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ASSIMILATION OF GOES CLEAR AIR WATER VAPOR ATMOSPHERIC MOTION VECTORS IN THE NCEP GLOBAL FORECAST SYSTEM

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Abstract

For data assimilation, the tropics consistently have the greatest wind errors both in forecast models as well as observations of derived motion from clouds in part to the impact of deep convection. Atmospheric Motion Vectors (AMVs) derived from tracking clear air water vapor fields avoid these areas of complex cloud dynamics while providing measurements in locations with limited operational wind data. The desire to improve the performance of the National Centers for Environmental Prediction (NCEP) Global Forecast System Data Assimilation System (GDAS) in the tropics has motivated this research to perform a new evaluation of the clear air water vapor (CAWV) AMVs. Departure statistics for the CAWV AMV are comparable to cloud top water vapor (CTWV) AMVs as well as infrared (IR) AMVs. Implementation of the Geostationary Operational Environmental Satellite GOES-13 & 15 CAWV AMVs in GDAS is discussed as well as results from two seasons to show the impact of this data on the analysis state and forecast skill. The addition of this data adjusts the circulation pattern for the GDAS analysis in the tropics at the vertical level near 350 hPa, the typical height of this AMV type. Forecast skill impact is generally neutral.

INTRODUCTION

NCEP global model forecast winds and cloud motion AMVs both possess large errors in the tropics (25°N – 25°S). This is usually attributed to the convective scheme influencing the model winds and localized deep convection influencing the quality of the cloud motion AMVs. The CAWV AMVs, however, track water vapor image features in clear sky regions avoiding the uncertainty introduced by cloud dynamics. While noting this benefit, one concern with CAWV AVMs is the depth of the sensed layer for the GOES 6.5µm Channel 3 image. This depth 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. Motion is derived by tracking features within this field, features created by gradients of high to low moisture amounts. Heights assigned to these motion vectors are determined by comparing a sample of coldest pixels in the feature to the forecast temperature profile and are typically around 350 hPa. For a feature present in a drier water vapor field, the depth of the layer contributing to the sensed temperature will be thicker which may impact the uncertainty of the heights assigned to these AMVs. Initially, this research intended to focus on the tropics, the region with the greatest wind errors but also larger water vapor magnitudes. However, examining the departure statistics for CAWV, CTWV and IR AMVs indicate that the performance of the CAWV AMVs are comparable to the IR and CTWV AMVs so the entire GOES coverage was used for this work. CAWV AVM speed departure for collocated rawinsondes for 20-50°N are shown in Figure 1. The mean speed departure for CAWV AMVs with respect to rawinsondes is similar or smaller than the mean departure for CTWV AMVs. The current operational GOES IR AMVs have a larger slow bias than both water vapor AMV types. Figure 2 demonstrates the increase in horizontal data coverage when including the CAWV AMVs in the GDAS observation set.

