GSI Hybrid/EnKF data assimilation for Hurricane Sandy

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Outline

- **Introduction**
- **Case overview**
- **Experimental setup**
- **Results**
- **Discussion**

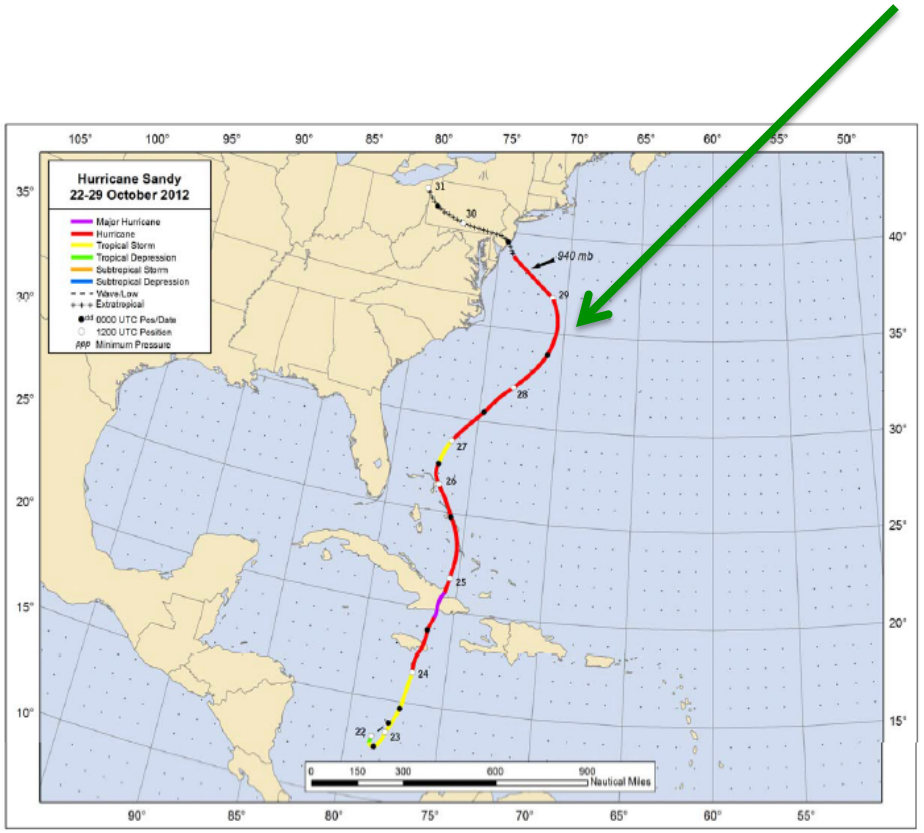
Introduction

- **Hurricane Sandy (2012)** made landfall on the New Jersey coast shortly before 0000 UTC 30 October 2012, causing 72 deaths and approximately $50 billion damage in United States (Blake et al. 2013).

- The major damage was caused by the storm surge leading to flooding and the inland precipitation with large amount.

- The northwestward turn at 29 October and its final landfall position at Mid-Atlantic make Sandy an extremely unusual hurricane in the past hundred years.

- Hall and Sobel (2013) estimated that the return period for an event like Sandy is over 700 years.



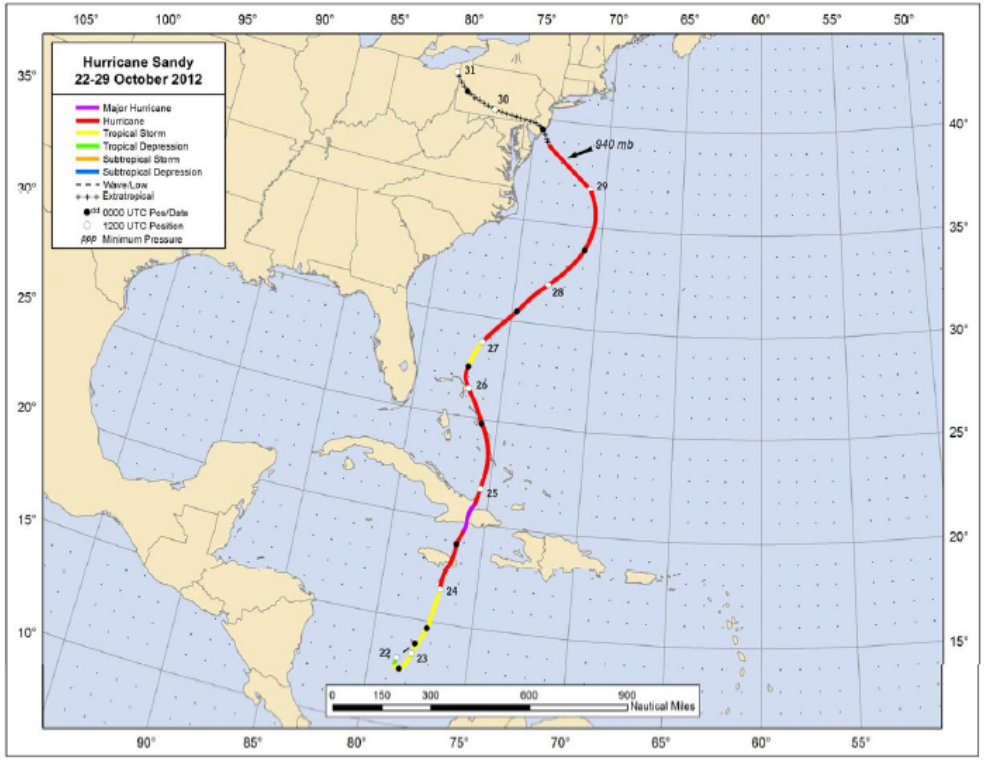
Introduction

- Zhu and Weng (2013) studied Sandy's warm core structure from an **observation angle**.
- Shen et al. (2013) investigated the predictability of Sandy's **genesis** with a global mesoscale model.
- Galarneau et al. (2013) aimed to determine the dynamic processes that controlled the second **intensification** period of Hurricane Sandy prior to its New Jersey landfall .
- Magnusson et al. (2014) evaluated **the performance of the ECMWF forecast** together with forecasts from other operational centers, and found that the ECMWF forecasts provided a clear indication of the landfall 6–7 days in advance while other forecasts did not show a consistent performance for the landfall forecast.
- Munsell and Zhang (2013) investigated the **forecast sensitivity and uncertainties**. They found that the uncertainties in the environmental steering flow are the dominant factor causing the divergence of Sandy's track forecasts.

Motivation

- **To study Hurricane Sandy from a data assimilation perspective**
- **To investigate if the Hybrid/EnKF DA system can improve forecasts in terms of track, intensity, and precipitation**
- **To investigate if the Hybrid/EnKF forecast can simulate the precipitation pattern and amount, and the storm structure near landfall that are closely related to the damage for coastal region**

