

## GOESR3 Periodic Reporting

**Reporting Period:** 01 January 2018 – 30 June 2018

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**Project Title:** Improving the Assimilation of High-Resolution GOES-16 Water Vapor Variables and Atmospheric Motion Vectors in the HWRF Model

**Project Number:** 439

### Executive Summary

Reliable forecasts of landfalling tropical cyclones (TCs) such as Hurricane Sandy (2012), Matthew (2016), Harvey (2017), Irma (2017) and Maria (2017) are critical for decision making and better preparation. Obtaining good TC intensity forecasts remains one of the most challenging aspects in NOAA operations. Observations of atmospheric water vapor variables and winds in the TC environment as well as in the inner core at high spatiotemporal resolution are very important to the prediction of the storm evolution and landfall impacts. Optimizing the assimilation of that information into the operational Hurricane WRF (HWRF) model is a vital step towards improving TC forecasts. To help address this need, the Advanced Baseline Imager (ABI) (Schmit et al. 2005; 2017) onboard NOAA's next generation of geostationary weather satellites (GOES-R series), beginning with GOES-16 launched on 19 November 2016, is routinely providing high temporal (every 1-5 minutes) and spatial (0.5-2 km) resolution imagery that can provide rapid-update moisture variables and atmospheric motion vector (AMV) information not previously available. This proposed work is to optimize the impact of the high spatiotemporal resolution GOES-R series water vapor information and AMVs for improving TC analyses and forecasts in HWRF. In particular, our study will focus on using GOES-16 observations in the analysis-sensitive regions associated with the TC near-environment, and optimizing the effective assimilation of these data into HWRF for improving TC moisture, wind, track, and intensity forecasts.

### FY17 Milestones

- (a) *Implement HWRF/hybrid GSI on S4 for hurricane forecast experiments;*
- (b) *Implement forward operators for LPWs into hybrid GSI on S4;*
- (c) *Process GOES-16 ABI LPWs for selected TC cases in 2017 and ingest them into BUFR for assimilation experiments;*
- (d) *Begin initial experiments on assimilating ABI radiances versus assimilating LPWs for improving the utilization of moisture information;*
- (e) *Derive AMV datasets at hourly intervals from GOES-16 during selected TCs in the 2017 season;*
- (f) *Begin initial experiments on assimilating these enhanced AMVs into HWRF.*

### Accomplishments (01 January – 30 June 2018)

- (1) All the tasks listed in “FY17 milestones” have been accomplished, as planned and expected.
- (2) LPWs and AMVs are tested successfully in the latest version of HWRf at S4; preliminary results show positive impact from assimilating ABI mesoscale AMVs, and neutral to slight positive impact from assimilating environmental ABI LPWs, respectively, for the Hurricane Irma case. Further experiments are ongoing.

Below is a more detailed report on our progress:

#### 1. All the tasks listed in “FY17 milestones” have been accomplished

- (a) Implemented HWRf/hybrid GSI on S4 for hurricane forecast experiments;
- (b) Implemented forward operators for LPWs into hybrid GSI at S4, therefore the hybrid GSI can be used to assimilate both ABI radiances and LPWs;
- (c) GOES-16 ABI LPWs have been processed for Harvey, Irma and Maria from 2017 hurricane season, and they are ready for GSI to assimilate;
- (d) Initial experiments on assimilating ABI radiances versus assimilating LPWs for improving the utilization of moisture information have been started, results (radiance assimilation versus LPW assimilation) will be presented in the next reporting period;
- (e) GOES-16 ABI mesoscale AMVs during Hurricane Irma at hourly intervals have been processed by the CIMSS TC team and converted to BUFR for initial DA tests in HWRf; these datasets will be expanded to include the larger-scale reprocessing with the GOES-R AMV tracking algorithm. Additional hurricane cases will be processed using this methodology and approach (including both the large TC environmental region and mesoscale TC region);
- (f) Initial experiments on assimilating these LPWs and AMVs conducted on S4 (Boukabara et al. 2016) with the latest version of HWRf, see below the detailed report on the AMV results.

