h}}}{30} \right) + \text{Forecast} \]

Average uncertainty in Best track: Landsea, C., and J. Franklin, 2013
ANPS forecast error homogeneously averaged over 2140 cases of 2008-2012 Atlantic storms.

- OFCL has the smallest track and intensity error;
- ANPS has the same track error as GFS, but has smaller intensity error;
- Initial intensity bias for ANPS and GFS are very large;
- ANPS is 2012 system, others are operational systems. (the comparison for other forecasts are unfair.)
ANPS track errors each year during 2008-2012

Homo Abs Error of position (km) for AL2008

2008, 398 cases

Homo Abs Error of position (km) for AL2009

2009, 167 cases

Homo Abs Error of position (km) for AL2010

2010, 481 cases

Homo Abs Error of position (km) for AL2011

2011, 470 cases

Homo Abs Error of position (km) for AL2012

2012, 624 cases
ANPS intensity errors each year during 2008-2012

- **2008, 398 cases**
- **2009, 167 cases**
- **2010, 481 cases**
- **2011, 470 cases**
- **2012, 624 cases**

- GFS initial bias is getting smaller over the past few years
- ANPS has smaller intensity error than GFS in 2008-2010
- ANPS after 72h is worse than GFS in 2011
- ANPS is worse than GFS in 2012
- Likely due to DA in GFS analysis
Different Global Analyses/Forecasts for ANPS: GFS vs. CFSRv2 for 2012 Atlantic Storms

- GFS upgrades lead to better ARW track forecasts but higher intensity bias and error
Recon Impact Tiger Team Recon : FL/drops vs. TDR

ATCF ID:
- **APCT (APCI):** ConTrol (regular GTS non-radiance obs)
- **APRC (APRI):** ReCon (FL + drops)
- **APAR (APAI):** All Recon (Doppler + FL + drops)

Experiment design:
- The system configurations are the same as APSU;
- The system is initialized with operational GFS, and cycled every 3 hours till the end of the storm or the storm moves to the north of 45N or the east of 30W;
- The inner domains follow TCvitals;
- Assimilating obs. within the area of 1200kmx1200km around the storm every 3 hours;
- Environment fields (out of the 1200kmx1200km area) will be replaced by GFS operational analysis every 6 hours;
- Deterministic forecasts are conducted every 6 hours.
<table>
<thead>
<tr>
<th>Year</th>
<th>Storm</th>
<th>APCT</th>
<th>APRC</th>
<th>APAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>04-Dolly</td>
<td>072012-072418</td>
<td>072012-072418</td>
<td>072012-072300</td>
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<tr>
<td></td>
<td>06-Fay</td>
<td>081400-082400</td>
<td>081400-082400</td>
<td>081400-081906</td>
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<tr>
<td></td>
<td>07-GUSTAV</td>
<td>082512-090200</td>
<td>082512-090200</td>
<td>082918-090118</td>
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<tr>
<td></td>
<td>09-Ike</td>
<td>090200-091312</td>
<td>090512-091312</td>
<td>090918-091218</td>
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<tr>
<td></td>
<td>11-Kyle</td>
<td>092300-092812</td>
<td>092318-092812</td>
<td>092318-092718</td>
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<tr>
<td></td>
<td>17-Paloma</td>
<td>110600-111000</td>
<td>110600-111000</td>
<td>110706-110900</td>
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<tr>
<td>2009</td>
<td>02-Ana</td>
<td>081200-081700</td>
<td>081612-081700</td>
<td>081618-081700</td>
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<tr>
<td></td>
<td>03-Bill</td>
<td>081600-082312</td>
<td>081812-082312</td>
<td>081818-082012</td>
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<tr>
<td></td>
<td>05-Danny</td>
<td>082612-082900</td>
<td>082612-082900</td>
<td>082612-082812</td>
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<tr>
<td>2010</td>
<td>01-Alex</td>
<td>062512-070112</td>
<td>062512-070112</td>
<td>062900</td>
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<tr>
<td></td>
<td>07-Earl</td>
<td>082600-090400</td>
<td>082712-090400</td>
<td>082900-090400</td>
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<tr>
<td></td>
<td>13-Karl</td>
<td>091412-091800</td>
<td>091412-091800</td>
<td>091300-091700</td>
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<tr>
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<td>19-Richard</td>
<td>102012-102600</td>
<td>102012-102600</td>
<td>102306-102312</td>
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<tr>
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<td>21-Tomas</td>
<td>102912-110806</td>
<td>102912-110806</td>
<td>110400-110700</td>
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<tr>
<td>2011</td>
<td>09-Irene</td>
<td>082000-082900</td>
<td>082012-082900</td>
<td>082400-082712</td>
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<td>13-Lee</td>
<td>090200-090612</td>
<td>090200-090612</td>
<td>090200</td>
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<td></td>
<td>16-Ophelia</td>
<td>092100-100218</td>
<td>092312-092900</td>
<td>092418</td>
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<td>18-Rina</td>
<td>102212-102818</td>
<td>102312-102800</td>
<td>102600-102718</td>
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<tr>
<td>2012</td>
<td>09-Isaac</td>
<td>082000-083018</td>
<td>082112-082906</td>
<td>082300-082900</td>
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<td>12-Leslie</td>
<td>083000-091100</td>
<td>090712-090812</td>
<td>090712-090812</td>
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<tr>
<td></td>
<td>14-Nadine</td>
<td>091000-100318</td>
<td>091118-100318</td>
<td>(GH dropsondes)</td>
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<tr>
<td></td>
<td>17-Rafael</td>
<td>101300-101718</td>
<td>101300-101718</td>
<td>101600-101700</td>
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<tr>
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<td>18-Sandy</td>
<td>102100-103018</td>
<td>102212-102918</td>
<td>102600-102900</td>
</tr>
</tbody>
</table>