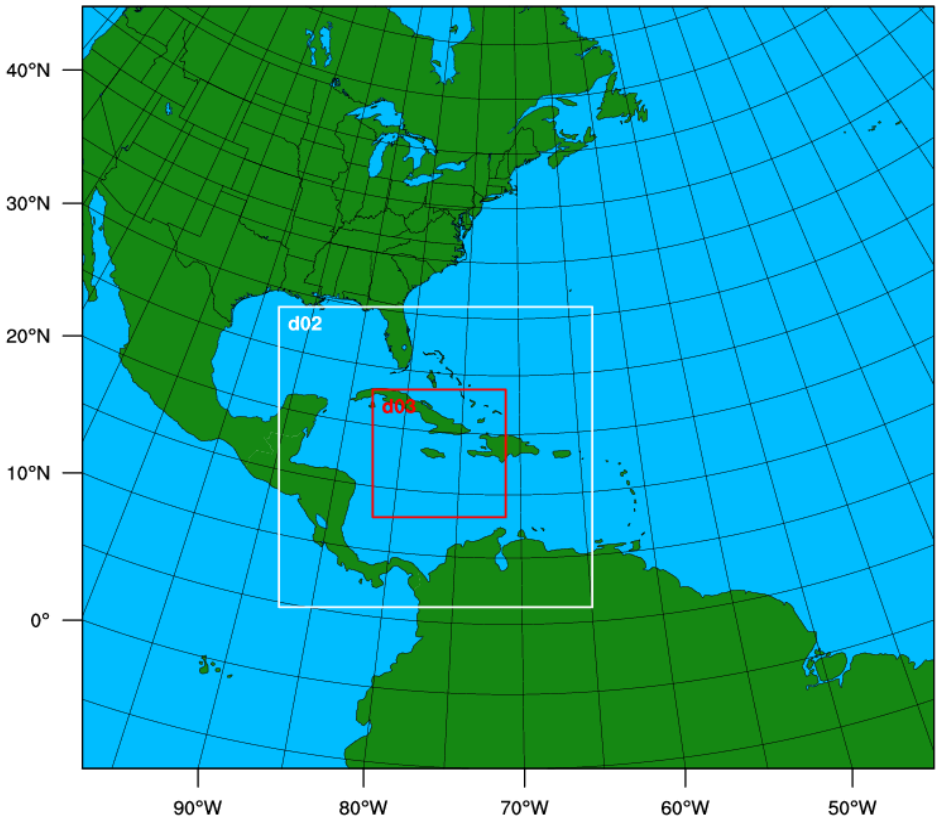
Case overview



- Sandy was identified as tropical depression at 1200 UTC October 22 and as hurricane at 1200 UTC 24 October
- Sandy curved unusually toward northwest at 29 October
- Sandy made landfall at 0000 UTC 30 October on New Jersey with 70kt maximum sustained winds

NHC report, Blake, et al. 2013

Experimental setup

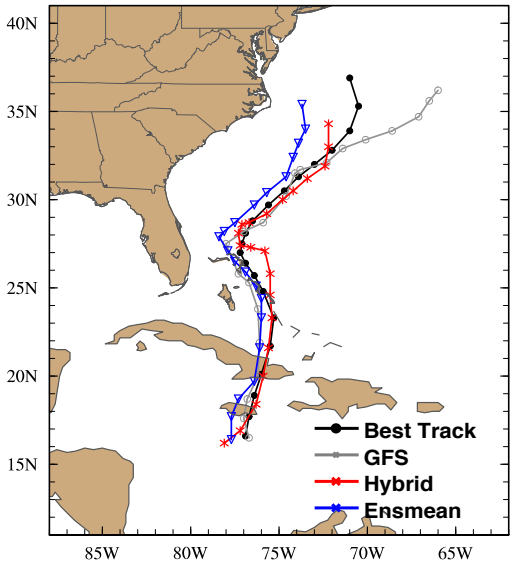


- WRF ARW with 3 nested domains at 27-, 9-, and 3-km grid spacings
- ICs/BCs are from the GFS analysis and forecasts.
- Parallel 6 hourly cycling for EnKF (27-km domain; 50-member) and Hybrid (27-and 9-km domains) DA from 00 UTC Oct 22 to 00 UTC Oct 29
- The 9-km Hybrid DA uses 27-km ensemble with “dual resolution” option

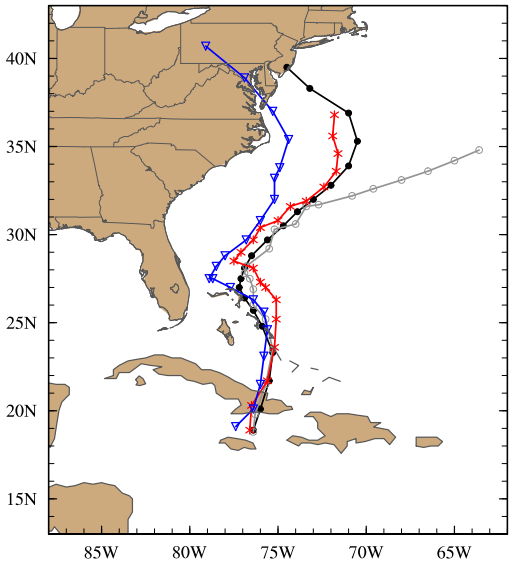
- 120h forecasts were carried out for both Hybrid analysis and EnKF mean analysis at each analysis time with the 3-km nest
- 27-km domain was fixed and 9- and 3-km domains move with storm

