GOESR3 Periodic Reporting

Reporting Period: 01 July – 30 December 2019

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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.

FY19 Milestones

- *(a) Investigate quality control (QC) procedures for more effective use of ABI moisture measurements and AMVs in HWRF/GSI;*
- *(b) Test the hourly and 3-hourly data assimilation experiments when the configurable cycling is available for HWRF from EMC;*
- *(c) Run combined experiments including both GOES-16 moisture plus AMVs for selected TC cases;*
- *(d) Conduct a full hurricane season experiments on typical hurricanes and compare impact results against benchmarked Control and operational forecasts;*
- *(e) Final report and publish findings.*

Accomplishments & Plans

Accomplishments (01 July – 31 December 2019)

(1) Most of the tasks listed in "FY19 milestones" have been accomplished, as planned and expected, for example tasks (a), (b), (c), and (d) have been mostly done, (e) has been partially done, the remaining tasks are expected to be finished before 30 June 2020.
(2) The assimilation of rapid scan AMVs has been optimized, the three typical cases (Harvey, Irma and Maria) in 2017 hurricane season have been re-run, and consistent results are obtained for all three hurricanes.
(3) A manuscript titled "Impact of rapid-scan-based dynamical information over the inner-core region of hurricanes from GOES-16 ABI on HWRF hurricane track forecasts" has been published in Journal of Geophysical Research: Atmospheres.

Below is a more detailed report on our progress:

1. Most of the tasks listed in "FY19 milestones" have been accomplished

(a) Investigate quality control (QC) procedures for more effective use of ABI moisture measurements and AMVs in HWRF/GSI

ABI water vapor radiance assimilation over land can be improved by implementing a quality flag (QF) through surface skin temperature Jacobian. The forecasts of tropical cyclones such as Harvey can be improved by effectively assimilating ABI three water vapor absorption band radiances over land with this QF. A manuscript has been accepted by AGU's open journal Earth and Space Science:
Lee, Jung-Rim, Jun Li, Zhenglong Li, Pei Wang, and Jinlong Li, 2019: ABI water vapor radiance assimilation in a regional NWP model by accounting for the surface impact. Earth and Space Science, Vol. 6, 1652 - 1666, doi: 10.1029/2019EA000711.

(b) Test the hourly and 3-hourly data assimilation experiments when the configurable cycling is available for HWRF from EMC

The hourly cycle configuration is not feasible in the currently used HWRF system. However, we take advantage of FGAT (First Guess at Appropriate Time) procedure in the HWRF, which can calculate the innovation (observation – background) at the observation time. The hourly LPW data have been processed and tested in HWRF/GSI, compared with 3-hourly and 6-hourly LPW data assimilation; it is found hourly data can provide better track forecasts, indicating the importance of high temporal information moisture information in TC forecast.

(c) Run combined experiments including both GOES-16 moisture plus AMVs for selected TC cases

The GOES-16 rapid scan ABI AMVs and water vapor information (three layered precipitable water - LPWs) have been tested for Hurricane Harvey (2017) case. Based on the ABI rapid scan mode during TC development, the observations are focused on the storm center domain (10 x 10 degree coverage centered on the TC storm), following the storm movement with time. The rapid scan based AMV datasets are produced at 15 minutes interval based on a set of sequential images scanned every minute for targeted meso sectors. To enhance the coverage, modifications of the minimum gradient, coherency and QC requirements are included. The types of wind to be assimilated include: VIS (0.64 µm) for low level, SWIR (3.9 µm) for cloud drift and low level, WVCT (6.19 µm) for upper level, and IR (11.2 µm) for cloud drift AMVs. For water vapor information, hourly derived three layered precipitable water (LPWs) are assimilated together with rapid scan based AMVs. The control run assimilated conventional data and operational satellite data, which is similar to the NOAA operational setting in HWRF. Analysis is updated every 6 hours, and a 120-hour forecast is followed after each analysis. The period for Harvey experiment is **2017082306 – 2017082612 with 14 analysis cycles.** The value added impact from ABI rapid scan AMVs and LPWs on Harvey track forecasts was found. It shows consistent improvement from AMVs, LPW, and combined AMVs/LPWs, respectively.

