Development of Advanced Data Assimilation Techniques for improved use of Satellite-Derived Atmospheric Motion Vectors

Reporting Period: 1 May 2015 – 30 April 2018

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7) 05/01/2015 – 04/30/2018
8) No
9) Final
10) Performance Narrative

Executive Narrative

A new Atmospheric Motion Vector (AMV) nested tracking algorithm was developed for the Geostationary Operational Environmental Satellite R/S series (GOES-R) Advanced Baseline Imager (ABI). This algorithm has been demonstrated to significantly improve the slow speed bias inherent in the AMVs derived from geostationary satellites. The benefit of AMVs derived from this new algorithm to global Numerical Weather Prediction (NWP) is currently being demonstrated at NWS/NCEP/EMC thanks to funding from the GOES-R satellite program. Newly developed quality control procedures and Gridpoint Statistical Interpolation (GSI) software modifications are currently being transferred to the National Centers for Environmental Prediction's (NCEP) Environmental Modeling Center (EMC) branch for inclusion into the Global Data Assimilation System / Global Forecast System (GDAS/GFS).

NCEP global model forecast winds and cloud motion AMVs both possess large errors in the tropics ($25^oN – 25^oS$). This characteristic is usually attributed to the localized deep convection influencing both the model winds and the generation of the cloud motion AMVs. The Clear Air Water Vapor (CAWV) AMVs, however, track water vapor image features instead of clouds making them independent of cloud dynamics. While this is clearly a benefit, there is concern about the depth of the layer that is being tracked. The depth of the layer being tracked depends on the vertical distribution of water vapor in the column. Drier atmospheres will typically allow the water vapor channel to see further into the atmosphere resulting in the derivation of winds over a thicker layer, thus increasing the uncertainty of the heights assigned to these AMVs. By focusing our data assimilation work to the region with the greatest wind errors and the most water vapor, we hope to maximize the potential for success.

In May 2014, the National Environmental Satellite, Data, and Information Service (NESDIS) Office of Satellite and Product Operations (OSPO) began production of hourly AMVs from the GOES satellites using the NESDIS heritage AMV algorithm. In preparation for GOES-R, NESDIS/OSPO also plans to generate AMVs using the new nested tracking AMV algorithm with the current GOES satellites. Work is currently underway to transition the NCEP GDAS/GFS to include the new GOES-R AMVs. Similar efforts will be required for other NCEP data assimilation systems to successfully use this new data stream. An example is the data assimilation system associated with the Hurricane Weather Research and Forecast (HWRF). The HWRF also uses the GSI, thus the current GDAS/GFS work can be leveraged to transition the HWRF to the new data set. The nested tracking AMV algorithm also provides the opportunity to generate AMVs at high spatial and temporal resolution potentially increasing the positive impact of this data type on the skill of the higher resolution assimilation systems such as the HWRF.

Overall Status: **GREEN**

	Green [1] (Controlled)	Yellow [2] (Caution)	Red [3] (Critical)	Deviation Summary[4]
Budget	☒	☐	☐	
Schedule	☒	☐	☐	
Scope	☒	☐	☐	

[1] *Project is within budget, scope and on schedule.*
[2] *Project has deviated slightly from the plan but should recover*
[3] *Project has fallen significantly behind schedule, is forecast to be significantly over budget, and/or has taken on tasks that are out of scope.*
[4] *Details of deviations provided in subsequent section of report*

Task 1: Clear Air Water Vapor AMV Assimilation in the Tropics

	Scheduled Milestones / Deliverables			
Milestone	**Start Date**	**Forecasted Completion**	**Actual Completion**	**Status**
1. Completion of the quality control procedures for the clear air water vapor AMVs	May 2015	September 2015	September 2015	Completed
2. Completion of tests involving the spatial and temporal thinning and review of assimilation weights	September 2015	May 2016	June 2016	Completed
3. Presentation to NCEP/EMC at NCWCP	Open	May 2016	July 2016	Completed
4. Presentation to International Winds Working Group	Open	June 2016	June 2016	Completed
5. Completion of the two months during two seasons experiments	May 2016	January 2017	February 2016	Completed
6. Completion of GSI software and regression tests	February 2017	April 2017	March 2016	Completed

Table 1. Project Milestone

Status Definition: Green (will meet schedule), Yellow (milestone will be delayed), Red (milestone cannot be met on current path)

	Accomplishments & Plans

Accomplishments Summary

Milestone 1. Completion of the quality control procedures for the clear air water vapor AMVs.

The initial look at the quality control parameters derived for the CAWV AMVs identified several issues. Typically during their generation, the AMVs are compared to the most recent forecast. If the AMV's direction is not within $+/- 50^o$ of the forecast, the AMV is rejected. This comparison to the model

forecast was not incorporated into the generation of the CAWV AMVs. A second concern is with the skill of the current AMV quality parameters used with the infrared (IR) and Cloud Top Water Vapor (CTWV) AMVs. Expected Error (EE) is generally used to determine the quality of the slower AMVs (less than ~20m/s). This quality parameter was not updated for the current GOES satellites. As such the EE shows no skill in identifying good/bad AMVs. The other quality parameter is called the Quality Indicator or QI and is also showing no skill at predicting the quality of the CAWV AMVs.