Results – track forecasts

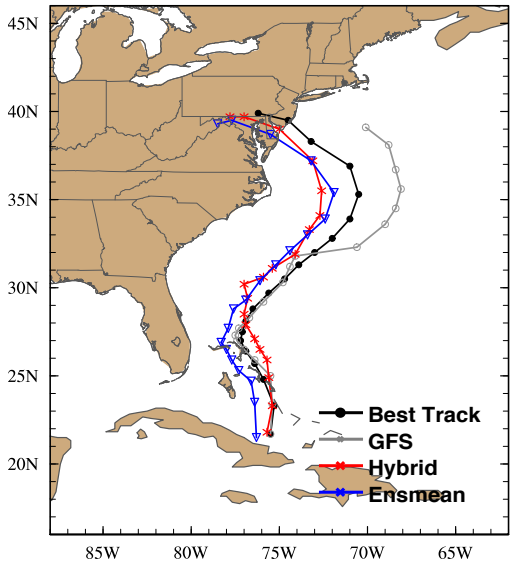
12 UTC October 24



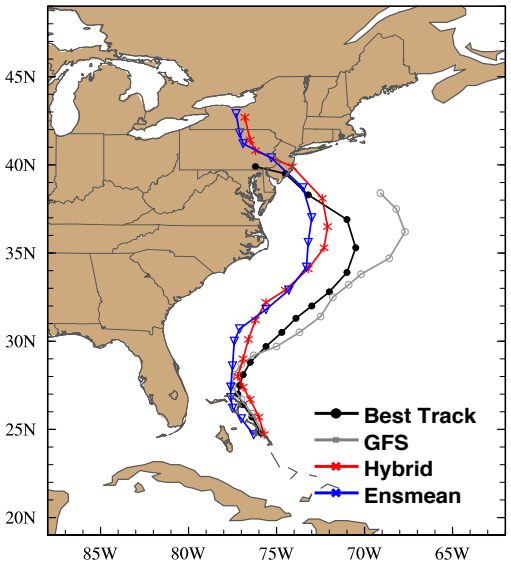
00 UTC October 25



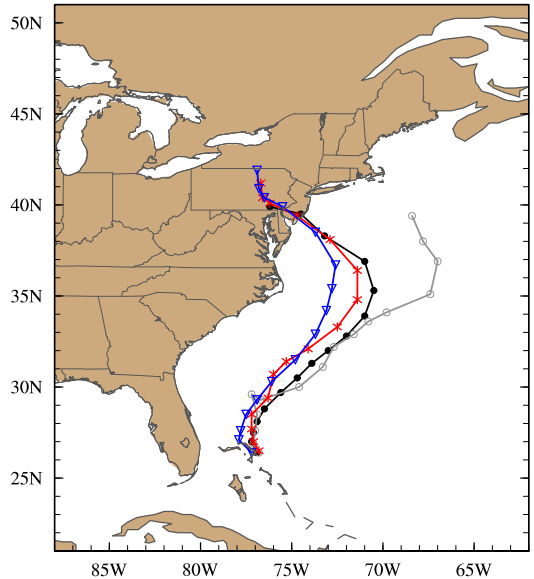
12 UTC October 25



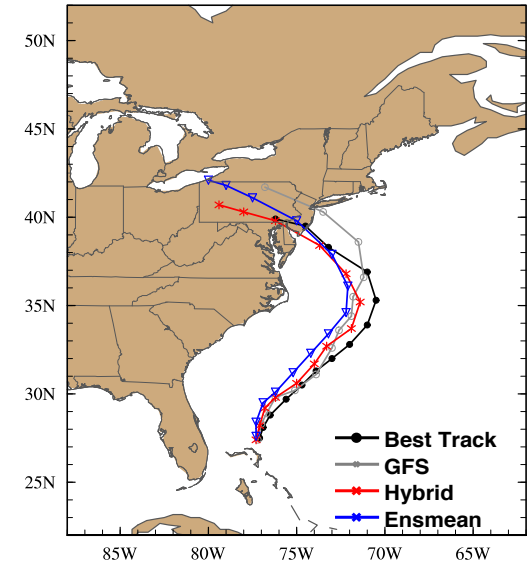
00 UTC October 26



12 UTC October 26

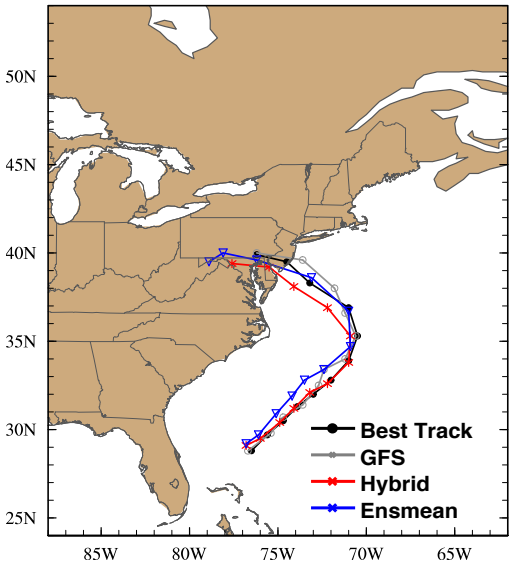


00 UTC October 27

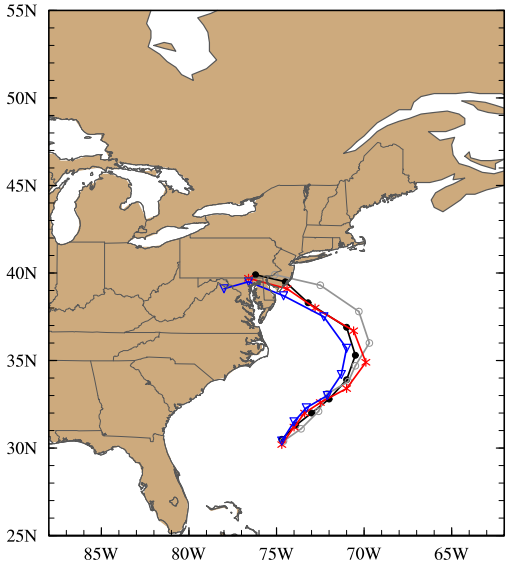


Results – track forecasts

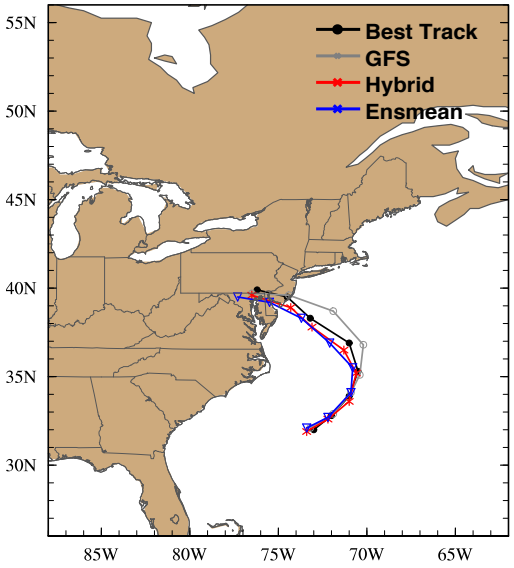
12 UTC October 27



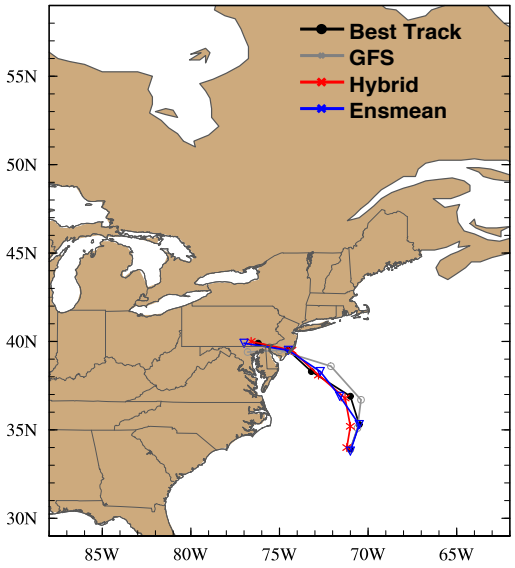
00 UTC October 28



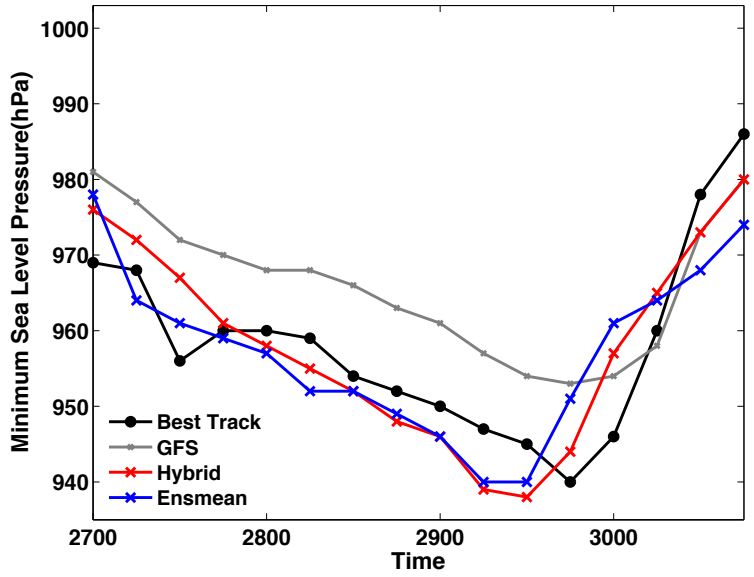