#### 2. Initial experiments on assimilating GOES-16 ABI AMVs conducted on S4 with the latest version of HWRf, with positive forecast impact found

GOES-16 ABI AMV assimilation experiments have been conducted for Hurricane Irma on S4 with the latest version of HWRf. In our previous report, the community HWRf\_v3.9a installed on S4 (HWRf/S4) was compared with the NOAA operational HWRf (HWRf/Op) for Hurricane Irma’s forecast track and intensity categories. The forecasts between HWRf/S4 and HWRf/Op are similar although using the slightly different GSI settings in the assimilation. The RMSE (root mean square error) statistics for track and maximum wind speed forecasts are also reasonably close (see our last report) between HWRf/S4 and HWRf/Op.

In the Irma experiments with mesoscale AMV assimilation, the time (forecast starting times) period is from 18 UTC 04 September 2017 to 00 UTC 10 September 2017. The analysis is cycled every 6 hours followed by 120-hour forecasts.

The control run includes:

- (a) With ocean coupled;

- (b) No hybrid ensemble;
- (c) Vortex correction/relocation included;
- (d) Data assimilated including: conventional, radiance (AMSUA, ATMS, CrIS, IASI etc), operational AMVs.

The experimental run (with GOES-16 mesoscale AMVs):

- (a) Same as control except adding CIMSS-processed GOES-16 AMV datasets (IRLW, IRSW, visible, WVCT) from the limited-sector GOES-16 mesoscale images at hourly intervals into the assimilation;
- (b) AMVs assimilated if their quality indicators met thresholds as determined by previous published studies:  $QI > 80$ , and  $EE < 0.9 * SPD$ ;
- (c) Unlike operational AMV data that cover the fixed, entire ocean basin, these data sets are focused on the moving storm domain (roughly 10 x 10 deg box centered on the storm), and processed at very high densities.

Figure J1 shows the GOES-16 ABI mesoscale AMVs after QC, superimposed on operational AMVs at 06 UTC 05 September 2017 analysis time, derived from four spectral bands. Hurricane Irma is centered near 17N, 57W at this time. The black color denotes the mesoscale AMVs while the other colors denote the operational AMVs. The IR shortwave AMVs are low-level only (700-950mb) while the Water Vapor cloud top AMVs are upper-level only (100-400mb). It can be seen that the mesoscale AMVs provide more information around the inner core area where the operational product does not provide sufficient data for assimilation (the visible band does not provide data at this night time).