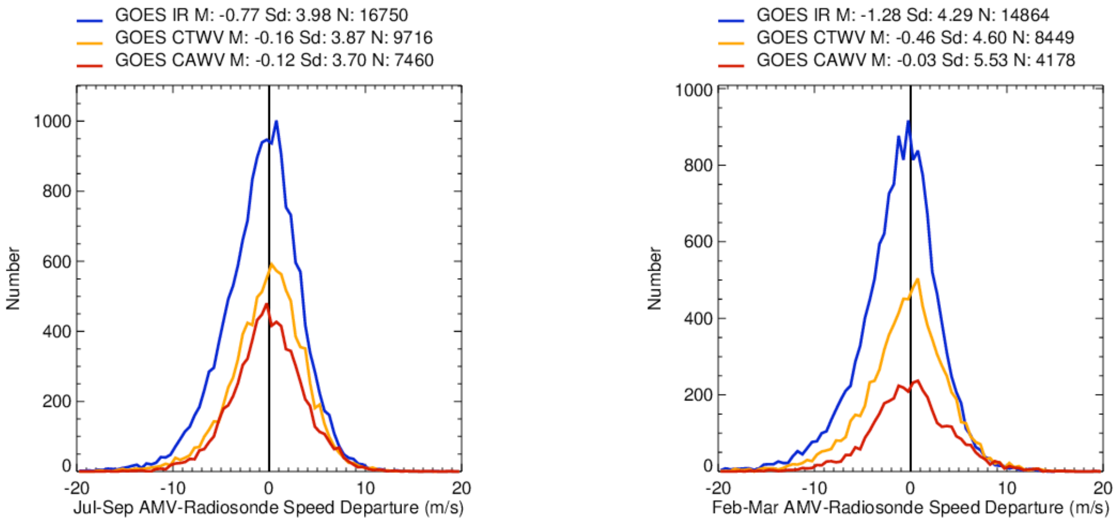

Figure 1: **Speed departure histograms for collocated GOES 13 & 15 AMVs and rawinsondes located between 20-50°N. Collocation was limited to distances smaller than 35 km, 100 hPa, and times within 30 minutes. Left plot includes data from February to March 2015. Right plot is for data from July to September 2015. Infrared (IR), cloud top water vapor (CTWV) and clear air water vapor (CAWV) AMVs departures are shown. The mean (M), standard deviation (SD) and count (N) are included in the legend.**

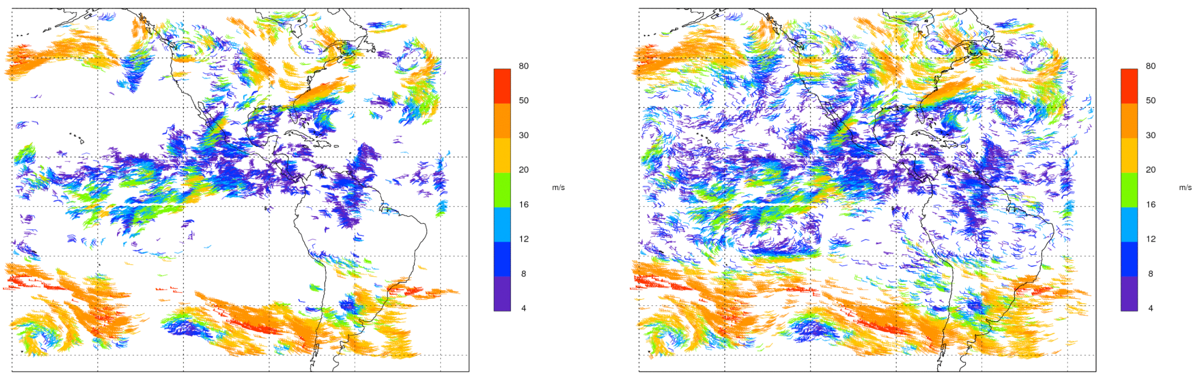

Figure 2: **AMV wind barbs in m/s for 18Z 15 Aug 2014. Color also indicates AMV speed. Left panel shows location of CTWV and IR AMV above 500 hPa for GOES 13 & 15. Right panel is the same with the inclusion of the CAWV AMVs.**

QUALITY CONTROL

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 IR and CTWV AMVs. Expected Error (EE, Le Marshall et al. 2004) is generally used to determine the quality of the slower AMVs (less than 20 m/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 Quality Indicator or QI (Holmlund 1998) is also showing no skill at predicting the quality of the GOES CAWV AMVs. Using 2 weeks of data from a GDAS simulation which did not include the CAWV AMV data, the AMV departure from the GDAS background was calculated (Figure 3) and found to not show dependency on either quality control parameter. Until these quality parameters can be reviewed for the GOES CAWV AMVs, the recommended quality control procedures do not include them. Instead, the following data screening has been implemented in the pre-operational GDAS: a maximum allowed direction departure of 50°, a minimum AMV speed requirement of 10 m/s, removal due to proximity to the surface and tropopause, and a departure check using the Log Normal Vector Difference (LNVD). The slower CAWV AMVs (less than 10 m/s) generally have greater direction departures with respect to the model forecast but this requirement should be reviewed again for GOES-R CAWV AMVS to investigate if the minimum AMV speed threshold can be reduced.