(d) Conduct a full hurricane season experiments on typical hurricanes and compare impact results against benchmarked Control and operational forecasts

The three typical hurricane cases (Harvey, Irma and Maria) in 2017 hurricane season have been re-run after AMV data assimilation is optimized; consistent positive results are found from using rapid scan based AMVs. Findings are presented at the Joint AMS/EUMETSAT Satellite Conference, 30 September – 04 October 2019, Boston, MA. A manuscript on our findings has been published in Journal Geophysical Research - Atmospheres. See detailed explanation on manuscript in this report.

(e) Final report and publish findings

A manuscript titled "Impact of rapid-scan-based dynamical information over the inner-core region of hurricanes from GOES-16 ABI on HWRF hurricane track forecasts" has been published in JGR-Atmospheres. " Final report will be submitted before 30 June 2021.

(2) The assimilation of rapid scan AMVs has been optimized, the three typical cases (Harvey, Irma and Maria) in 2017 hurricane season have been re-run, consistent results are obtained for all three hurricanes

In the assimilation of rapid high-resolution AMV datasets prior to the model initialization, modified quality control (QC) steps were invoked in order to try and retain the added wind information content over the storm core and near environment. Here we used a combination of vector quality information provided during the AMV processing (vector Quality Indicator, QI) and an adjustment to the normal observation error profiles for AMV data types. Only AMVs with a QI greater than 0.8 were used in the assimilation, based on previous studies. The traditional observation error profiles of AMVs and associated QC settings are mainly based on the global model systems and operational AMV observations. These settings and profiles are not optimized to retain smaller-scale flow features. After limited empirical experimentation, looser constraints in the GSI gross error check and adjusted observation error profiles for channels 2 and 7 (visible and shortwave IR) by a factor of 0.75 were adapted. Despite these modifications, a large percentage of the AMVs over the storm core region were not provided to the assimilation step, warranting further attention in future experiments

After applying these QC procedures, the GOES-16 rapid-scan AMVs were assimilated into HWRF in addition to conventional data, satellite radiances and operational GOES-13 AMVs. The results versus control runs without the enhanced GOES-16 AMVs for three selected hurricanes in 2017 (Harvey, Irma and Maria) demonstrate a consistent forecast track improvement, with also a notable reduction in the storm size bias especially at longer forecast lead times. Intensity forecasts yielded mixed results, as impacts were generally small.

Figure 1 shows the HWRF forecasted wind structures at three different wind speed ranges (>34, >50, >64 kt) and four different pressure levels (250, 500, 750, 1000 hPa) for Hurricane Maria (2017) case. At the analysis time (0 hour forecast at the top), both the CNTL and the AMV runs have similar storm centers close to the observed location. The wind fields in the CNTL are more symmetric at low levels (750, 1000 hPa) than in the AMV experiment, which is elongated along the east-west direction, particularly for >34 kt winds. At 250 hPa the AMV run has a region of strong wind speed >64 kt on the southeast side of the center, while the CNTL depiction of >64 kt is broken into two parts around the center. After 48 hours into the forecast, the storm strengthens and widens in both experiments. The wind field shape and intensity are also similar. By 96 hours, the storm in the CNTL run at lower levels is larger and the shape more elongated in the northwestern to southeastern direction than in the AMV experiment. The mean tangential wind distribution (not shown) indicates a stronger tangential wind in the CNTL from the beginning to the end of the forecast. Therefore, the track forecast differences between the CNTL and the AMV runs for Hurricane Maria could again result from the different beta effects also noted in the Irma case (not shown).