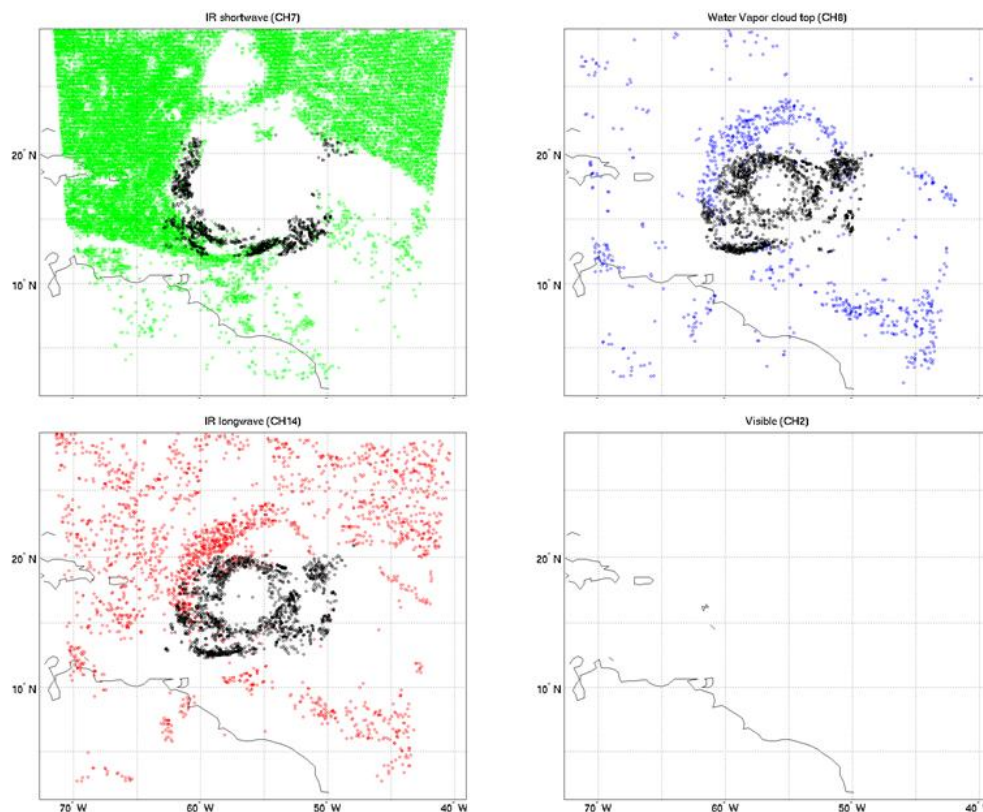
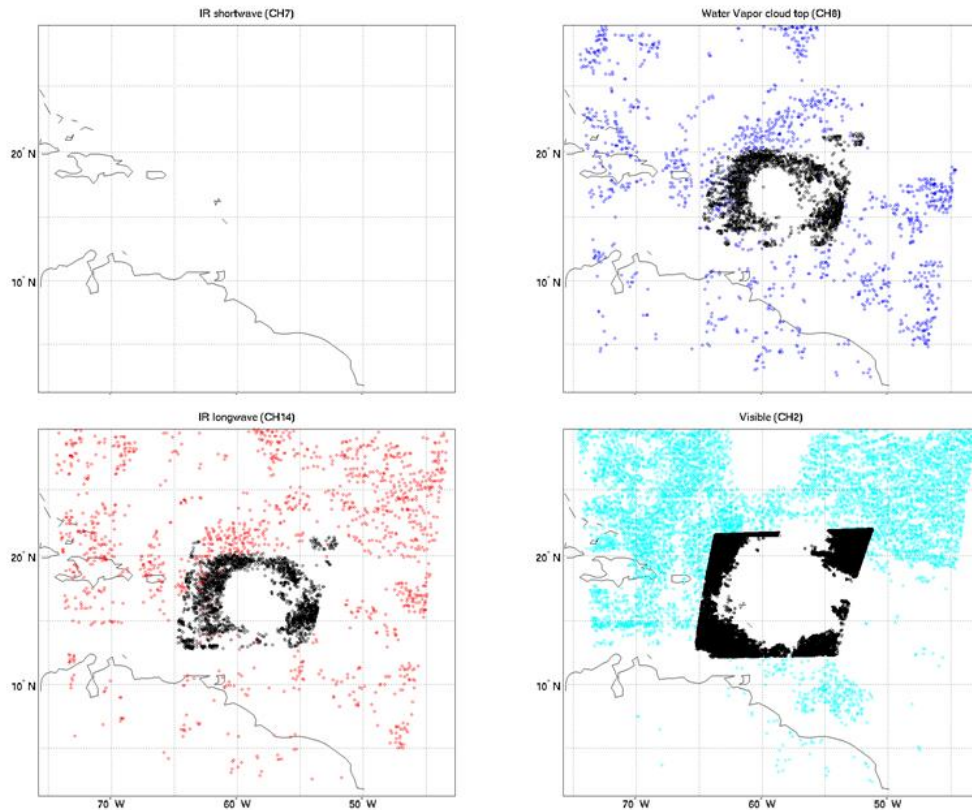


Figure J1. GOES-16 mesoscale AMVs superimposed on operational AMVs at 06 UTC 05 September 2017 analysis time during Hurricane Irma.