We have reviewed the quality control procedures used by the other AMV types in the GSI and performed analysis on observation minus model background error statistics. It was found that the slower CAWV AMVs (less than 10 m/s) generally have the greatest departure with respect to the model forecast. During this analysis to determine quality control procedures, several misperceptions were identified. The CAWV AMVs have a positive (fast) speed bias, the error characteristics do not have a latitudinal dependence, and the vertical error structure is consistent with the other AMV types. Figure 1 shows the mean speed departure as a function of latitude for the GOES-13/15 AMVs. The errors characteristics of the CAWV AMVs are a little higher but have the same latitudinal characteristics as the other AMV types. The speed departure statistics in Figure 2 shows the impact of including a minimum speed requirement of 10 m/s to the quality control on the count and bias of the departure statistics. The speed departure distribution is relatively normal with an approximately 1-2 m/s bias. After adding a Log-Normal Vector Difference (LNVD) check, a procedure planned for GOES-R cloud tracked AMVs, the CAWV AMVs have very similar error characteristics.
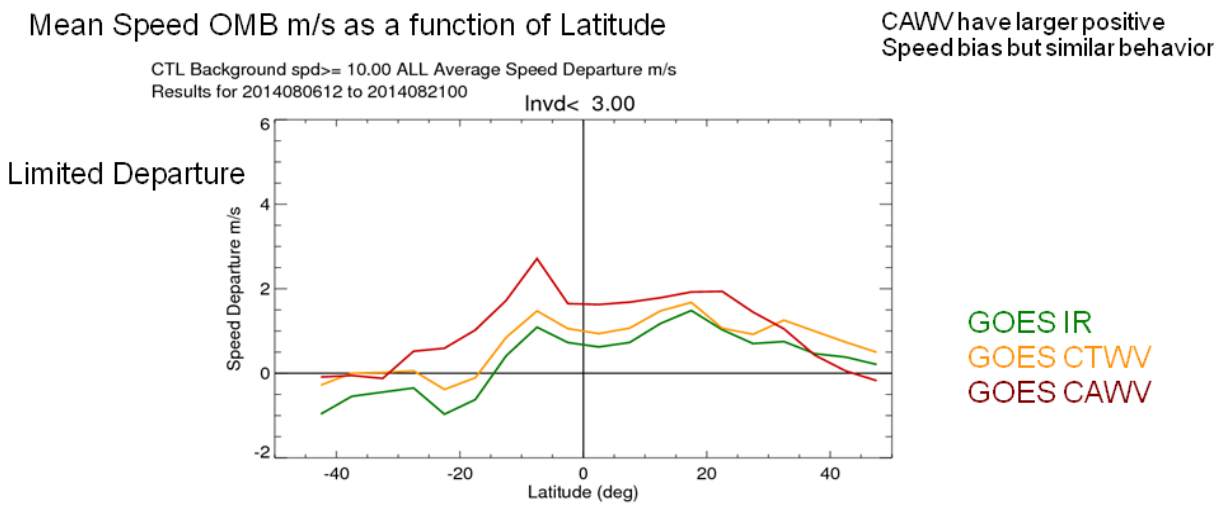

Figure 1: Mean speed Observation – minus- background statistics for the GOES IR (green), GOES Cloud Top Water Vapor (yellow) and GOES Clear Air Water Vapor (red) atmospheric motion vectors. The GOES CAWV AMVs have a faster speed bias than the other AMV types but show no latitudinal anomalies with respect to the other AMV types. The peak at 10°S is likely due to an increase in the background forecast error in the data sparse southern hemisphere tropics.
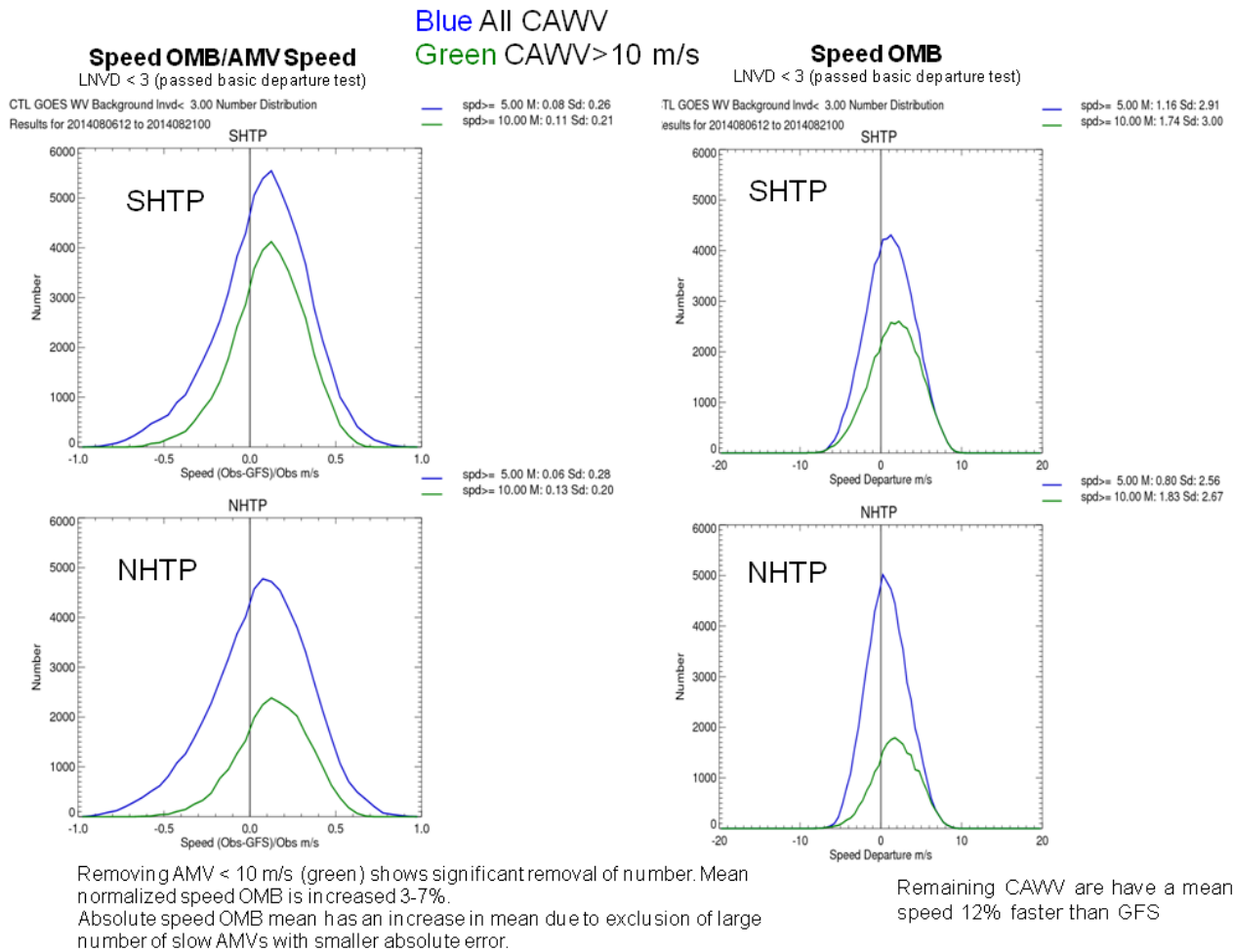
Figure 2: Statistics before and after the 10 m/s quality control was applied. The distribution is relatively normal with an approximately 1-2 m/s speed bias. NH = Northern Hemisphere, SH = Southern Hemisphere, TP = Tropics (0° – 20° Latitude) NHTP = Northern Hemisphere Tropics (5^oN to 20^oN), SHTP = Southern Hemisphere Tropics TP (20^oS to 5^oN)

Milestone 2. Completion of tests involving the spatial and temporal thinning and review of assimilation weights.