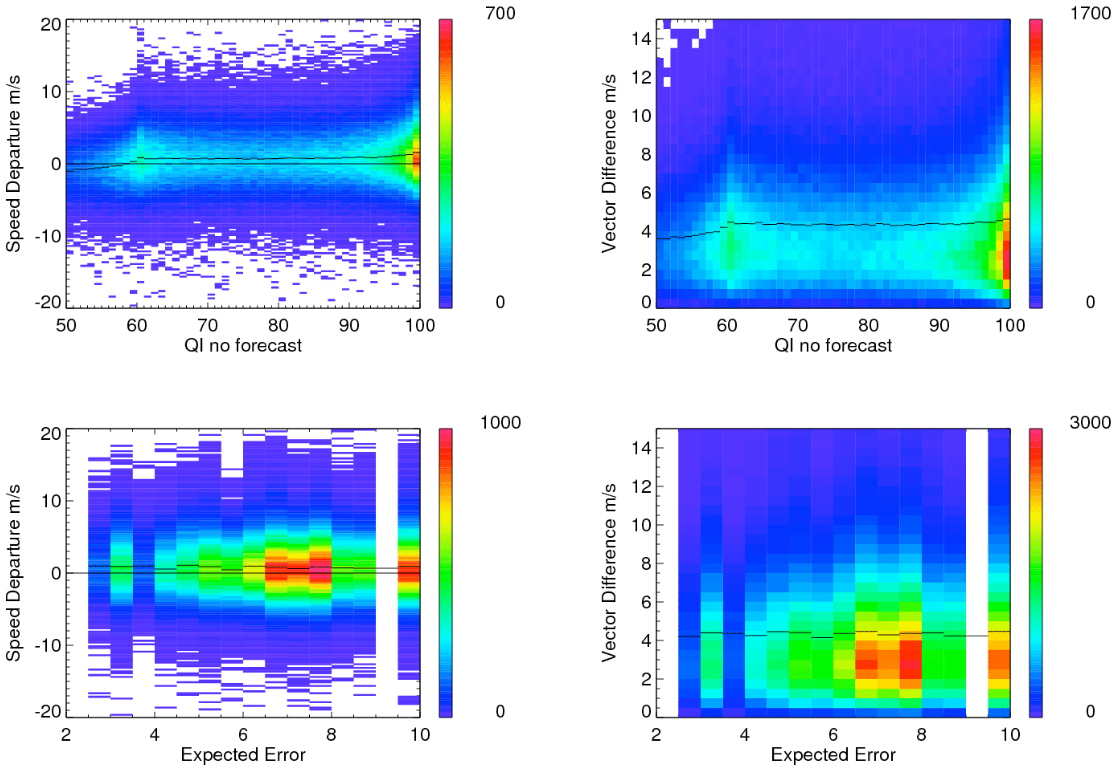

Figure 3: **Density plots for CAWV AMV – GDAS Background Speed and Vector difference for 6-21 Aug 2014 for the range of the quality control parameters, Quality Indicator (QI) without the forecast component (top panels) and the Expected Error (EE m/s, bottom panels). Color indicates number in the parameter/departure bin. The mean departure value for each x bin is included as a black line. Increasing values of QI should indicate increasing quality while decreasing values of EE denote AMVs with decreasing error.**

OBSERVATION ERROR

The current GOES AMVs have observation error settings specified with a reference vertical profile that begins with 7 m/s near surface and increases sharply at 500 hPa to reach 14 m/s around 250 hPa. These error settings were put in place when the GOES AMV data volume increased by a factor of 6; data previously produced every 6 hours are now produced hourly. This GOES profile results in an observation error of 12-13 m/s at the level of the CAWV AMVs, generally near 350 hPa. Comparing the departure bias for speed and vector difference of the CAWV AMVs with the upper level GOES IR and CTWV AMVs revealed similar magnitudes of bias (Figure 4) for the range of latitudes of this data. The CAWV AMVs have slightly larger (fast) speed bias and similar vector difference bias compared to CTWV AMVs with an approximate magnitude near 4.5 m/s. In the area with a dense network of conventional data, the continental US at 25-50N, and therefore a smaller background error for the GDAS forecast, the error characteristics of the GOES AMVs are the most similar. Given these similarities and a mean vector difference magnitude much smaller than 12-13 m/s, the decision to apply the same GOES observation error settings for operational AMVs is reasonable for the CAWV AMVs.