Figure JL2 is the same as JL1 but at 18 UTC 05 September 2017 analysis time. Visible AMVs are available for assimilation at this time, but shortwave IR AMVs are not produced due to the high solar reflective component in this band during daytime. It can be noted that there are a lack of AMVs right over the storm center in both examples, even with this version of the mesoscale processing. Part of this is due to the DA QC, and part to the cloud-tracking methodologies. This is a dynamic region of the storm cloud canopy, and the issue is being addressed by the CIMSS AMV team. Modifications/enhancements to the processing will ensure that subsequent datasets will have much better coverage over this region of the hurricane.



*Figure JL2. GOES-16 mesoscale AMVs superimposed on operational AMVs at 18 UTC 05 September 2017 analysis time during Hurricane Irma.*

The assimilation was conducted four times a day (at 00, 06, 12 and 18 UTC) from 18 UTC 04 September 2017 to 00 UTC 10 September 2017, followed by 120-hour forecasts. The track, minimum sea level pressure (SLP), and maximum wind speed (SPD) are derived from forecasts and compared with the best estimate from the National Hurricane Center (NHC). Root mean square error (RMSE) is calculated from 22 groups of forecasts for Hurricane Irma. Note that the sample numbers (at top of the figure) are different in RMSE calculations at different forecast times depend on the availability of the best track data. Figure JL3 shows the track and SPD forecast RMSEs from control (HWRF/S4) in blue line, NOAA operational (HWRF/Op) in red line, mesoscale AMV experiments (HWRF/S4\_AMVs) in green line, along with NOAA GFS operational forecasts in cyan line. It can be seen that adding mesoscale AMVs provides improvement on track forecasts when compared with control, and also slightly outperforms the operational HWRF even without using hybrid ensemble assimilation. For SPD, adding mesoscale AMVs reduces the RMSE from control substantially and consistently, although the improvement is not as large as that in the track forecasts. The differences between control and

HWRf/Op are mainly due to slightly different assimilation settings, for example, no ensemble component in the background error covariance in the control experiments.

