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Assimilation of All-sky Infrared Brightness Temperatures and Atmospheric Motion Vectors in Tropical Cyclone Analysis and Forecasting

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1. INTRODUCTION

Accurate initialization of the inner-core structure and intensity of tropical cyclones (TCs) through data assimilation is essential in TC forecasting, while there is a general lack of in-situ observations in the inner-core region over tropical oceans where TC genesis and development occur. Because of the high-spatial and temporal coverage of geostationary satellites, effective assimilation of satellite-measured and/or retrieved data is paramount to further improvement in TC forecasting.

Further enhancement in remote sensing capabilities arrives with the next-generation satellites such as the Advanced Baseline Imager (ABI) on the Geostationary Operational Environmental Satellite-R (GOES-R ABI) to be launched in 2016 and the Advanced Himawari Imager on Himawari-8 launched in 2014. These satellites will provide unprecedented high temporal and spatial resolution infrared brightness temperature, as well as retrieved variables such as atmospheric motion vectors (AMVs). The purpose of this study is to assess the impacts of such newer generation satellites on the analysis and forecast of TCs.

2. METHODOLOGY

2.1. *Models and Data Assimilation System*

An ensemble-based data assimilation system is used to assess the impact of assimilating all-sky infrared brightness temperatures. We coupled the Community Radiative Transfer Model (CRTM) to the ensemble Kalman filter (EnKF) data assimilation system developed at Pennsylvania State University (PSU, Zhang and Weng, 2015) and built around the Weather Research and Forecasting model (WRF). This new

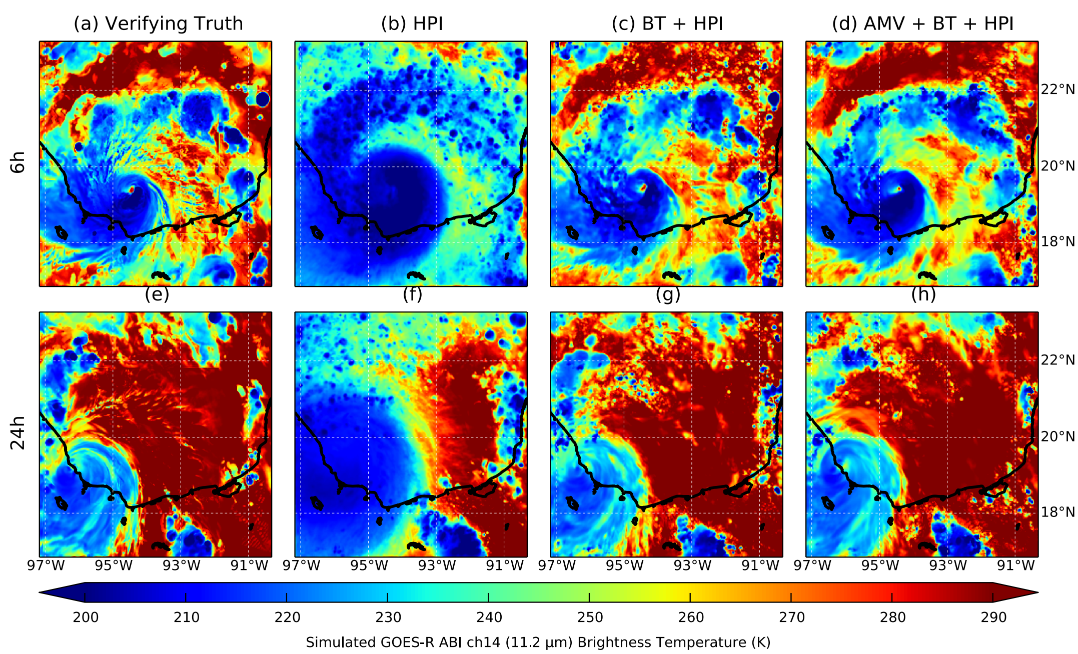

Figure 1. Simulated brightness temperatures of GOES-R ABI channel 14 at (top row) 6-hour after initial assimilation (04Z/17) and (bottom row) 24-hour after initial assimilation (22Z/17) from the (1st column) verifying truth, (2nd column) HPI OSSE, (3rd column) BT+HPI OSSE and (4th column) AMV+BT+HPI OSSE.