Data source
- GFS: Jet HSMS: /mss/fdr/YYYY/MM/DD/grib/ftp/7/0/96/0_259920_0, grib2.
- Dropsonde data: /mss/fdr/2012/10/25/data/dropsonde/netcdf, netcdf.
DA Tiger Team:
APCT vs. ANPS errors for 2008-2012

- PSU cycling ARW-EnKF system assimilating non-radiance GTS obs only
  performs comparable to ANPS initialized from GFS
DA Tiger Team:
APRC vs. APCT errors for 2008-2012

- Assimilation of additional recon flight-level plus dropsondes improves both track and intensity forecasts
DA Tiger Team:
APRC, APCT & APAR errors for 2008-2012

- Somewhat surprisingly, addition of TDR does not further improve beyond FL +drops
DA Tiger Team:
APAR vs. APSU (2012 system) errors for 2008-2012

- For all the TDR cases, no significant performance difference between experiments
- More tests needed
Looking Forward

• 2013 stream 2.0:
  – APSU: ARW deterministic forecast initialized by cycling PSU WRF-EnKF system with GTS non-radiance data, Recon data, NOAA TDR and satellite derived winds assimilation. Four times per day
  – AP01-AP10: ensemble forecast with 10 members twice per day initialized with APSU EnKF perturbations

• Continue the Recon Data Impact Experiment by adding an ocean model, and improving EnKF configurations

• Development and implementation of a WRF/AHW-based coupled EnKF and 4DVar system (E4DVar) for convection-permitting hurricane analysis and prediction (2014?)
E4DVAR: 2-way Coupling of EnKF with 4DVar

Necessary Variable Changes:
- EnKF provides ensemble-based background error covariance ($P_f$) for 4DVar
- EnKF provides the prior ensemble mean ($x^f$) as the first guess for 4DVar
- 4DVar provides deterministic analysis ($x_a$) to replace the posterior ensemble mean for the next ensemble forecast

E4DVar, E3DVar vs. EnKF, 3DVar, 4DVar
RMSE of 12~72h forecast for BAMEX domain, June 1-30 2013

(Zhang and Zhang 2012; Zhang et al. 2013 MWR)
Assimilation of PREDICT Dropsondes for Hurricane Karl (2010) with Coupled EnKF-4DVar (E4DVar)

- WRF-ARW V3.4; 451 x 226 x 35 domain
- 13.5 km grid spacing; 30-/60-member ensembles for WRF-EnKF; new WRF-4DVar
- Data assimilated (EnKF, 4DVar and E4DVar) every 6 h from 06 UTC 08 Sept. to 00 UTC 15 Sept. 2012 (9 days); GFS analysis and forecast as ICs and BCs
- Observations include all MADIS data (except radiance) and dropsondes from the NASA Genesis and Rapid Intensification Processes (GRIP) experiment

Ongoing research of Jon Poterjoy
Forecasts Sensitivity to PREDICT Dropsondes: Tracks

- Forecasts are plotted starting from 18 UTC Sept 12
Forecasts Sensitivity to PREDICT Dropondes: Intensity

E4DVar-noPREDICT

E4DVar-PREDICT

Ongoing research of Jon Poterjoy
Forecasts Sensitivity to Data Assimilation Methods

EnKF-PREDICT

4DVar-PREDICT
Computational Considerations

With a 40.5-km WRF setup of Karl, the time for each DA:

Average number of 4DVar iterations: 37.4
Average number of E4DVar iterations: 25.6

Average TLM time: 37 s
Average ADM time: 78 s
Average NLM time: 22 s

Average 4DVar analysis time: 82 minutes

Estimated EnKF time: 46 minutes + (22 minutes)

Average E4DVar analysis time: 59 m + 46 m + (22 m)