12 UTC October 28

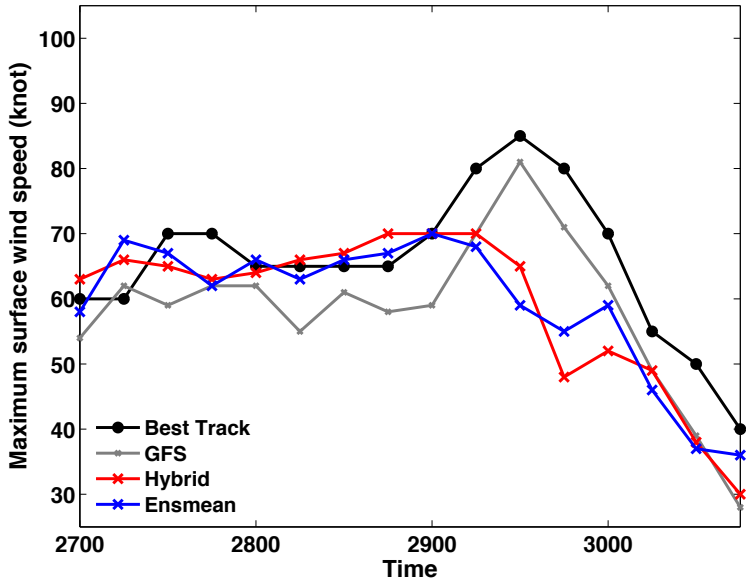


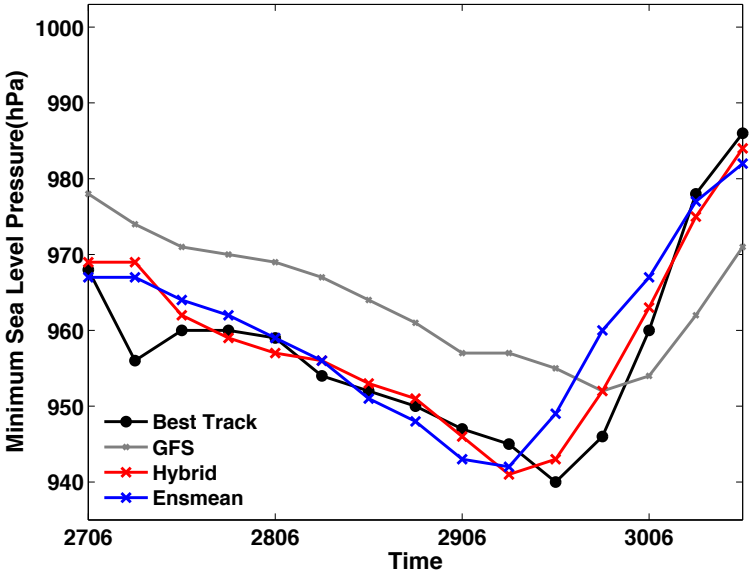
00 UTC October 29

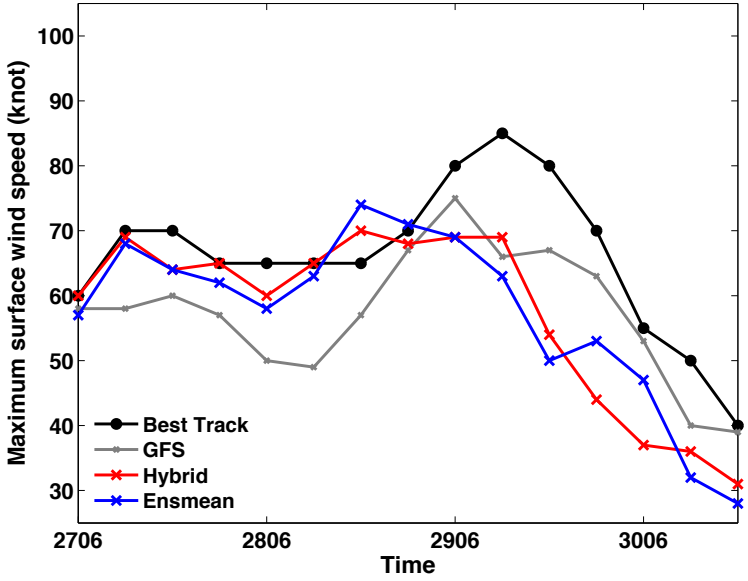


Results – intensity forecasts

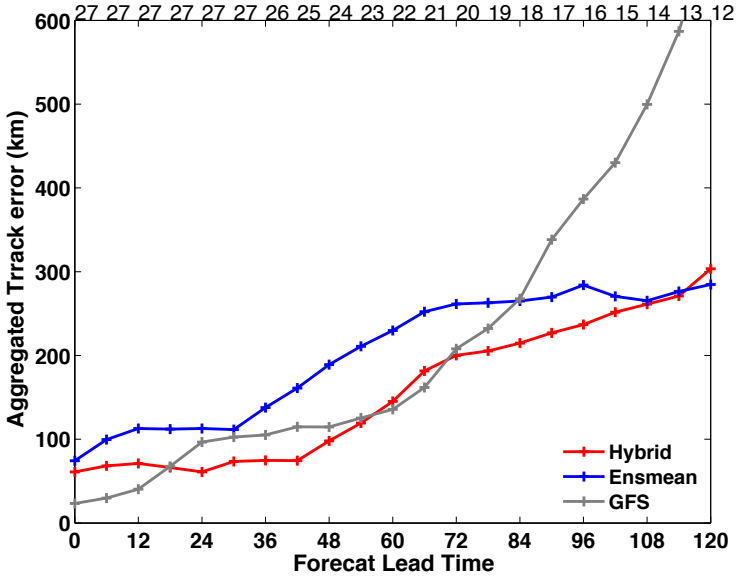




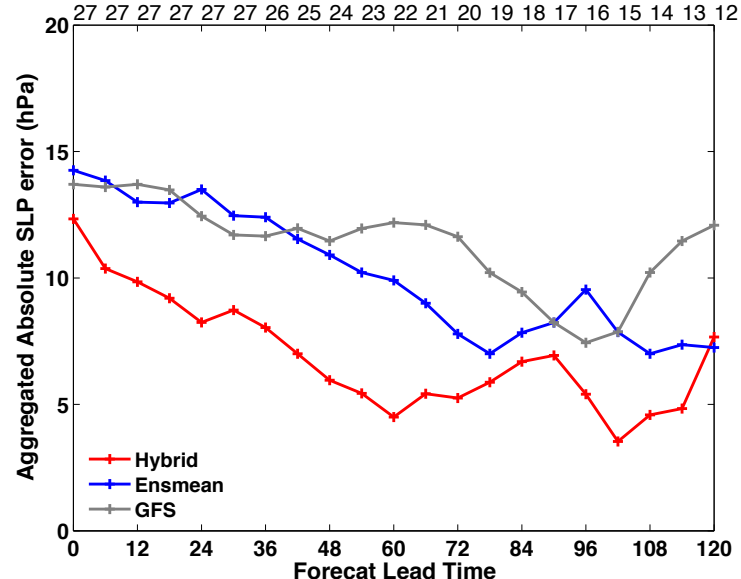


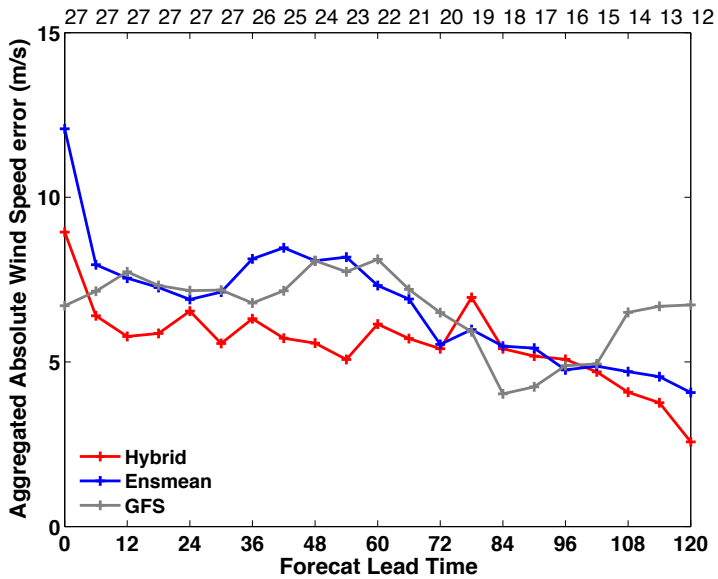


Results – Aggregated error



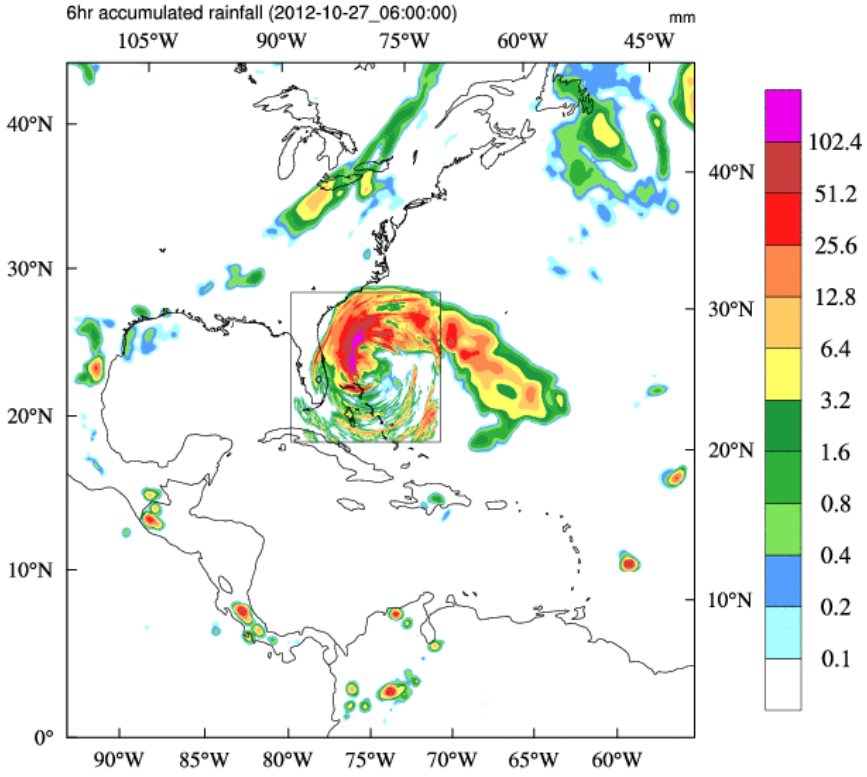
- Both the Hybrid and the EnKF mean forecasts have smaller errors than the GFS forecasts for longer lead time
- Hybrid overall performs better than the EnKF mean forecasts.