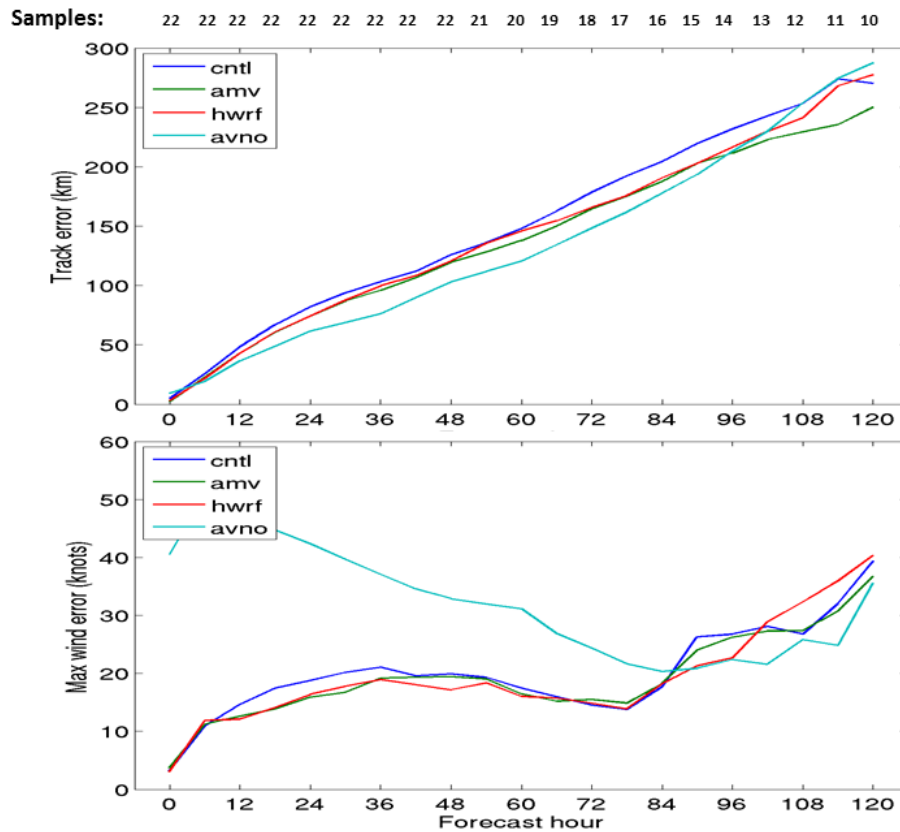


Figure JL3. The track (upper panel) and SPD (lower panel) forecast RMSE from control (HWRf/S4) in blue line, NOAA operational HWRf (HWRf/Op) in red line, mesoscale AMV experiments (HWRf/S4\_AMVs) in green line, along with NOAA GFS operational forecasts in cyan line, for Hurricane Irma (2017).

Figure JL4 is the same as Figure JL3, but focused only on the results from the HWRf control and mesoscale AMV experiments, and more clearly showing the forecast improvements from adding GOES-16 mesoscale AMVs over the control which assimilates just the operational AMV data.

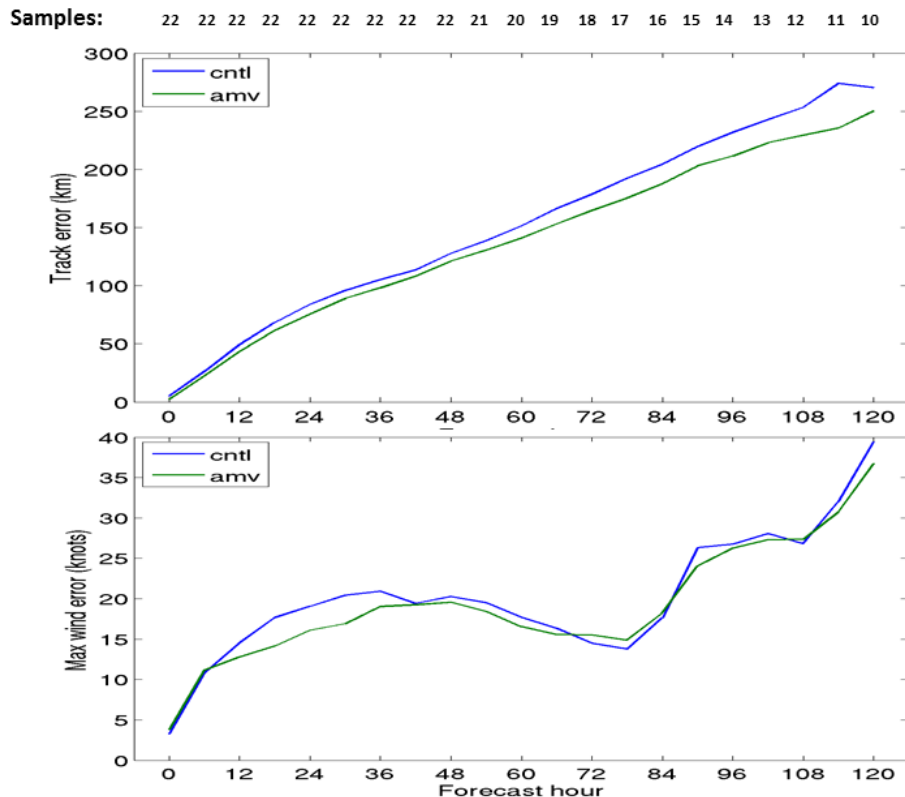


Figure J14. The track (upper panel) and SPD (lower panel) forecast RMSE from control (HWRFS4) in blue line, and mesoscale AMV experiments (HWRFS4\_AMVs), for Hurricane Irma (2017).