The assimilation weights for the CAWV AMVs were originally set to missing. We have determined that the vertical error characteristics of the CAWV AMVs are similar to the IR and CTWV AMVs. We have used the same values specified for the IR and CTWV AMVs. The CAWV AMVs are also incorporated into the non-linear QC, which also adjusts the assimilation weights.

In reviewing the spatial and temporal coverage, it was determined that the GOES CAWV AMVs have generally similar characteristics to the other GOES upper level AMV types. In light of this, we decided to extend the CAWV AMVs coverage from the original plan of 25°N/S to approximately 55° N/S to be consistent with the other GOES AMVs. Statistics suggested there was no benefit from temporal thinning the CAWV AMVs in the current GFS so the CAWV AMVs are used every hour similar to the other GOES AMV types.

Milestone 3. Presentations to NCEP/EMC on project progress.

Several presentations were given by Sharon Nebuda to NCEP/EMC as to the status and progress of this project at NCEP/EMC's bi-weekly AMV assimilation meetings. Discussions with NCEP/EMC, NESDIS/STAR and others concerning quality control procedures and experiment design during these meetings improved the scientific merit of this project and everyone's overall knowledge of AMV assimilation.

Milestone 4. Presentation to International Winds Working Group.

The 13th International Winds Workshop was held in Monterey California at the end of June 2016. A presentation was made to attendees about this research and an extended abstract has been submitted.

Milestone 5. Completion of the two months during two seasons experiments.

To evaluate the impact of the CAWV AMVs on the GFS/GDAS, two seasons were selected for the control and experiment simulation pairs, Feb-Mar and July-Sep 2015. Quality control procedures remained as described above: a minimum speed of 10 m/s was required, the near surface and tropopause checks were included to remove data from these areas, and finally the Log-Normal Vector Difference (LNVD) check as well as a directional departure check was applied. The observation error profile was specified with the same profile used by the GOES infrared and cloud top water vapor AMVs. All experiments were completed with the T670 Hybrid EnKF GFS/GDAS with the most current pre-implementation GSI version available at the start of these simulations.

For both seasons, the effect of including the CAWV AMVs on the analysis state is a regional strengthening of the circulation in the tropics around 350 hPa. This impact is at the level with the maximum data count for the GOES East and West satellite regions. The 15 Jul – 15 Aug 2015 average U component speed difference for the experiment with the CAWV AMVs from the control at 350 hPa is shown in Figure 3. The speed is increased for both the Easterlies along the equator and the Westerlies at mid latitudes, especially within the region of both GOES satellites.

The change to the GFS forecast skill is neutral as measured by the standard verification software package. By verifying the forecasts of the control and experiment to the assimilation which included the AMVs, the presence of the CAWV AMV data on the initial condition is evident in the Vector Wind RMSE. Figure 4 shows the mean forecast RMSE for the 500 hPa vector wind in the tropics for forecasts during Jul-Sep 2015 for the control and experiment; the impact on the initial conditions with the CAWV AMVs are seen up to forecast day 3. Finally, noting that the hurricane sample is too small from one season (Jul-Sep 2015) to be conclusive, the storm tract statistics were found to be mildly improved and, more importantly, not degraded.
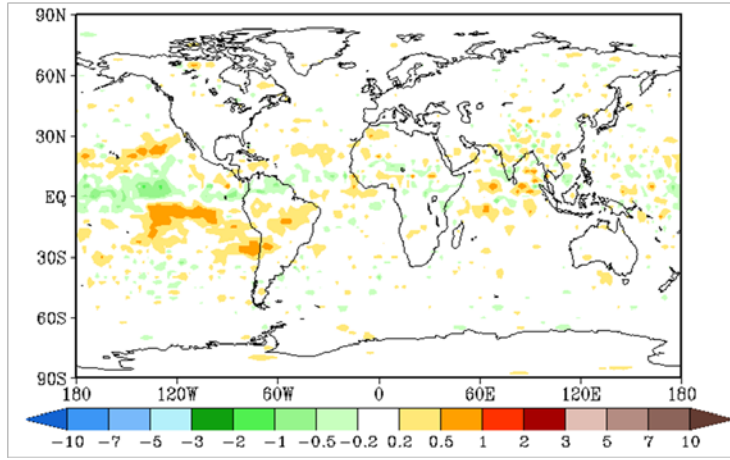
Figure 3: Average U component of wind difference (m/s) at 350 hPa for 15 July – 15 August 2015.
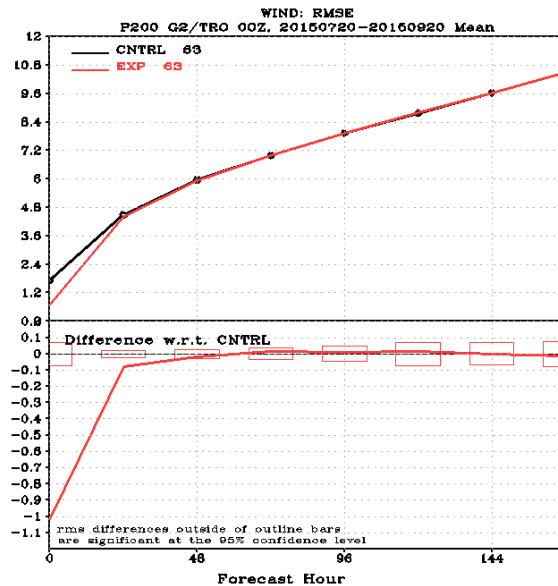

Figure 4: Mean Wind RMSE for forecasts during 20 July – 20 Sep 2015 for EXP experiment which included the CAWV AMVs and the CNTRL simulation without the CAWV AMVs.

Milestone 6. Completion of GSI software review and regression tests.