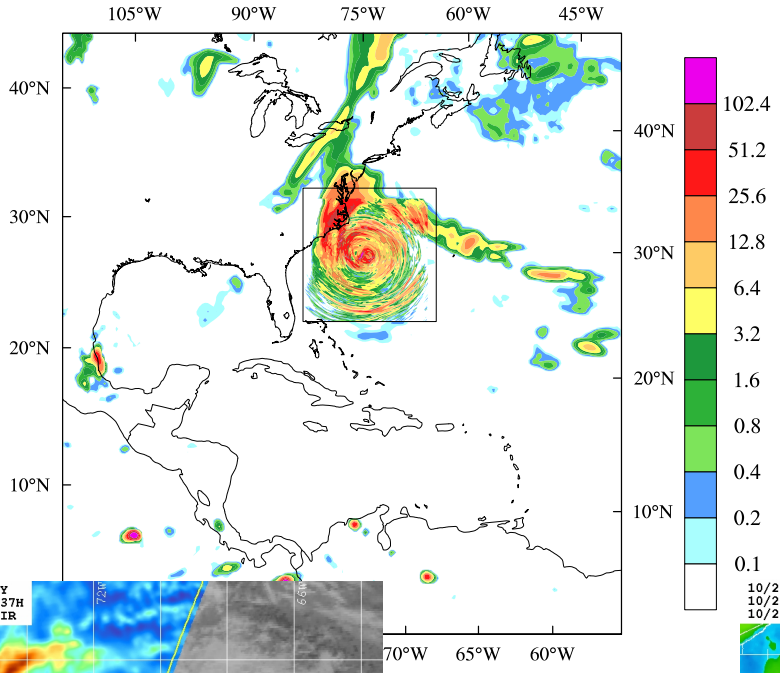
Results – precipitation evolution

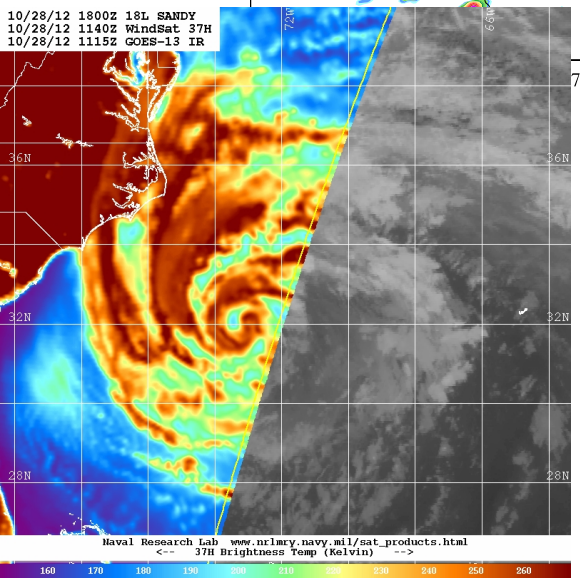
6h accumulated precipitation initialized at 00 UTC 27 hybrid analysis



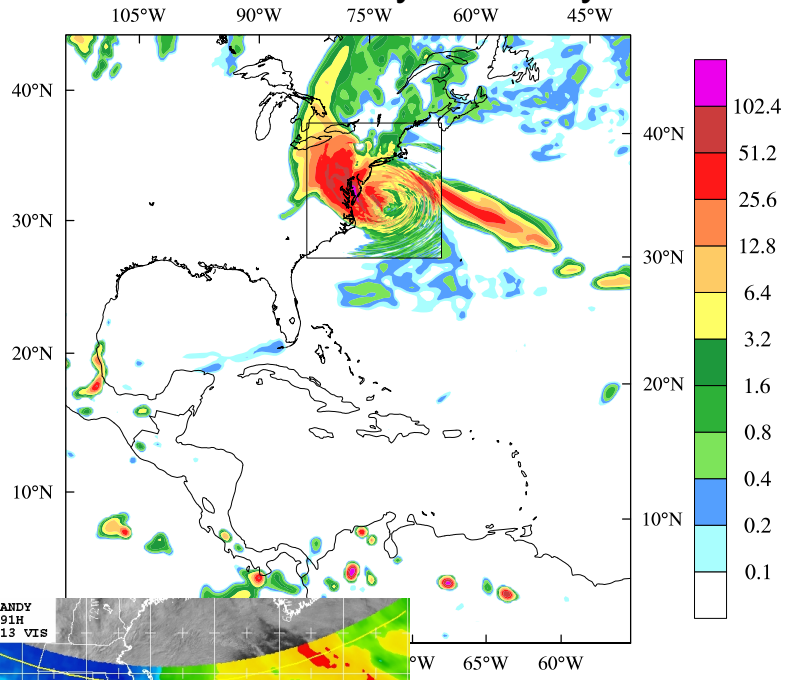
Results –6h accumulated precip. forecast

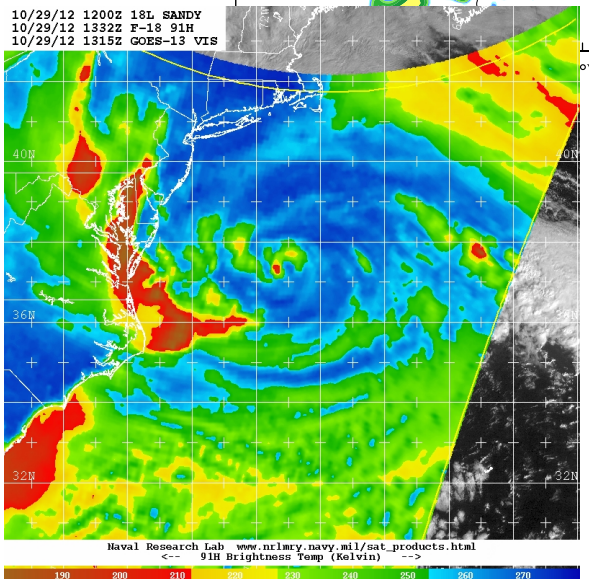
36h forecast valid at **12Z 28** initialized at 00 UTC 27 hybrid analysis