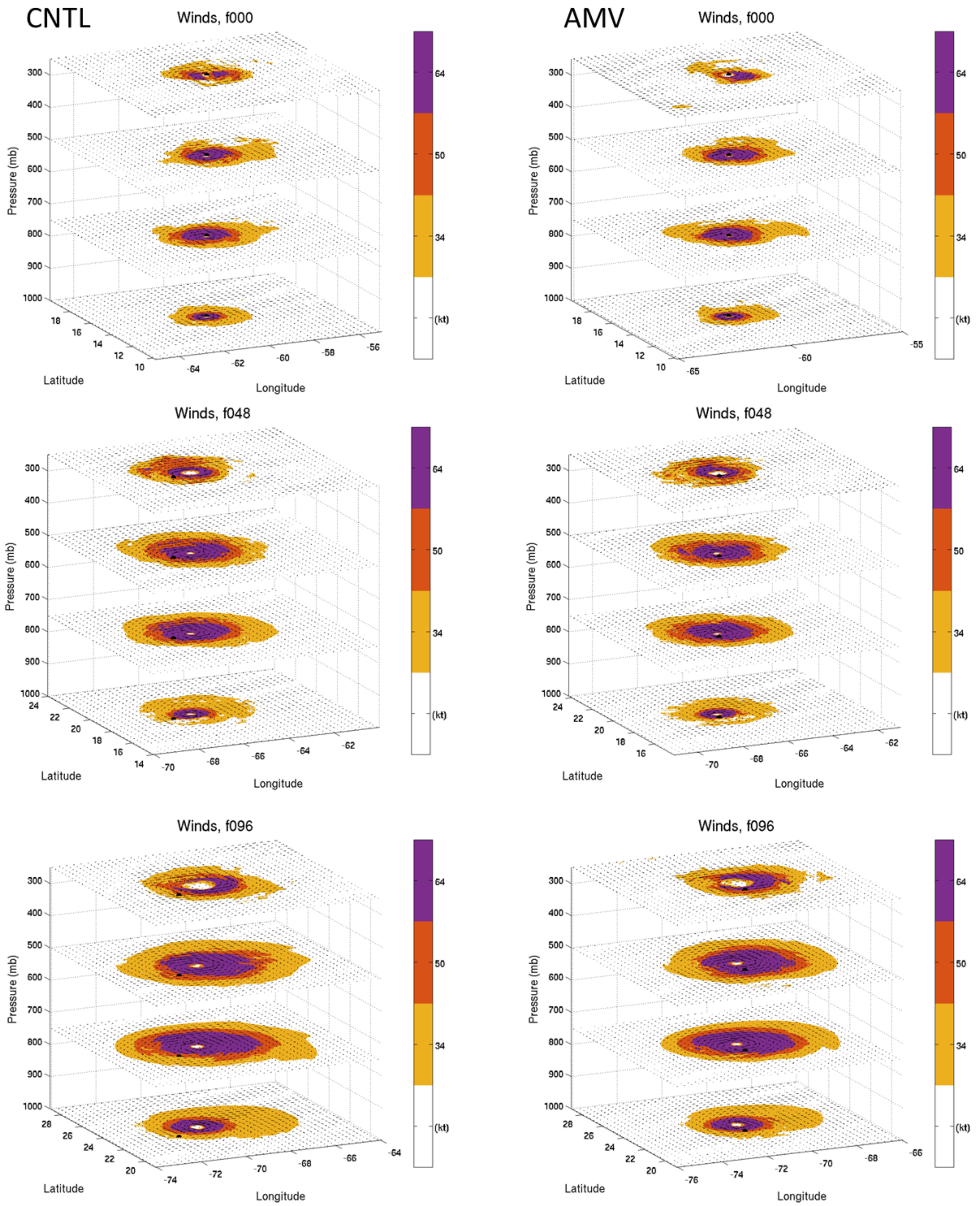

Figure 1. HWRF wind structure forecasts from Hurricane Maria for 4 pressure levels (250, 500, 750, 1000 hPa)

starting from 18 UTC 18 September 2017. Left column: cntl run, right column: AMV exp. Top row: 0 hour forecast, middle row: 48 hour forecast, bottom row: 96 hour forecast. The three colors represent the 3 different wind speed ranges: purple for >64 kt wind, orange for >50 kt wind, and yellow for >34 kt winds.