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framework enables us to directly assimilate multiple channel brightness temperatures with high temporal and spatial resolution into the WRF-EnKF. In this study, the localization radius of influence is set as 30 km for hydrometeors and 200 km for other variables. For the WRF settings, three two-way nested domains with 27-, 9- and 3-km spacing are used. The simulated brightness temperatures were computed with CRTM.

2.2. *Experimental Design*

Firstly, we conducted Observing System Simulation Experiments (OSSEs). We chose to model hurricane Karl (2010). Hurricane Karl progressed westward across the Bay of Campeche before making landfall on 17 September. The truth-run was initialized at 2100 UTC 16 and integrated until 0000UTC 18.

The first experiment assimilates hurricane position and intensity (hereafter called HPI), the second one added the brightness temperatures to HPI (hereafter called BT+HPI) and the third one contains satellite-retrieved AMVs as well as BT and HPI, hereafter called AMV+BT+HPI. It is worth noting that all those observing systems can be applied globally. The assimilated BT includes three water vapor channels of GOES-R ABI: channel 8 (6.19-μm), channel 9 (6.95-μm) and channel 10 (7.34-μm). The temporal frequency of assimilation is 10 minutes for BT and 1 hour for HPI and AMVs. All experiments assimilated synthetic observations from 2200UTC 16 until 0000UTC 18. Finally, we conducted experiments with the same assimilation strategies as the OSSEs, but using real-data radiance observations of channel 3 from GOES-13.

3. RESULTS

3.1. *Simulated Brightness Temperatures*

Figure 1 shows the EnKF analysis of simulated brightness temperatures of GOES-R ABI channel 14. We utilized channel 14 (11.2-μm) for a verification because it is not assimilated and also because it is a good indicator of cloud reproduction. Assimilation of infrared brightness temperatures (BT+HPI and AMV+BT+HPI) greatly improved model's representation of Karl's detailed structures through 6-hour cycling assimilation (Figure 2a-d). Continuous assimilation for 24 hours further improved the infrared brightness temperature fields (figure 2(f-h)). The structure of the hurricane's primary rainbands, eye, individual convective clouds, and the surrounding cloud-free regions are captured well. Those characteristics are