60h forecast valid at **12Z 29** initialized at 00 UTC 27 hybrid analysis



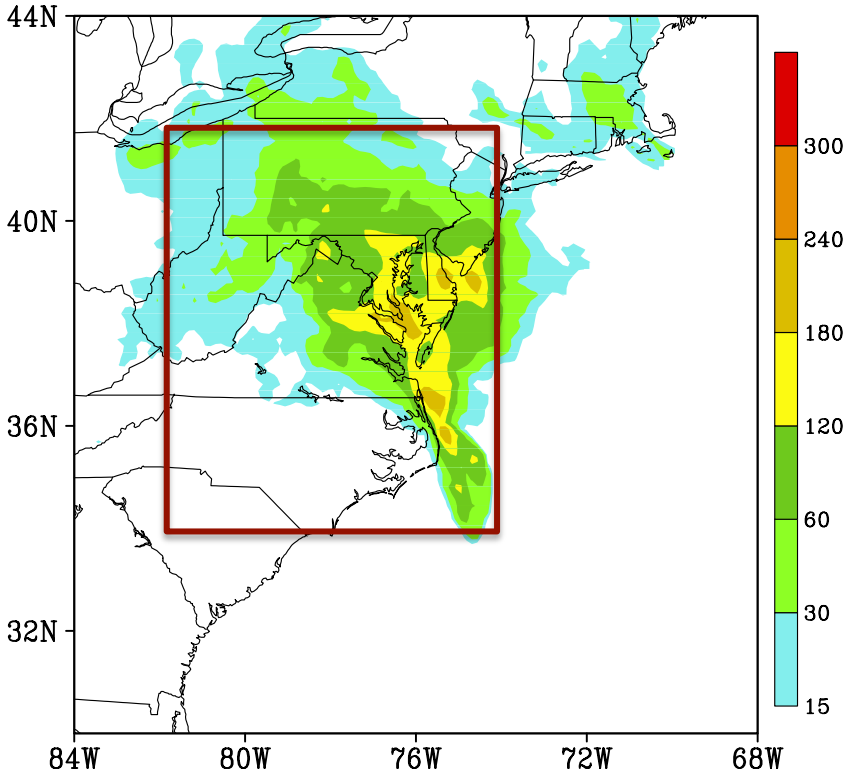


Satellite image courtesy of NRL

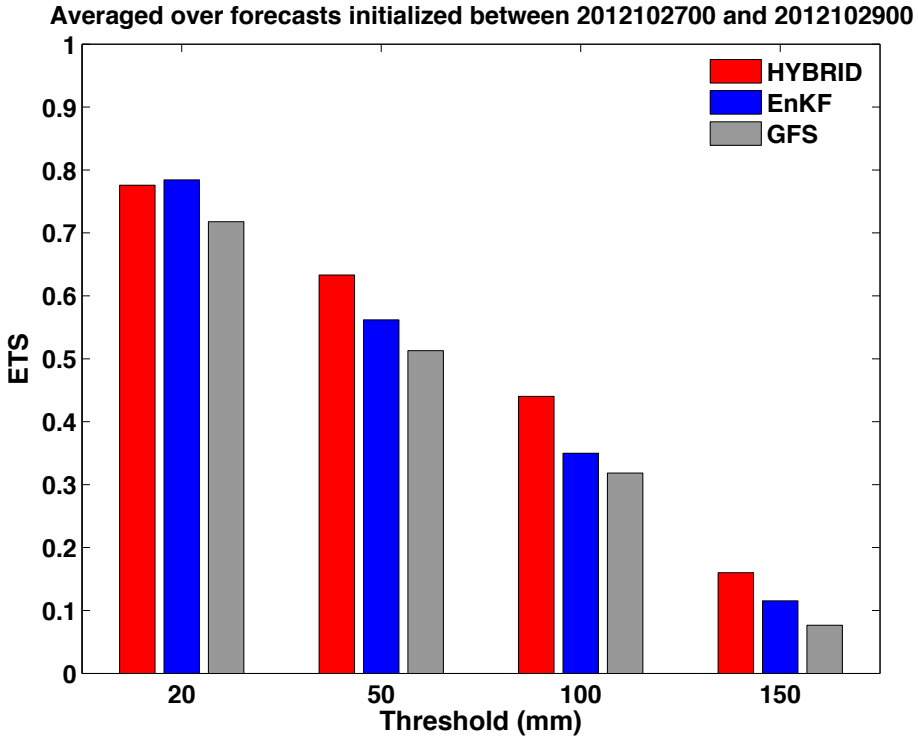
Results –precipitation verification at landfall time

24h accumulated precipitation
(00 Oct 29 -00 Oct 30)

Climatology-calibrated precipitation analysis at 0.125° **(*Hou et al 2014)**

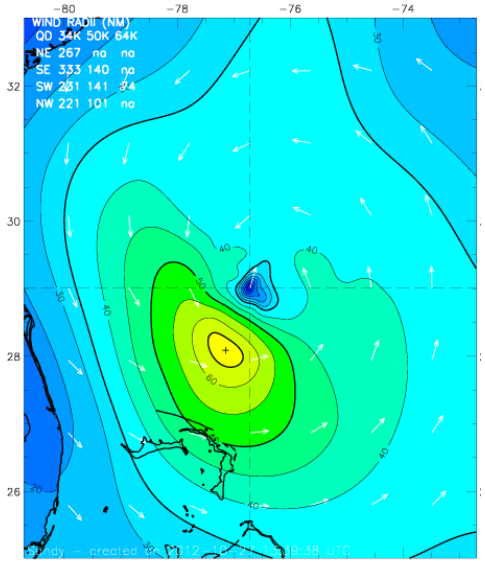


Threshold Scores averaged
over forecasts
between 00Z 27 and 00Z 29 October



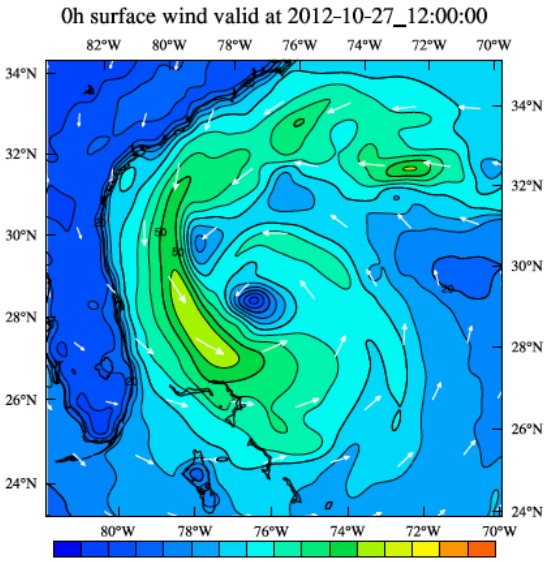
Results –surface wind structure evolution

HWIND analysis at 1330 UTC 27

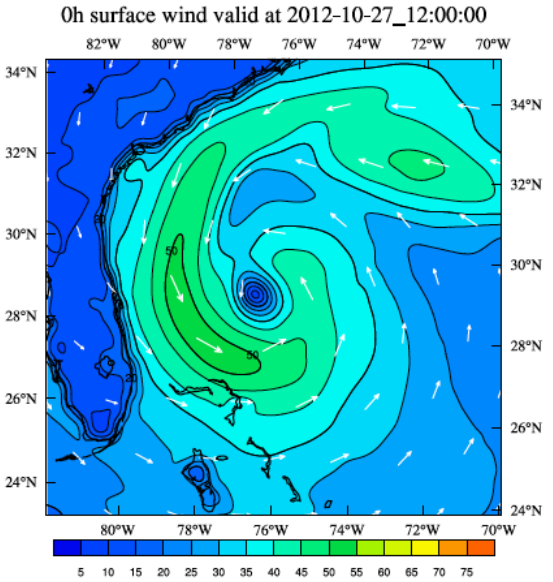


0h fcst at 12 UTC 27

Hybrid forecast



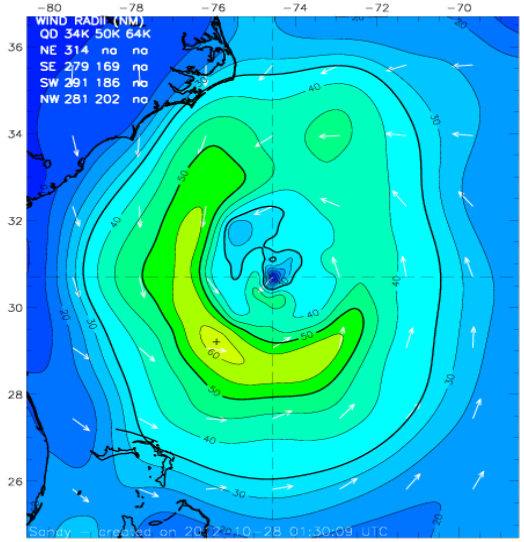
EnKF forecast



Powell et al 1998

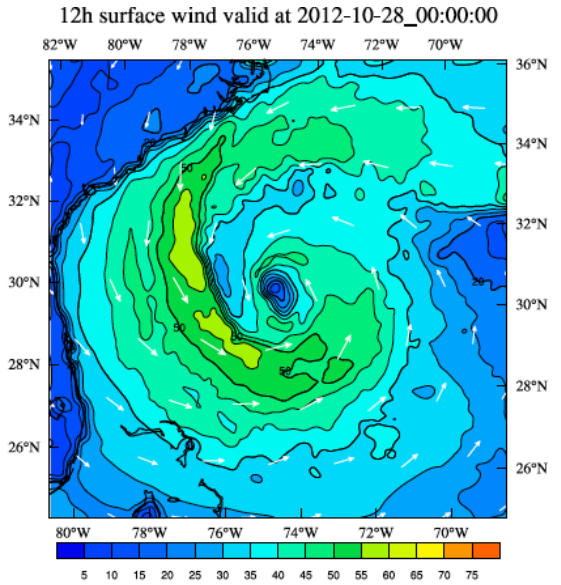
Results –surface wind structure evolution