It should be noted that only a 3DVAR version of HDAS was used in this study due to limited computer resources. 3DVAR uses a static background error covariance matrix, which is mainly constrained by large scale geostrophic balance. Lu et al. (2017) pointed out that using a static background error covariance might not be optimal for the TC inner-core data assimilation, and using a flow dependent error covariance from self-cycled ensemble forecasts could achieve better dynamic and thermodynamic coherency for the TC vortex structure. With that in mind, it is expected that the rapid-scan AMVs could provide further positive forecast impacts (especially for TC intensity) by using the HDAS hybrid-ensemble assimilation method along with improved GSI QC optimization. Advanced assimilation could further show finer inner vortex structure changes which are hardly demonstrable in this study. Finally, the frequent temporal sampling of the AMV datasets could be explored with the more frequent assimilation cycles. A 6-hour cycle was used in this study, but a shorter cycle interval (e.g. 3 hour or even 1 hour) could better match the observation times, which would be helpful in fast-changing vortex region conditions.

While the initial results presented in this study are promising, it is likely that the full information content of the enhanced AMV datasets in the TC core region is not entirely being realized. To address this, future work will focus on optimizing the AMV and GSI QC procedures, examining ensemble-based background error covariance, and including more frequent assimilation cycles. The balance of AMV data assimilation and vortex initialization may also need more attention to get the most benefit from the TC inner core AMV data.

(3) Manuscript on rapid scan AMVs for HWRF assimilation has been published in the Journal of Geophysical Research: Atmospheres

A manuscript titled "Impact of rapid-scan-based dynamical information over the inner-core region of hurricanes from GOES-16 ABI on HWRF hurricane track forecasts" has been written and revised based on reviewers' comments, it has been published in the Journal of Geophysical Research: Atmospheres. The key points and findings of this manuscript are: (a) Mesoscale atmospheric motion vectors (AMVs) have been developed from rapid scan GOES-16 ABI measurements; (b) Assimilation of inner-core regional rapid scan AMVs in HWRF model indicates consistent improvements on Hurricane Harvey, Irma and Maria forecasts; improvements are mainly from better initialization in the inner core region; and (c) Through rapid scan observation mode in the inner core region, the new generation of geostationary satellite provides an important way for hurricane forecast improvement.

Publications and conference presentations (01 July–31 December 2019)

Li, Jinlong, Jun Li, Christopher Velden, Pei Wang, Timothy J. Schmit, and Jason Sippel, 2020: Impact of rapid-scan-based dynamic information from GOES-16 on HWRF hurricane forecasts, Journal of Geophysical Research - Atmospheres. Vol. 125, No. 3, DOI: 10.1029/2019JD031647.

Li et al. 2019: Impact of rapid scan based dynamic information in the inner-core region from ABI on HWRF hurricane forecasts, AMS/EUMETSAT Joint Satellite Conference, 29 Sept – 04 Oct 2019, Boston, MA.

Additional Information

1. Interaction with operational partners – communication with DTC and HWRF team on using the latest version of HWRF and updates. Jason Sippel from NHC provided feedback on AMV assimilation in HWRF.
2. Funding concerns – no.

3. Outside project publicity – CIMSS SDAT webpage, GOES-16 LAP validation tool webpage.
4. Journal articles – Two papers published (one in the Earth and Space Science, another in the Journal of Geophysical Research: Atmospheres). The rapid scan paper in JGR got lots of attentions from both operational and scientific community.

Plans for the next Reporting Period

- Impact from combining rapid scan AMVs and ABI water vapor radiances;
- Final report.