NCEP/EMC has specific procedures and coding standards for transitioning new GSI capabilities to NCEP Operations. These procedures are outlined on their subversion GSI home page. These procedures and standards were followed through the course of this project. A branch of NCEP/EMCs GSI trunk was used for code development, updated when necessary. Experiment procedures were reviewed, and results were presented to the review committee. The review committee approved these changes in March 2017. The use of the GOES CAWV AMVs was transitioned into NCEP Operations during the July 2017 upgrade.

Additional Work. Examination of Clear Air Water Vapor AMVs from Himawari-8 AHI imagery.

The successful completion of the milestones for Task 1 allowed for the additional effort to investigate CAWV AMVs produced by NESDIS/STAR using the Advanced Himawari Imager (AHI) on Himawari-8. NESDIS/STAR has processed the three water vapor channels available from AHI; the three channels allow tracking features at a range of heights. The motivation to explore this data is two-fold, increasing AMV coverage in the Eastern Pacific to improve forecast skill as well examining this data as a proxy for GOES-R ABI multi-channel water vapor AMVs. Two weeks of collocated background winds were collected from the GDAS for the AMVs to determine quality control procedures. The speed departure for the three AMV channels is similar to current GOES CAWV in that the bias tends to be positive with a mean of 0.5 m/s for the highest channel (6.2 μm), 1.5 m/s for the mid-level channel (6.9 μm), and 0.8 m/s for the lowest channel (7.3 μm). The number of AMVs for the mid-level water vapor channel is of comparable magnitude with respect to the highest peaking channel whereas the lowest channel has significantly less AMVs.

Quality control procedures were chosen to follow those established for the GOES-13/15 CAWV AMVs which includes a direction departure limitation of 50° and a vector difference departure limit using the Log Normal Vector Difference check to be less than 3. The requirement of a minimum AMV speed was not applied; the improvement in the water vapor imagery from the AHI should translate into a reduction in AMV tracking error. The observation error for this hourly available AMV was set to the same error profile as the GOES-13/15 AMVs. Using these settings, a control and experiment GDAS simulation was completed for June-July 2016. The impact of the CAWV AMVs on the analysis circulation mean wind components for July 2016 at 300 hPa is shown in Figure 5.
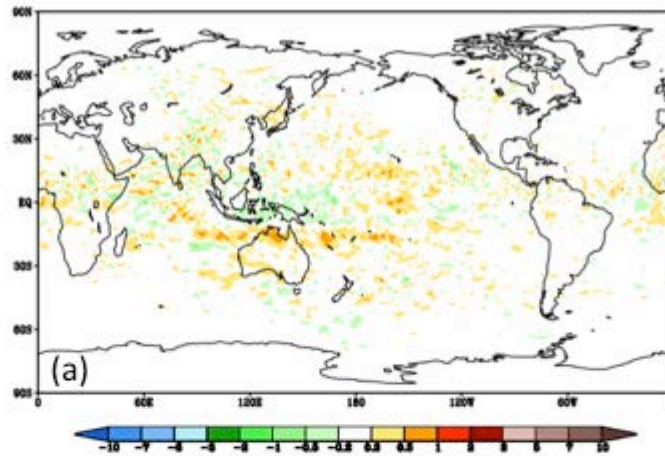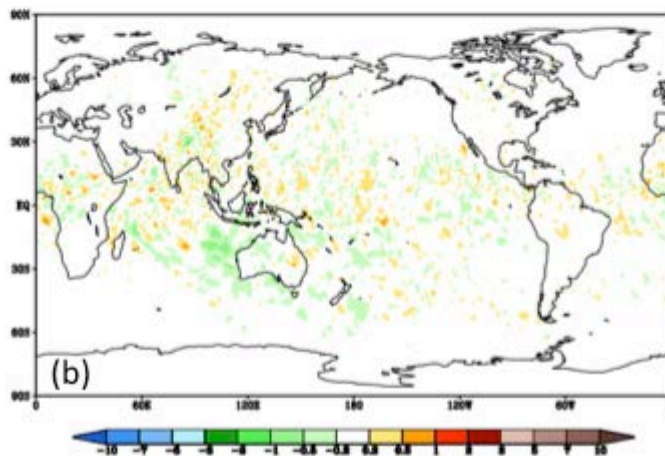
Figure 5: 300 hPa wind difference for the GFS experiment simulation which included the Himawari-8 CAWV AMVs minus the control simulation for the (a) zonal component and (b) meridional component for July 2016.

Examining the CAWV AMV impact on the GFS forecast skill revealed similar neutral impact as the addition of the GOES-13/15 CAWV AVMs; both data sets are regional in scope and limited to the mid-troposphere. The Himawari-8 CAWV AMVs did however have a very small but statistically significant negative impact to the five day forecast 500 hPa height anomaly correlation shown in Figure 6. To reduce the negative interaction of this data with the GDAS system, quality control requirements should be more restrictive to improve the performance. A minimum AMV speed requirement and restricting the vertical location of the AMV data are being considered. Guidance in this decision will be provided from collocated rawinsondes departure statistics collected by NOAA/NESDIS. Final decisions about quality control procedures and evaluating the impact on forecast skill will be made when future funding is obtained.
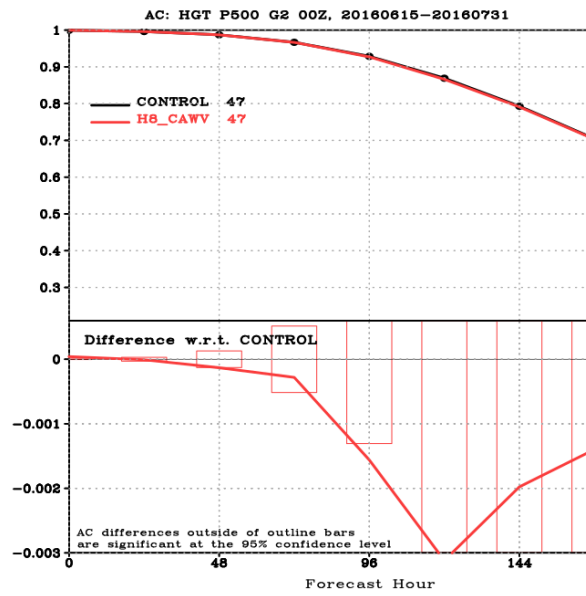
Figure 6: Global 500 hPa Geopotential height anomaly correlation for the GFS experiment simulation, H8_CAWV, which included the Himawari-8 CAWV AMVs and the control simulation, CONTROL, for 15 June to 31 July 2016.