## Publications and conference presentations (01 January – 30 June 2018)

### Peer-reviewed journal publications:

Wang, Pei, Jun Li, Timothy J. Schmit, Jiazhen Lu, Bing Lu, Yong-Keun Lee, Agnes H. N. Lim, Jinlong Li, and Zhiquan Liu, 2018: Impact of Moisture information from Advanced Himawari Imager Measurements on Heavy Precipitation Forecasts over land in a regional NWP model, *Journal of Geophysical Research – Atmospheres*, 123, 6022 - 6038. <https://doi.org/10.1029/2017JD028012>.

Lu, J., J. Li et al. 2018: Impact of assimilating Himawari-8 derived water vapour on WRF cumulus and microphysics parameterization schemes for typhoon prediction - a case study of Typhoon Hato, *Journal of Geophysical Research – Atmospheres* (submitted).

### Conference presentations:

Lee et al., 2018: Validation of GOES-16 atmospheric precipitable water and instability indices products for operational applications, 98th American Meteorological Society Annual Meeting, 07 – 12 January 2018, Austin, TX.

Li et al., 2018: All-sky layered precipitable water products from ABI/AHI and their applications in nowcasting and forecasting the severe storms, 98th American Meteorological Society Annual Meeting, 07 – 12 January 2018, Austin, TX.

Li, J., et al., 2018: Value-added impact from geostationary hyperspectral infrared sounding on nowcasting and forecasting high-impact weather events, 98<sup>th</sup> American Meteorological Society Annual Meeting, 07 – 12 January 2018, Austin, TX.

1. Interaction with operational partners – telecon discussion with HWRF team on 02 February 2018.
2. Funding concerns – no.
3. Outside project publicity – CIMSS SDAT webpage, GOES-16 LAP validation tool webpage.
4. Journal articles – one article published, one is under review, see the above for the list.

**Plans for the next Reporting Period**

- More results and findings on assimilation of LPW and AMVs in HWRF;
- Conduct ABI radiance assimilation versus LPW assimilation in HWRF;
- Combining mesoscale AMVs and LPWs;
- Finish a paper on assimilating mesoscale AMVs in HWRF.