Key Graphics

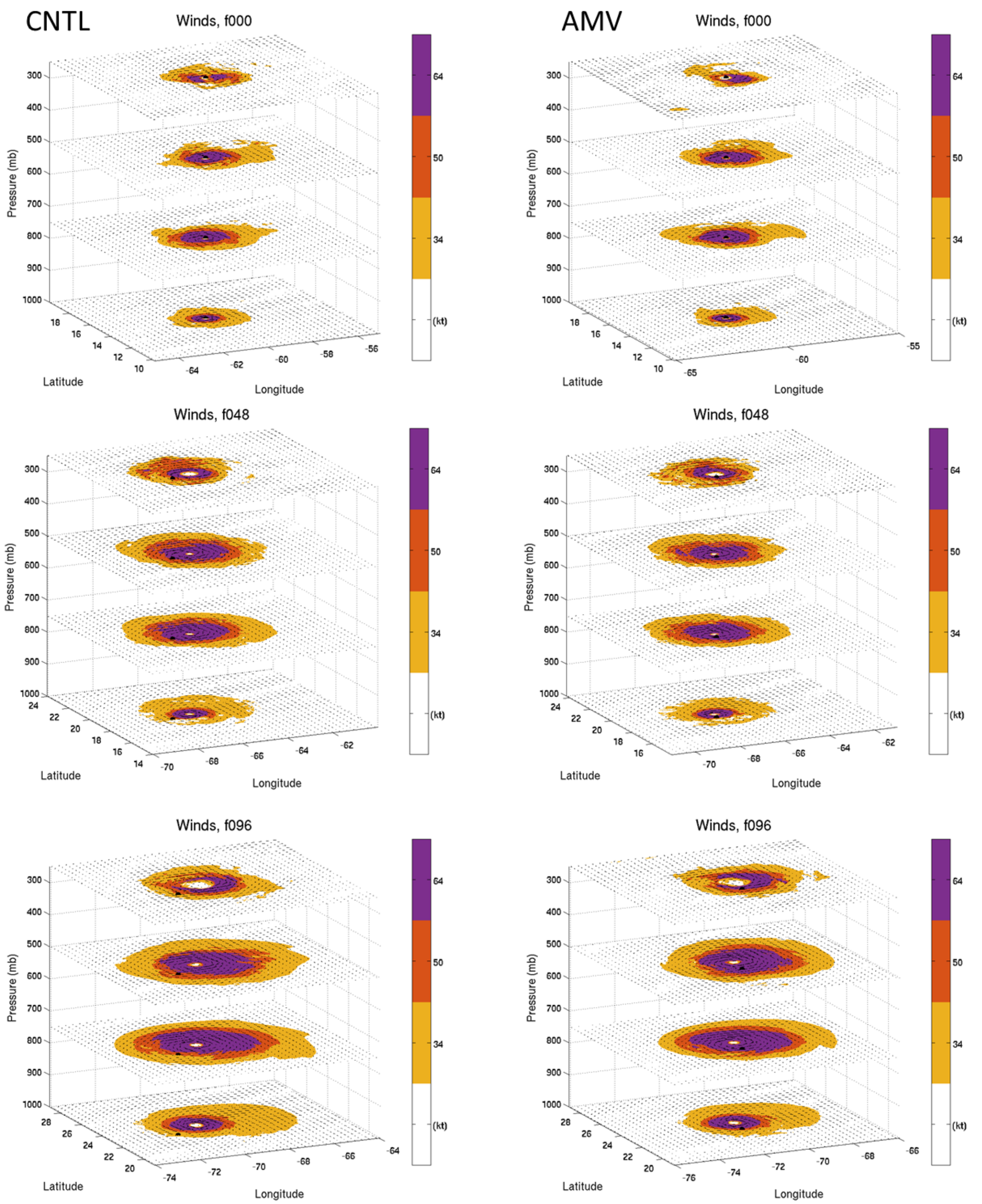

Figure 1 (above). HWRF wind structure forecasts from Hurricane Maria for 4 pressure levels (250, 500, 750, 1000 hPa) starting from 18 UTC 18 September 2017. Left column: cntl run, right column: AMV exp. Top row: 0 hour forecast, middle row: 48 hour forecast, bottom row: 96 hour forecast. The three colors represent the 3 different wind speed ranges: purple for >64 kt wind, orange for >50 kt wind, and yellow for >34 kt winds. (from Li et al. (2020).