Task 2: Transition HWRF to hourly AMV assimilation and GOES-R data format.

		Scheduled Milestones / Deliverables		
Milestone	**Start Date**	**Forecasted Completion**	**Actual Completion**	**Status**
1. Complete the generation of GOES-R like AMVs for the case storms	May 2015	June 2015	April 2016	Completed
2. Complete the development of HWRF specific quality control procedures. Compute forecast impact statistics for case storms and portions of the 2014 hurricane season	May 2015	January 2016		Completed
3. Add clear air water vapor, shortwave, and visible GOES AMVs and complete NCEP/EMC/HWRF implementation tests.	August 2016	December 2016	March 2017	Changed/Completed
4. Presentation to NCEP/EMC at NCWCP		December 2016	December 2016	Completed
5. Attend International Winds Working Group	Open	June 2016	June 2016	Completed

Table 1. Project Milestone

Status Definition: Green (will meet schedule), Yellow (milestone will be delayed), Red (milestone cannot be met on current path)

|	Accomplishments & Plans

Accomplishments Summary

Milestone 1. Complete the generation of GOES-R like AMVs for the case storms.

We identified the time periods and consulted with NCEP to prioritize the tropical storms. The case storms are divided into three groups, high priority storms, low priority storms, and implementation (all) storms. There are 6 high priority storms and they include the Atlantic Storms Florence, Ernesto, Humberto, and Karen and the East Pacific Storms Miriam and Hector. The University of Wisconsin-Madison Space Science and Engineering Center's GOES archive was accessed to retrieve images for processing. AMVs (all types including VIS (0.65um), SWIR (3.9um), WV (6.7um), and LWIR (11um))

have been successfully reprocessed using the GOES-R algorithms every hour for the entire lifetime of Florence, Ernesto, Miriam, and Hector.

GOES-R like AMVs for Atlantic storm Florence (2012) were generated and sent to NCEP to have sample BUFR files generated. Several problems that resulted in missing data or misclassification of the AMVs were identified and resolved. GOES-R like AMVs for 5 storms (Florence, Ernesto, Humberto, and Karen) for Atlantic and Hector in the East Pacific have been completed. BUFR files needed for assimilation were also generated.

During this project, the list of storms required for HWRF implementation tests was updated. 2015 storms were added to the list. Additional storms for 2013 and 2014 were also added. 2011 storms were removed as inputs required for retrospective runs were deleted in January 2016.
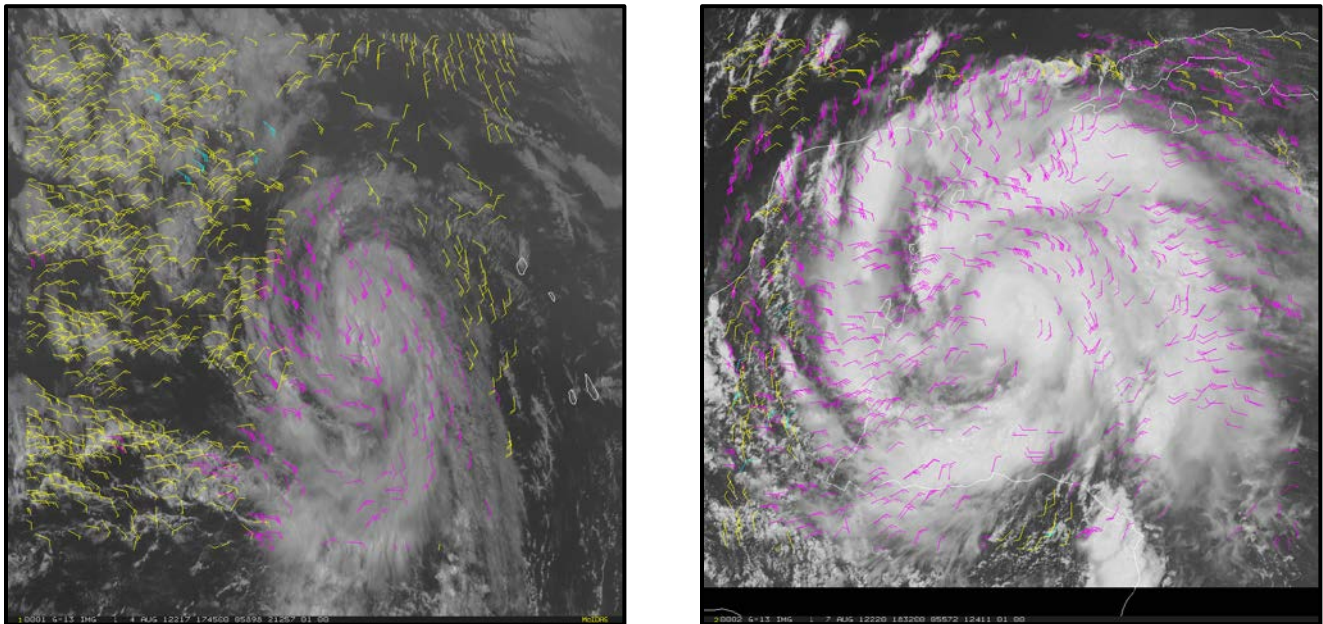
Figure 7: AMVs centered over Tropical Storms Florence (left) and Ernesto (right). Upper level (100-400hPa) AMVs are show in magenta, Mid-Level (100-400 hPa) AMVs in cyan, and Lower Level (> 700 hPa) are shown in yellow.

Milestone 2. Complete the development of HWRF specific quality control procedures. Compute forecast impact statistics for case storms and portions of the 2014 hurricane season.

Access to JET was granted on 26 January 2016. Account setup was completed on 3 February 2016 and access to the restricted data was approved on 15 March 2016. Agnes Lim attended the HWRF tutorial from 22-27 January to familiarize with the model. A branch (LIM_HWRF_GOESR_AMV) using the GSI trunk (29 April 2016) was created within the GSI software management system. HWRF (trunk version as of 31 March 2016) and this new GSI branch were checked out and set up on JET. Additional quality control needed for the assimilation of the GOES-R like AMVs that did not make it into the GSI trunk were added.