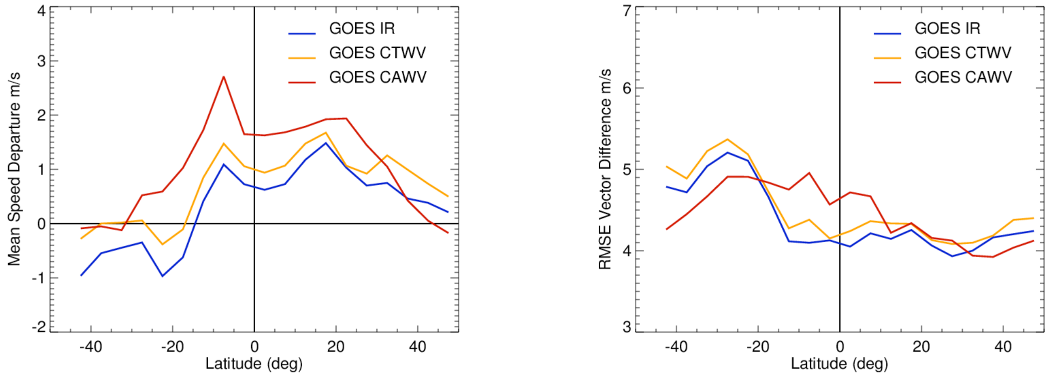

Figure 4: **Mean speed bias for AMV – GDAS Background (left) and RMSE vector difference for 6-21 Aug 2014 for AMVs above 500 hPa and faster than 10 m/s for GOES IR, CTWV, and CAWV AMVs. Departure has been limited by the Log Normal Vector Difference check.**

DEPARTURE STATISTICS

To evaluate the impact of the CAWV AMVs on the GDAS, two seasons were selected for the control and experiment simulation pairs, Feb-Mar and July-Sep 2015. All experiments were completed with the T670 3D Hybrid EnKF GDAS with the most current pre-implementation GSI version available at the start of these simulations. Quality control procedures and observation error settings were applied to the CAWV AMVs for the experiment simulations as described above. Using the July-Sep 2015 simulation which included the CAWV AMVs, the speed depature mean and vector difference RMSE are shown (Figure 5). The speed bias is faster than the CTWV AMVs by approximately 0.5 m/s from 25°S to 30°N but comparable in the extratropics. Similarly, CAWV AMV RMSE vector difference is largest in the tropics and smaller in the extratropics. This behavior is the same for the Feb-Mar 2015 data with a seasonal flip of the trends.

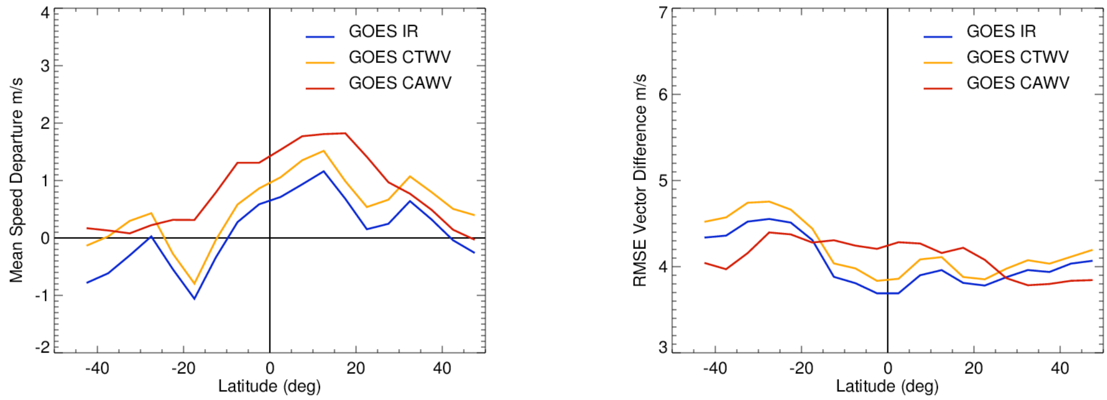

Figure 5: **Mean speed bias for assimilated AMV – GDAS Background (left) and RMSE vector difference for Jul-Sep 2015 for AMVs above 500 hPa and faster than 10 m/s for GOES IR, CTWV, and CAWV AMVs.**

ANALYSIS AND FORECAST SKILL IMPACT

For both seasons examined in this research, the effect of including the CAWV AMVs on the analysis is a regional strengthening of the circulation in the tropics around 350 hPa, the level with the maximum data count. The monthly mean wind components for the experiment with the CAWV AVMs are shown for Sep 2015 as well as the wind component difference from the control simulation (Figure 6). This result was consistent for other months given the slight shifts in circulation patterns. The change to the GDAS forecast skill is neutral as measured by the standard verification software package. By verifying the forecasts of the control and experiment to the analysis which included the GOES CAWV AMVS, the influence of the CAWV AMV data on the initial condition is evident in the vector wind RMSE. The tropical vector wind bias and RMSE are shown for 200 and 500 hPa during Jul-Sep 2015 (Figure 7). Significant improvement on the vector wind RMSE using the CAWV AMVs are seen up to forecast day 3; vector wind bias is also impacted for this season but remains neutral for Feb-Mar 2015 forecasts. The 500 hPa height anomaly correlation skill does not show any impact for forecasts which had the GOES CAWV AMVS added to the GDAS.