HWIND at 0130 UTC 28

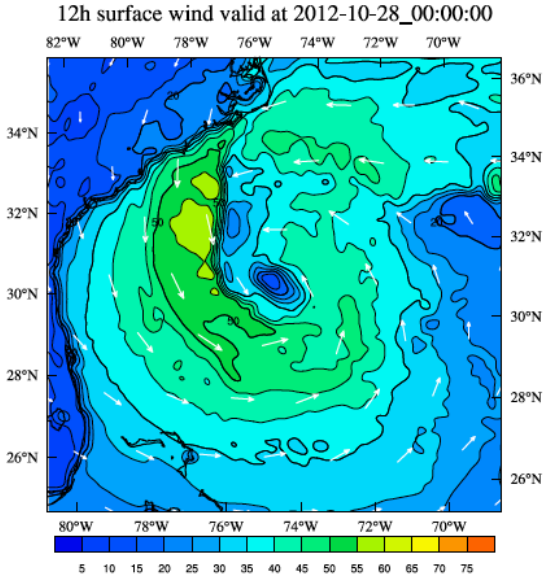


Hybrid forecast

12h fcst at 00 UTC 28

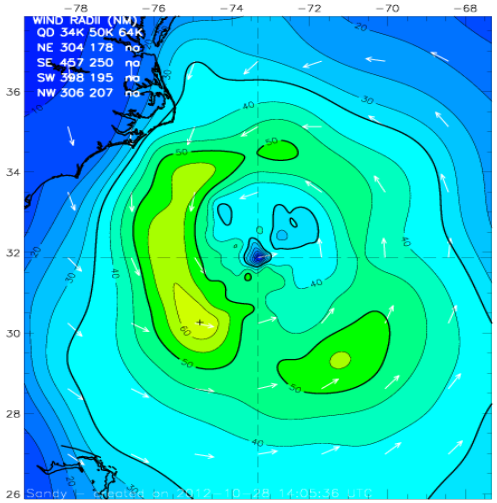


EnKF forecast



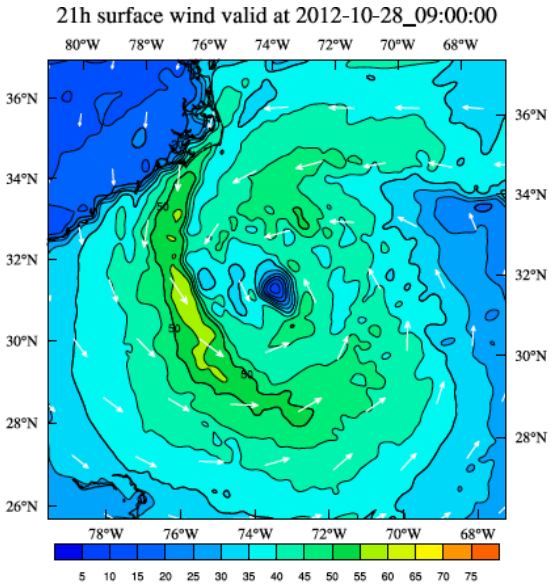
Results –surface wind structure evolution

HWIND at 1030 UTC 28

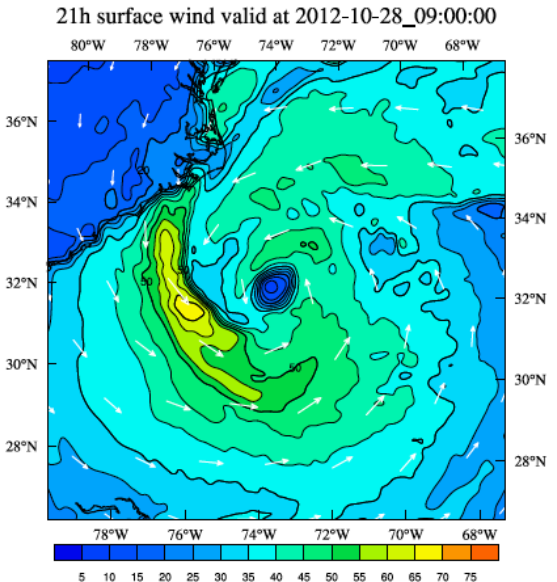


Hybrid forecast

21h fcst at 09 UTC 28

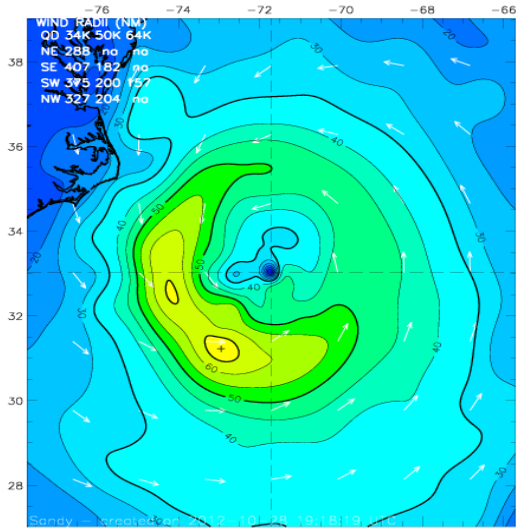


EnKF forecast



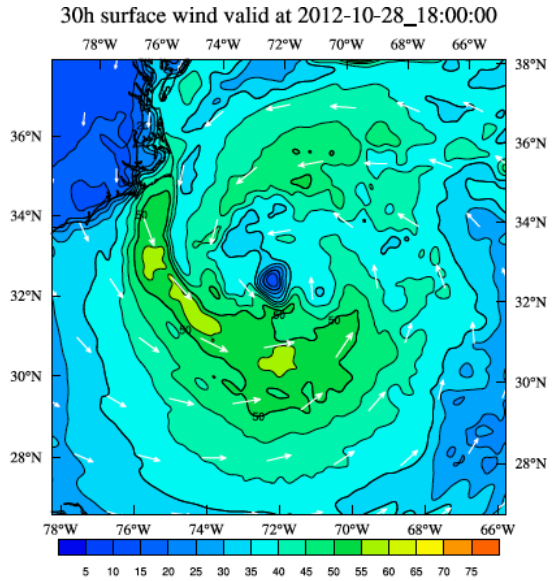
Results –surface wind structure evolution

HWIND at 1930 UTC 28

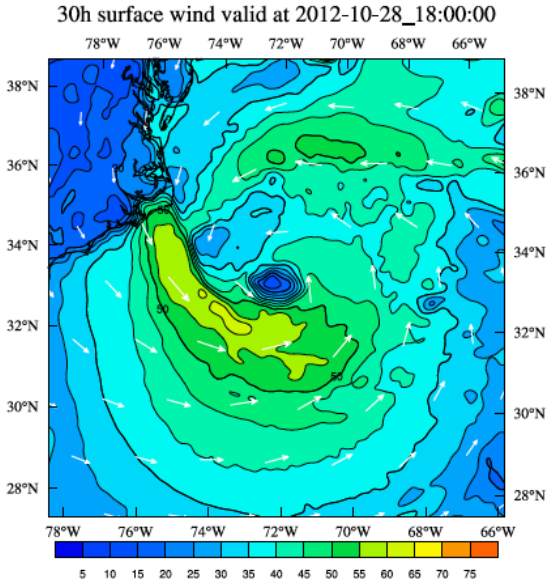


30h fcst at 18 UTC 28

Hybrid forecast

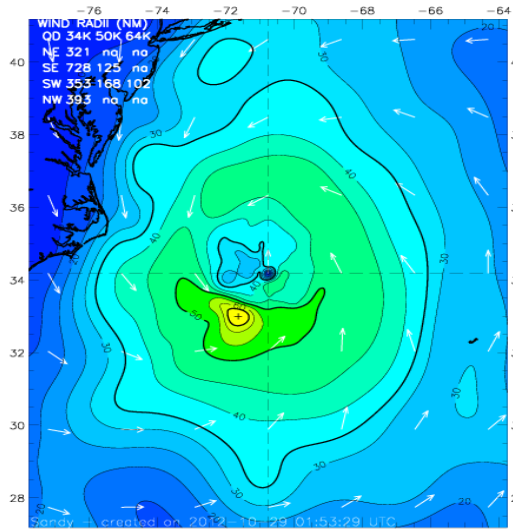


EnKF forecast



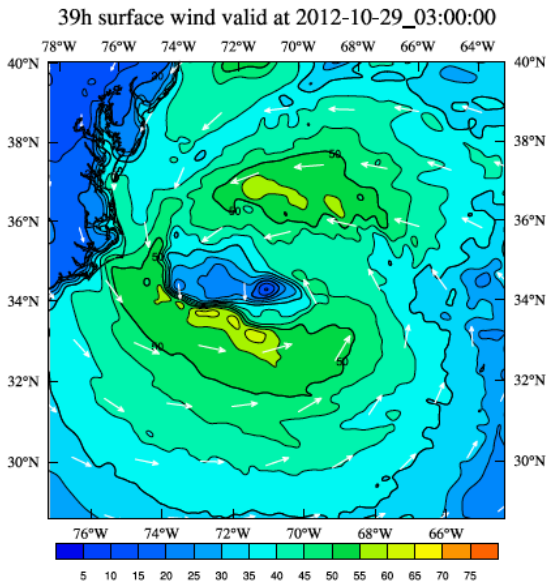
Results –surface wind structure evolution