Hurricane Ernesto was run using the LIM_HWRF_GOESR_AMV branch. The observational errors for shortwave, clear air water vapor and visible winds were not set. For the clear air water vapor winds, we adopted the same observational errors as the infrared and cloud top water vapor. Larger observational

errors were used for the shortwave and visible winds. Analyzing the observational counts assimilated showed that a large proportion of the visible winds were being rejected due the PCT1 check. PCT1 is the standard deviation of the group of motion vectors for a tracked cluster divided by the distance the cluster travels. Large and small extreme values of PCT1 were found to be associated with larger mean speed errors and a fast bias respectively in other wind types. Since past studies on this QC parameter focus on the infrared winds and in discussions with NESDIS/STAR, this QC check was deemed unreliable for the visible winds. Most of the observations were recovered when this check was disabled as shown by the difference between the red and blue curves in Figure 8. Previous studies assimilating AMVs for hurricane forecast indicated greater speed and direction difference could be allowed. After reviewing the log-normal vector difference (LNVD) check, it was also disabled.
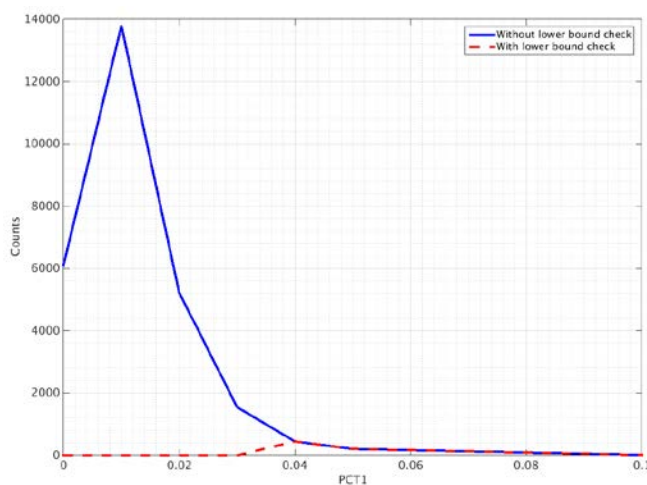

Figure 8: Histogram of used observations against PCT1 for 2012-08-02 12z cycle

A series of experiments were conducted using Hurricane Ernesto and Tropical Storm Hector from 2012 to review the existing QC procedures and test new ones. Assimilation statistics from these two storms showed that histograms of observed – first guess/ analysis (O-B/A) are doing what was expected, i.e. there is no bias after assimilation, histograms had a normal distribution and standard deviations were reduced. Analysis increments (analysis – first guess) and analysis differences (analysis of experiment – analysis of control) did not reveal any problems. Fits to rawinsondes indicate the standard deviations of the AMVs are slightly smaller.

Metrics used to evaluate the impact of AMVs on hurricane forecasting are track, intensity (maximum wind speed) and minimum center pressure errors. Figure 9 and 10 show these errors for Hurricane Ernesto and Hector for the different experiments conducted. Storm tracks were improved with the assimilation of GOES-R like winds. Improvement of storm intensity is greater for the weaker storm.
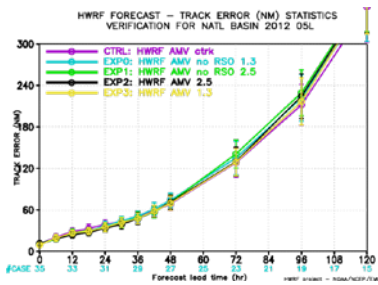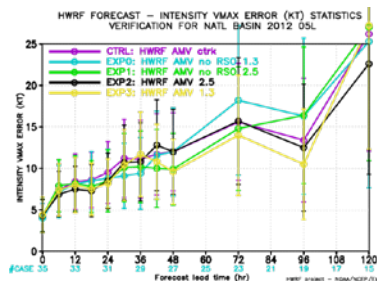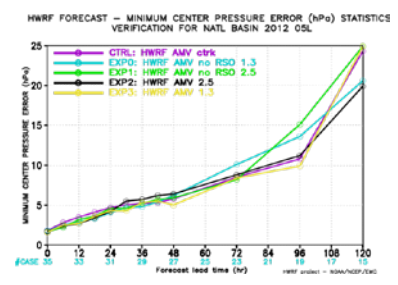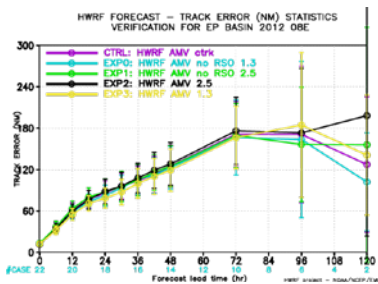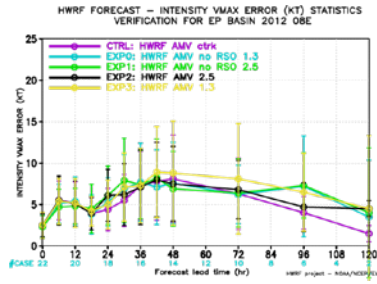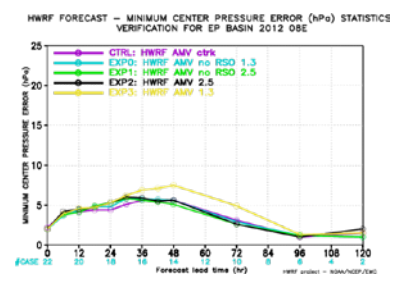
(a) (b) (c)

Figure 9: 2012 Hurricane Ernesto forecasts (a) track error, (b) intensity error and (c) minimum center pressure error

(a) (b) (c)

Figure 10: 2012 Tropical Storm Hector forecasts (a) track error, (b) intensity error and (c) minimum center pressure error.