**Key Graphics**

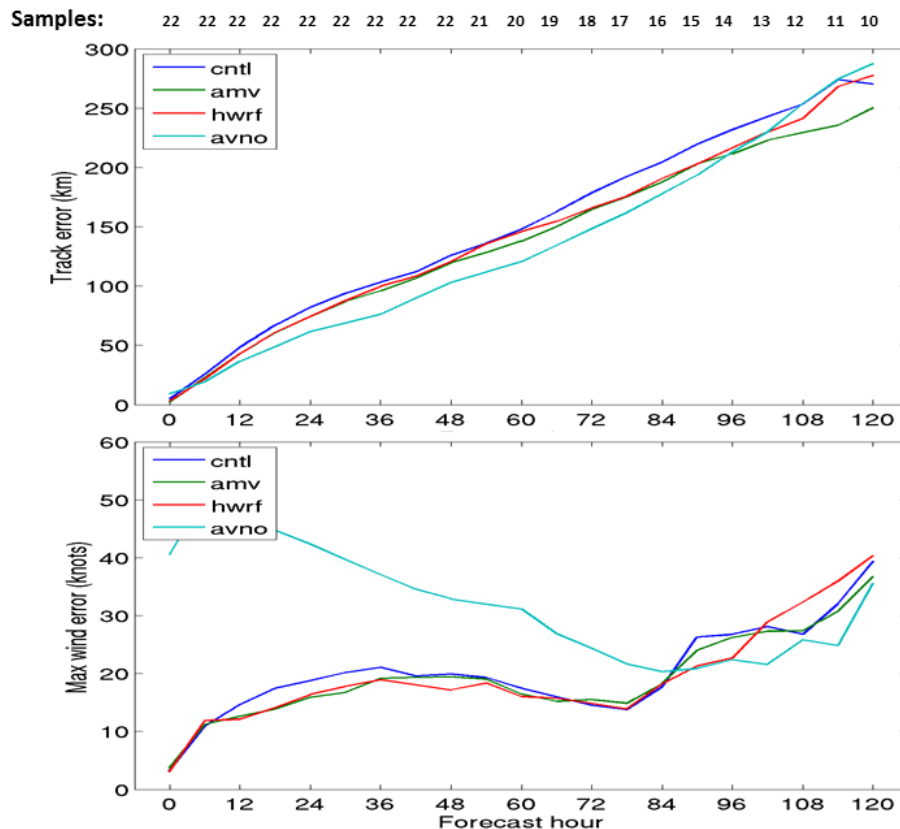


Figure JL3. The track (upper panel) and SPD (lower panel) forecast RMSE from control (HWRF/S4) in blue line, NOAA operational HWRF (HWRF/Op) in red line, mesoscale AMV experiments (HWRF/S4\_AMVs) in green line, along with NOAA GFS operational forecasts in cyan line, for Hurricane Irma (2017).

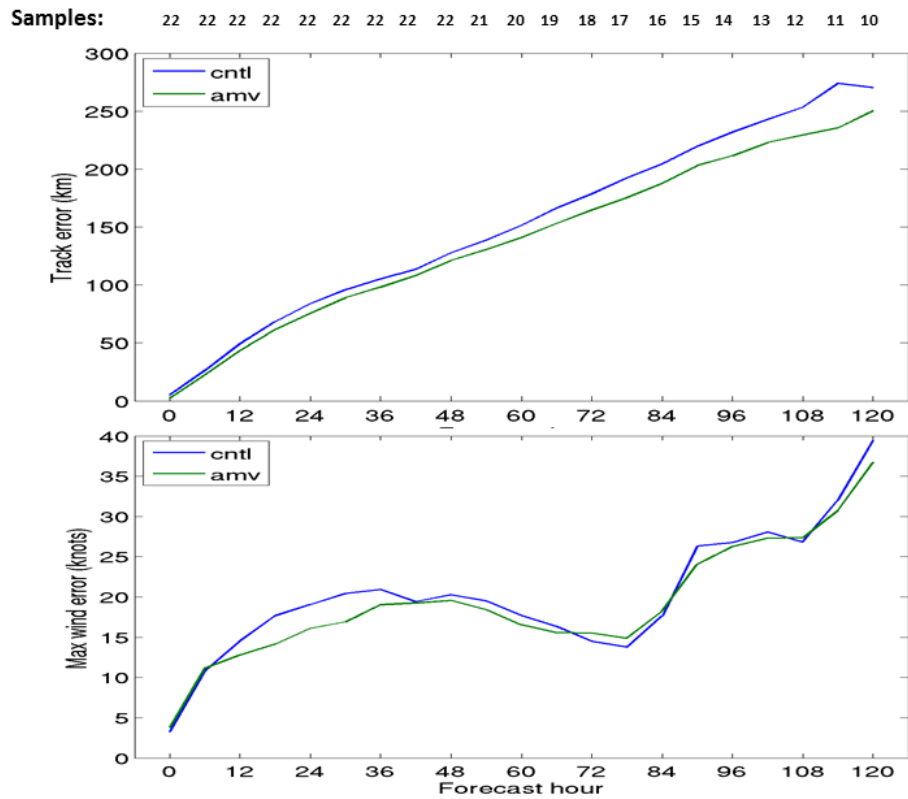


Figure JL4. The track (upper panel) and SPD (lower panel) forecast RMSE from control (HWRF/S4) in blue line, and mesoscale AMV experiments (HWRF/S4\_AMVs), for Hurricane Irma (2017).