HWIND at 0130 UTC 29

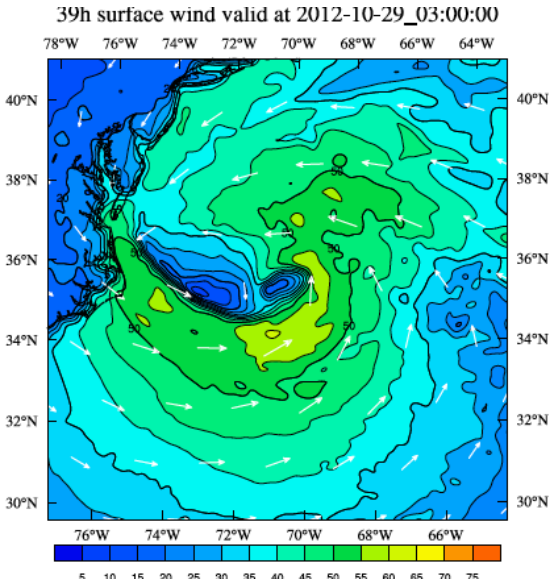


39h fcst at 03 UTC 29

Hybrid forecast

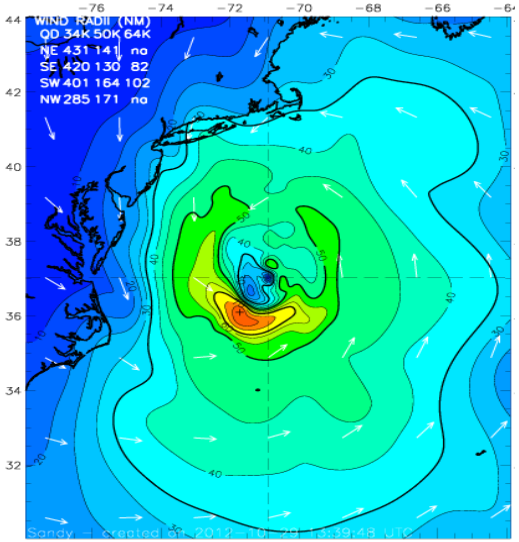


EnKF forecast



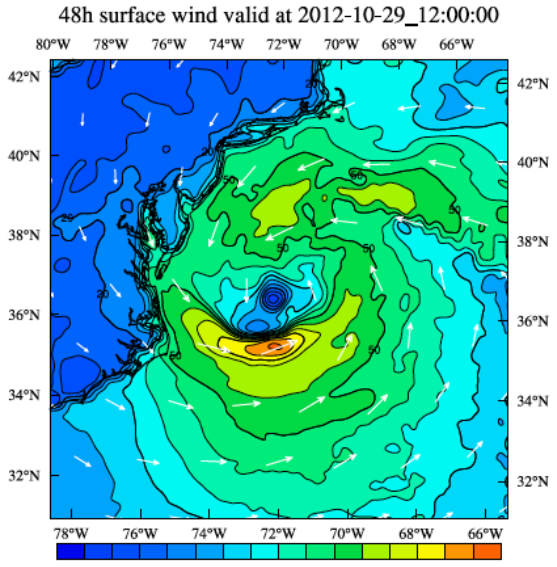
Results –surface wind structure evolution

HWIND at 1330 UTC 29

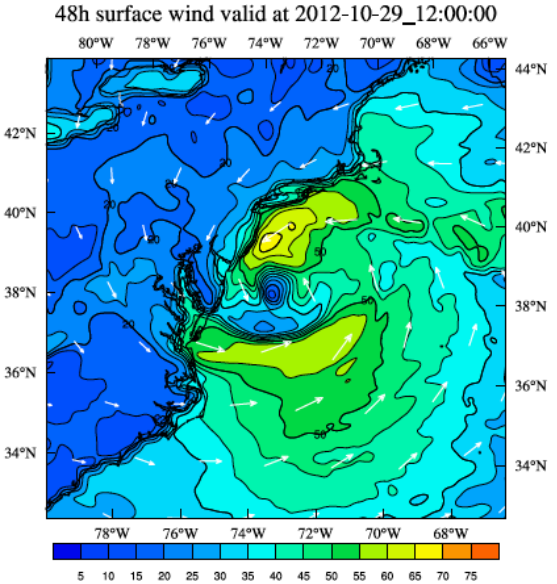


48h fcst at 12 UTC 29

Hybrid forecast

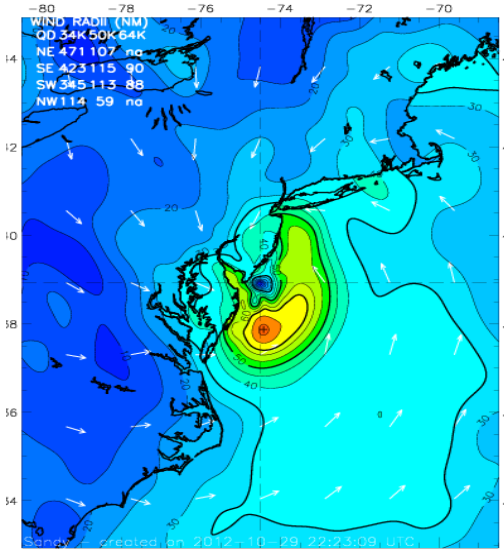


EnKF forecast



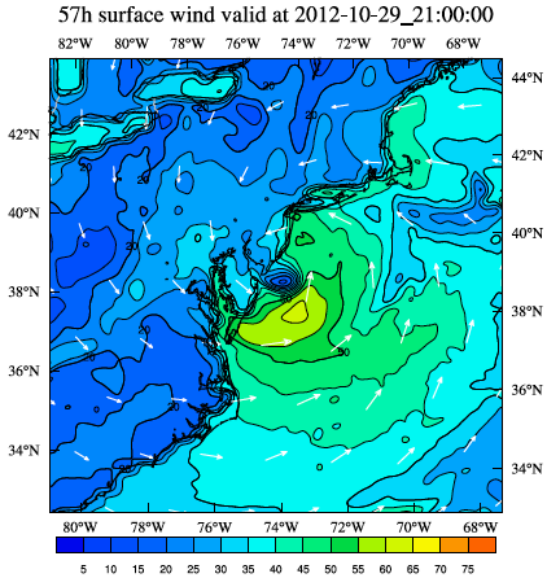
Results –surface wind structure evolution

HWIND at 2230 UTC 29

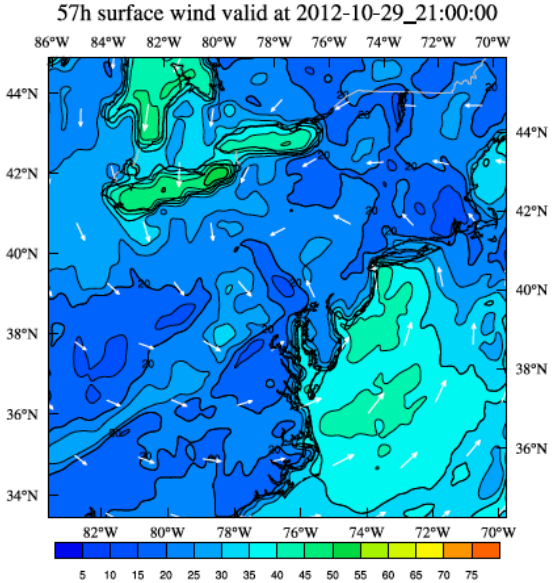


57 h fcst at 21 UTC 29

Hybrid forecast



EnKF forecast



Discussion

• Cycled Hybrid/EnKF DA experiments were conducted with WRF ARW model in 27/9km resolution. 120h forecasts with 3km resolution were carried out at each DA cycle for both the Hybrid and EnKF mean analyses. Statistical performance was evaluated based on these forecast sample.

• Track and intensity were compared among the Hybrid, EnKF and GFS global forecasts, and it is found that both the Hybrid and EnkF forecasts share similar patterns and both are superior to the GFS forecast.

• Aggregated errors show that the Hybrid overall performs better than the EnKF mean forecasts.

• Both the Hybrid and EnKF forecasts are able to capture the evolution of the precipitation pattern and the surface wind structure during the storm life cycle, especially near landfall time, through qualitative comparisons with available data.

• The TSs quantitatively demonstrate that Hybrid obtains the highest score for the precipitation during landfall, and GFS has the lowest scores.