Milestone 3. Complete the generation of GOES-R like AMVs during the previous three seasons for NCEP/EMC/HWRF implementation tests.
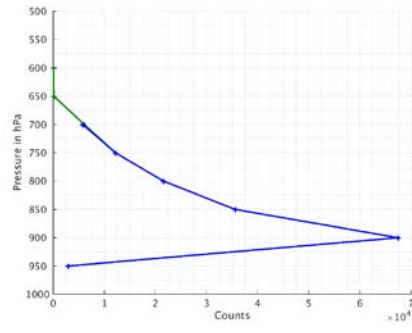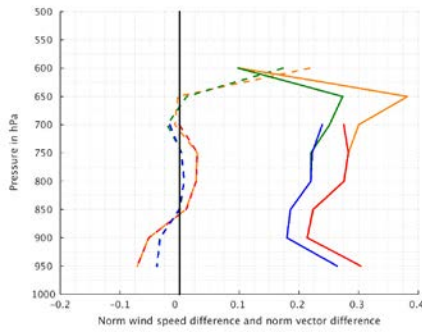
NESDIS did not receive year two funding to generate the GOES-R like data files for the specified case storms in our proposal. We met with NCEP/EMC/HWRF and NESDIS/STAR on 4 August 2016 to discuss alternatives and a timeline for operational implementation. Instead of our proposed path, NCEP/EMC/HWRF requested that we review the quality control, and conduct assimilation tests of the shortwave, clear air water vapor and visible winds generated from the heritage algorithm. Currently the HWRF only assimilates the infrared and cloud top water vapor AMVs in operations.

Statistics from Hurricane Kate showed that additional quality control procedures are required. The new QC procedures added are (1) reject shortwave winds above 700hPa, (2) lower the wind speed cut off from 10m/s to 8m/s and reject observations below 450hPa for clear air water vapor winds and (3) reject visible winds above 750hPa. Figure 11 shows the statistics from Hurricane Kate after modifying the QC procedures. Biases improved for shortwave and clear air water vapor winds. The bias of visible winds are double that of the other two. Investigation into the cause of this excess bias continues. HWRF near surface winds are generally 10-20% weaker than the observations.
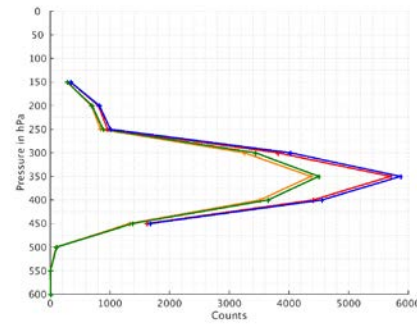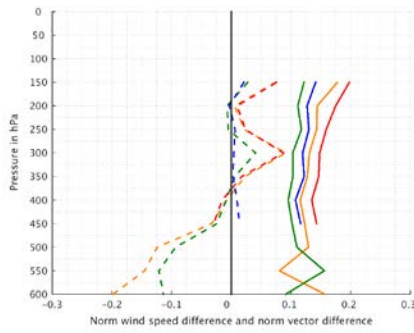
Statistics   Counts

Short-wave winds

Clear air water vapor winds

Visible winds

Legend:
- AMV1 OMB bias
- AMV1 OMA bias
- AMV1 OMB stdev
- AMV1 OMA stdev
- AMV2 OMB bias
- AMV2 OMA bias
- AMV2 OMB stdev
- AMV2 OMA stdev
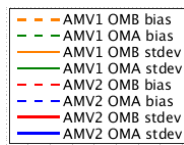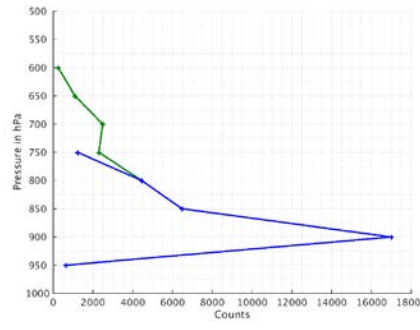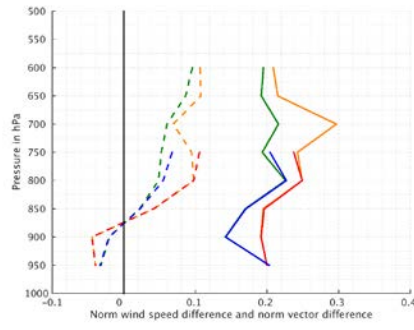
- AMV1 OMB
- AMV1 OMA
- AMV2 OMB
- AMV2 OMA

Figure 11: Bias of normalized wind speed, standard deviation of normalized vector difference and observation counts binned every 50hPa for 2015 Hurricane Kate for the three new wind types to be assimilated.

The above statistics were also evaluated for two other storms; major hurricane Joaquin and tropical storm Ida. Again biases were improved with the additional quality control checks. These QC changes were applied to all storms for the implementation tests. Observation errors used for these new winds are shown in Figure 12.
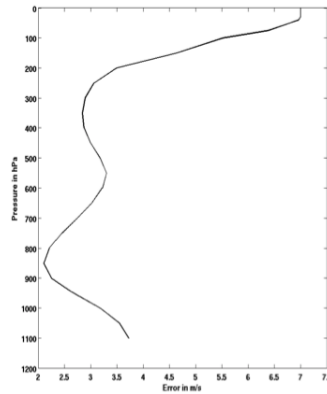
Figure 12: Observational error profiles for shortwave, clear air water vapor and visible AMVs