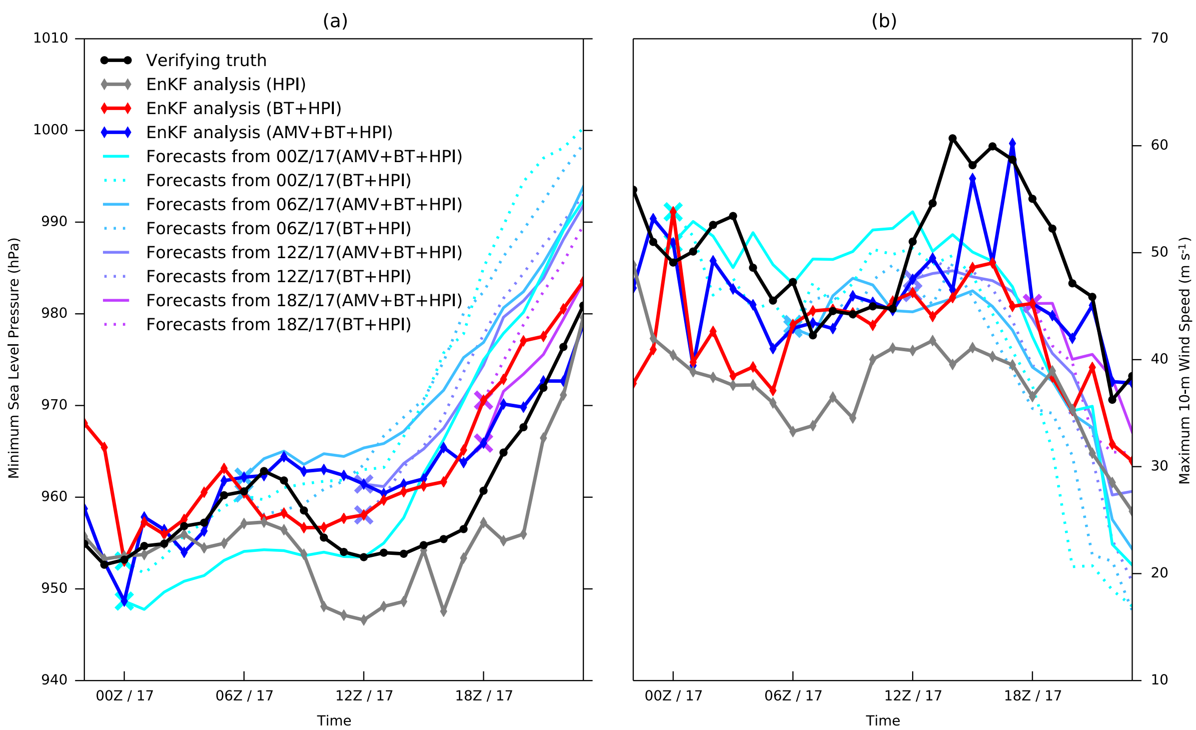

Figure 2. Time evolution of tropical cyclone intensity in terms of (a) minimum sea level pressure (hPa) and (b) maximum 10-m wind speed (m s^{-1}) for the verifying truth and OSSE EnKF analyses and forecasts (color coded).

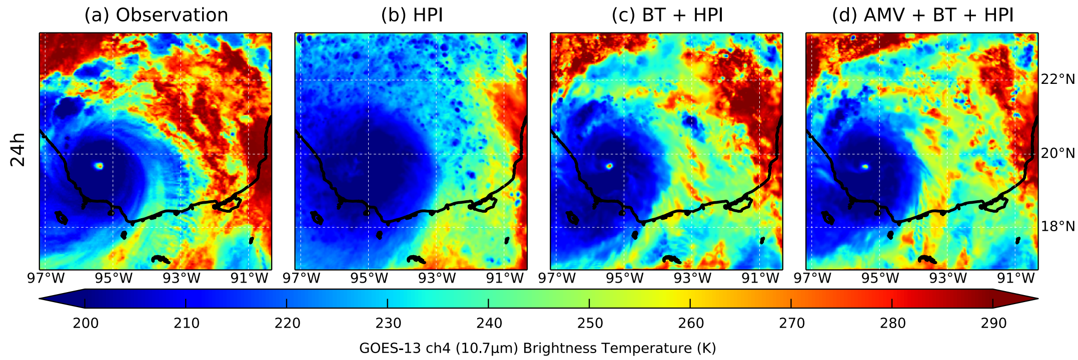

Figure 3. Same as figure 1(e-h) except for using GOES-13 real-observations

poorly captured in the HPI-only experiment, highlighting the impact of BT assimilation. Coincident assimilation of AMVs helped developing more coherent structure of TCs, indicating the complementary impacts of assimilating BTs and AMVs.

3.2. *Tropical Cyclone Intensities*

The impacts of assimilation are not limited to infrared brightness temperature field. In Figure 2, the EnKF analysis of both BT+HPI and AMV+BT+HPI generally followed the temporal change of TC intensities. In particular, assimilation of brightness temperatures helped capturing the maximum 10-m wind speed, which is not well captured by HPI-only simulation.

The deterministic forecasts from the EnKF mean analyses with assimilation of brightness temperatures (BT+HPI) at different times also generally captured the weakening tendency of the simulated Karl. Moreover, most of the forecasts from the AMV+BT+HPI EnKF analysis improved accuracy from BT+HPI, further exhibiting the complementary relation between satellite-measured brightness temperatures and satellite-retrieved AMVs.

3.3. *Real-Data Assimilation*

Finally, Figure 3 shows the result of assimilating real GOES-13 measured and retrieved data. Even with the larger uncertainty of real-data compared to synthetic observations from the perfect-model OSSEs, the EnKF analyses have consistent improvement with those from OSSEs. They captured the complicated structure of Karl, indicating the importance of not only retrieving AMVs, but also directly assimilating brightness temperatures from even the current generation geostationary satellites (GOES-13).

4. CONCLUSIONS

We assessed the impact of assimilating satellite-measured all-sky infrared brightness temperatures and satellite-retrieved AMVs. Using the CRTM in the Pennsylvania State University WRF-EnKF framework, we have captured well the systematic structure of the hurricane, as well as the detailed individual convective clouds. The assimilation of BT and AMVs vastly improved the ensemble analysis and forecast capabilities of TC structure and intensity. Because this is a preliminary result, further investigation must be conducted to make the full use of current and future advanced satellite infrared imagers.

5. REFERENCES

Zhang F. and Weng Y. (2015). Predicting Hurricane Intensity and Associated Hazards: A Five-Year Real-Time Forecast Experiment with Assimilation of Airborne Doppler Radar Observations. *Bulletin of the American Meteorological Society*, *96*(1), 25–33. doi:10.1175/BAMS-D-13-00231.1