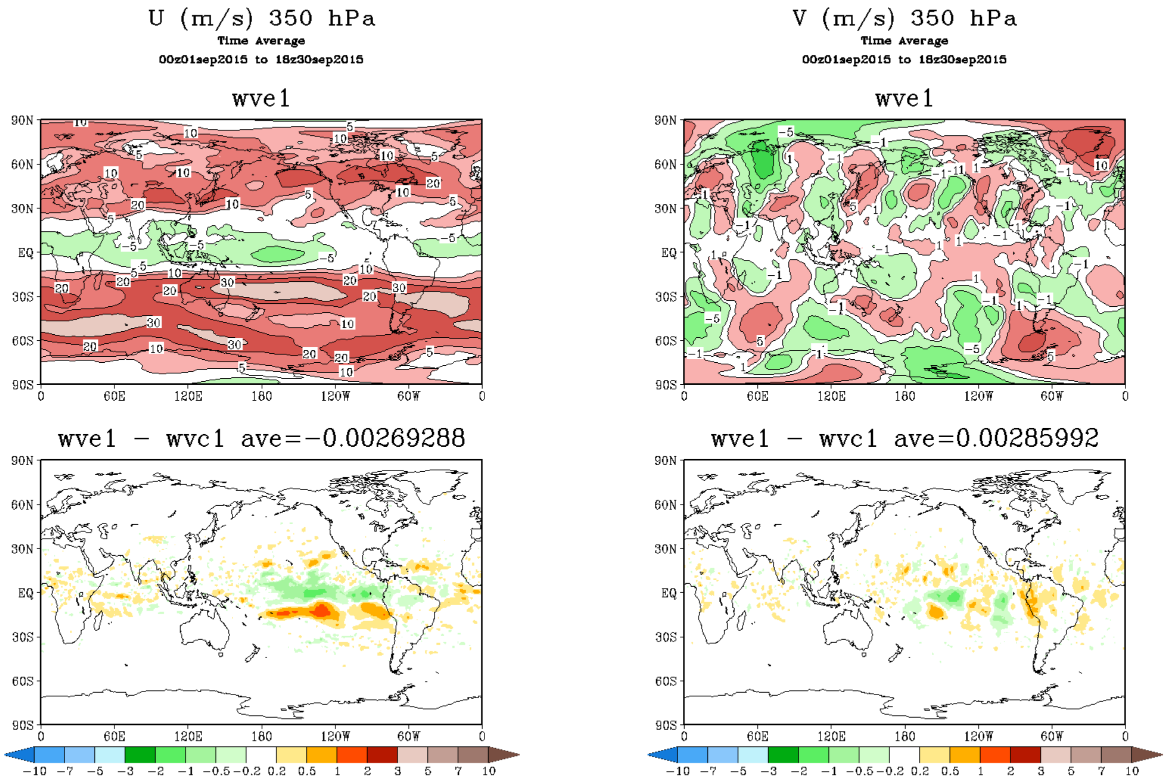

Figure 6: **350 hPa monthly mean wind components for Sep 2015 for the GDAS analysis with the CAWV AMVs (wve1, top panels) and the difference compared to the analysis without CAWV AMVs (wvc1, bottom panels). The zonal speed is increased for both the Easterlies along the equator and the Westerlies in the midlatitudes, especially within the region of both GOES satellites**.