A total of 25 storms from the 2015 and 2016 hurricane seasons were run for the HWRF implementation tests. Figure 13 shows the forecast performance with and without the addition of the three wind types. Track forecast is neutral with the addition of the new winds. However, intensity forecast in terms of maximum wind speed shows a large improvement beyond 36 hours. Minimum center pressure error is also reduced for forecast hours longer than 36. The radii of 34 kts and 50 kts wind define storm size. Reduced error in storm size forecast is achieved with the assimilation of the news up to 72 hours and 108 hours. Piecewise Frequency of Superior Performance (FSP) defines the percentage of times that the experiment is superior to the other in terms of forecast error. Positive FSP is seen only during the first 6 hours for track (not shown) but intensity has better FSP from 30 hours onwards.
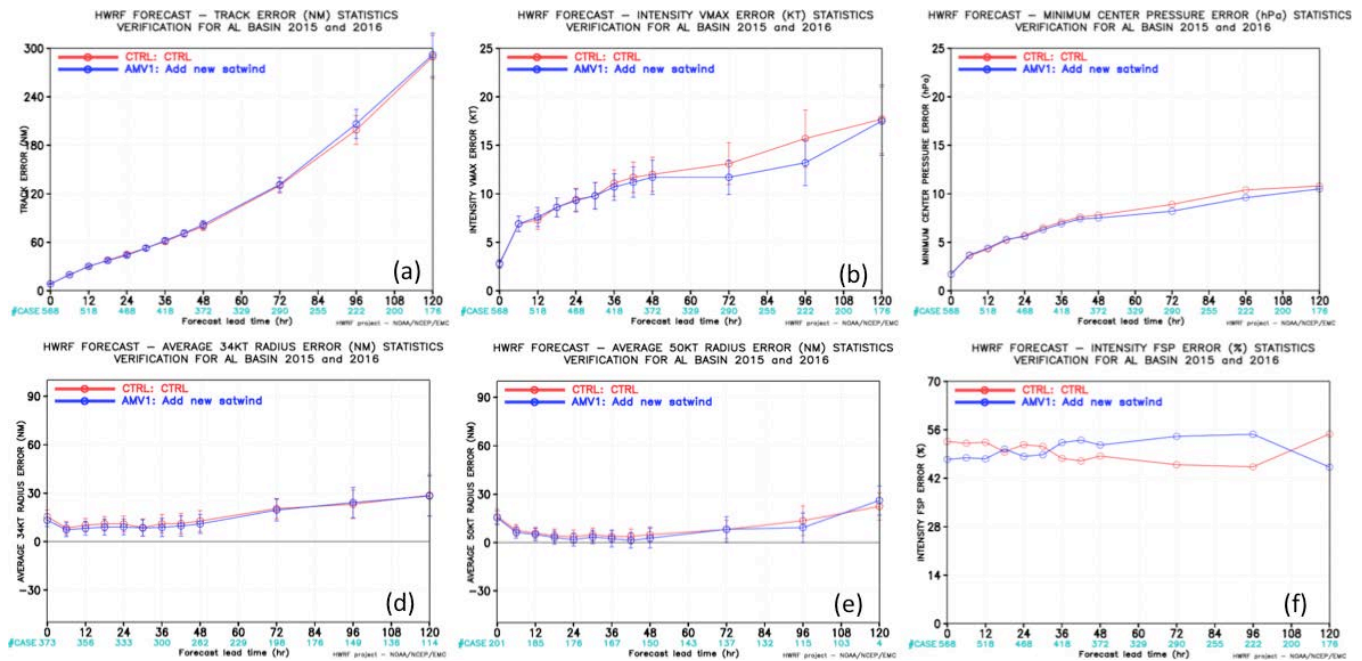

Figure 13: Verification statistics for 2015 and 2016 hurricane (a) track error, (b) intensity error, (c) minimum center pressure error, (d) average 34ht radius error, (e) average 50kt radius error, (f) FSP error for intensity. Error bars represent 95% confidence interval.

Milestone 4. **Presentation to NCEP/EMC at NCWCP.**

Results from this work were presented to NCEP/EMC at a bimonthly AMV meeting and to NCEP/HWRF during a HWRF weekly meeting on 7 and 8 December 2016 respectively. Research has completed for this task and work to document this effort by a peer-reviewed publication continues.

Additional Information

1.Interaction with operational partners –

We have worked with NESDIS/STAR on identifying and improving the quality control parameters associated with the CAWV AMVs. We also worked with NESDIS to generate the AMVs required for the HWRF impact studies.

We collaborated with NCEP/EMC to develop scientifically credible experiments and to aid in transitioning any technologies selected to be a part of their upgrades. This required using recent versions of the HWRF and Global Forecast Systems, NCEP/EMC's subversion code management system and NCEP/EMC's real time observation data.

NCEP Central Operations (NCO) has received and implemented the GSI changes required to assimilate the GOES-13 & 15 CAWV AMVs within the GFS. These AMV data were assimilated starting with the July 2017 upgrade. NCO has also received and implemented the GSI changes required to assimilate the GOES-13 & 15 AMV types of VIS, SWIR, IR, CTWV, and CAWV within the HWRF. The HWRF started assimilating the GOES AMV data in August 2017.

2. Conference/workshop participation –

Lim, A., J. A. Jung, S. Nebuda, W. Bresky, J. Daniels, M. Tong, and V. Tallapragada 2016: Assimilation of High Temporal Satellite Derived Atmospheric Motion Vectors to Improve Hurricane Forecasts Using HWRF, *21st Conference on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface*, 97th AMS Annual Meeting, Seattle WA

Nebuda, S. J. A. Jung, J. Daniels, J. Le Marshall, I. Genkova, 2016: Assimilation of GOES Clear Air Water Vapor Atmospheric Motion Vectors in the NCEP Global Forecast System. *13th International Winds Workshop*, Monterey CA, 27June – 1July 2016.

Jung, J. A., and Coauthors 2017: Development of Advanced Data Assimilation Techniques for Improved Use of Satellite Derived Atmospheric Motion Vectors, *15th JCSDA Technical Review & Science Workshop*, College Park MD 17-19 May 2017.

Visit to the Bureau of Meteorology Australia hosted by Prof. John Le Marshall from 2-7 Oct 2017 under GOES-R VSP (Travel) to exchange quality control and assimilation techniques between NOAA and BoM on optimizing techniques for using high temporal AMV data to improve tropical cyclone (TC) forecasts. Melbourne, Australia.

3. Funding concerns –

   None

4. Outside project publicity –

None

5. <u>Journal articles</u> –

Lim, A. H. N., J. A. Jung, S. E. Nebuda, J. M. Daniels, W. Bresky, M. Tong, V. Tallapragada, 2017: Hurricane Track and Intensity Forecasts Impact Assessment from the Assimilation of Hourly Visible, Shortwave and Clear Air Water Vapor Atmospheric Motion Vectors in HWRF, *Submitted to Weather and Forecasting.*

Plans for the next Reporting Period:

Task 1: Completed

Task 2: Completed

Project Deviation Details

Issues[1]:

- NESDIS/STAR year 2 funding was not received. Alternatives were discussed with NCEP/HWRF and NESDIS/STAR. Milestone #3 was modified accordingly.

Change Status[2]:

- None

Risk Status[3]:

- **Risk:**
- **Mitigation:**

[1] *Issues requiring resolution by Project Manager.*

[2] *Changes raised for consideration that change the approved project baselines. Would require approval by the Project Manager*

[3] *Report on any change in priority or status of major project risks, and any risks discovered since earlier risk assessments along with proposed risk response.*