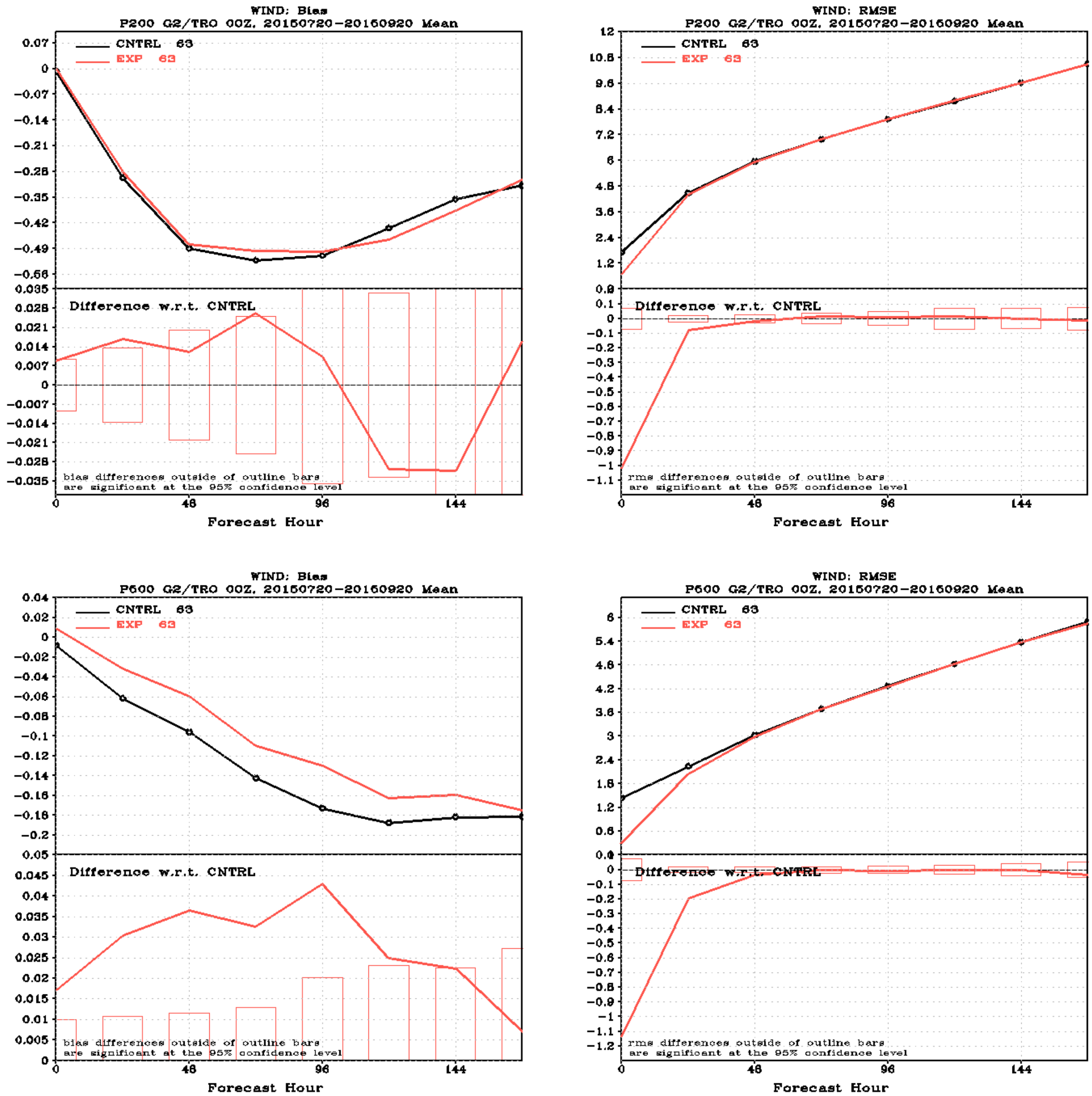

Figure 7: **Tropical forecast wind bias (left panels) and RMSE (right panels) for the Jul-Sep 2015 GDAS CNTRL (no GOES CAWV AMVs) and EXP (with GOES CAWV AMVs) as a function of forecast hour verified to the analysis which included the GOES CAWV AMVs. Top panels are results at 200 hPA and bottom panels are results at 500 hPa.**

SUMMARY

Noting that improvements in NCEP GDAS forecast skill due to the of addition of the CAWV AMVs from GOES 13 & 15 were small to neutral in the standard GDAS verification metrics, the analysis circulation was impacted by the addition of AMVs to regions with little to no other conventional data present. The CAWV AMVs are currently processed and available for assimilation within the NCEP GDAS; implementing quality control procedures and observation error settings was the only remaining effort needed to allow the use of this data. The recommended software modifications have been made to the NCEP GDAS and the GOES CAWV AMVs will be assimilated in 2017.

REFERENCES

Holmlund, K., 1998: The utilization of statistical properties of satellite-derived atmospheric motion vectors to derive quality indicators, Wea. Forecasting, 13, pp 1093-1104.

Le Marshall, J., R. Seecamp, A. Rea, M. Dunn, J. Jung, J. Daniels, and C. Velden, 2004: Error Characterization and Application of Atmospheric Motion Vectors over Australia and high Latitudes. In Proceedings of the 7 International Winds Workshop, Helsinki, available from EUMETSAT, Germany, www.eumetsat.int