Feature-tracked Winds from Moisture Fields Derived from AIRS Sounding Retrievals

David Santek, Sharon Nebuda, Dave Stettner

CIMSS/UW-Madison, 1225 W. Dayton St., Madison, Wisconsin, 53706 USA

Abstract

For more than a decade, polar winds from the Moderate Resolution Imaging Spectroradiometer (MODIS) imagery have been generated by NOAA and the Cooperative Institute for Meteorological Satellite Studies (CIMSS). These datasets are a NOAA/NESDIS operational satellite product that is used at more than 10 major Numerical Weather Prediction (NWP) centers worldwide.

The MODIS polar winds product is composed of both infrared window (IR-W) and water vapor (WV) tracked features. The WV atmospheric motion vectors (AMV) yield a better spatial distribution than the IR-W since both cloud and clear-sky features can be tracked in the WV images. As the new generation polar satellite era begins with the Suomi National Polar-orbiting Partnership (S-NPP), there is currently no WV channel on the Visible/Infrared Imager/Radiometer Suite (VIIRS), resulting in a data gap with only IR-W derived AMVs possible. This scenario presents itself as an opportunity to evaluate moisture retrievals from consecutive overlapping satellite polar passes to extract atmospheric motion from clear-sky regions on constant (and known) pressure surfaces; i.e., estimating winds in retrieval space rather than radiance space. Perhaps most significantly, this method has the potential to provide vertical wind profiles, as opposed to the current MODIS-derived single-level AMVs.

This report summarizes this technique as applied to Atmospheric Infrared Sounder (AIRS) moisture retrievals from NASA's Aqua satellite, the resulting winds, and assimilation and forecast impact results using the Goddard Earth Observing System Model, Version 5 (GEOS-5). Also, plans to produce these AMVs in near real-time at CIMSS will be detailed.

INTRODUCTION

The MODIS polar winds product is composed of both IR-W and WV tracked features. However, the WV AMVs are only attainable at mid- and upper- tropospheric levels due to the MODIS WV atmospheric contribution function, while IR-W images also provide cloud tracers for vectors at lower levels. Despite their limited usage, the WV AMVs yield a better spatial distribution than the IR-W because both cloud and clear-sky features can be tracked in the WV images.

The new generation of polar satellites beginning with S-NPP has the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument, which unlike MODIS, does not have a WV channel. Therefore, a potential data gap will result as no WV features can be tracked, resulting in only the standard IR-W derived AMVs. This scenario presents itself as an opportunity to investigate using Single Field of View (SFOV) AIRS moisture retrievals from consecutive overlapping polar passes to extract atmospheric motion from clear-sky regions on constant (and known) pressure surfaces; i.e., estimating winds in retrieval space rather than radiance space.

The goal was to create a blended product of MODIS imager- and AIRS retrieval-derived AMV datasets. This capability could be extended to S-NPP for generating cloudy AMVs from VIIRS and using moisture retrievals derived using the Cross-Track Infrared Sounder (CrIS) to produce clear-sky AMVs.

In addition to comparing AIRS winds to MODIS winds, we ran three experiments in which we blend the experimental AIRS moisture retrieval AMVs with the already proven MODIS AMVs to create 3-D polar wind fields. Lastly, we performed Numerical Weather Prediction (NWP) experiments with the blended product to determine the overall impact on numerical forecasts and the relative contributions of each data type (MODIS vs. AIRS).

DATA PROCESSING COMPONENTS

The data processing was controlled by Linux shell scripts, with the following software packages:

- International MODIS/AIRS Processing Package (IMAPP),
- Interactive Data Language (IDL),
- Man computer Interactive Data Access System (McIDAS), and
- the AIRS winds software.

There are three main components needed to process the AIRS retrieval winds, which are described below.

AIRS Retrievals

The AIRS Standard Retrieval Product provides profiles of retrieved temperature, water vapor, and ozone. The product is generated from 3x3 Fields of View (FOV) of AIRS radiances that results in a horizontal resolution of 40 km. However, this is much too coarse for tracking features from successive orbits as a one-pixel displacement corresponds to 6.7 ms^{-1}. A similar algorithm was developed at the SSEC using SFOV AIRS footprints, which retained the native horizontal resolution at 13.5 km/pixel and resulted in temperature, humidity, and ozone profiles at 101 pressure levels from 0.005 to 1100 hPa. We utilized the SFOV product in our AIRS AMV generation, since it provides the best spatial resolution for our application. The SFOV AIRS product software is available in the IMAPP package.

AIRS Image Processing

The AIRS retrieval algorithm generates profiles of moisture and ozone at each AIRS footprint in the original satellite swath projection. Using IDL, these profiles are used to create horizontally sliced swath images on constant pressure surfaces. Because the pixel-to-pixel variation in moisture and ozone images, the cross-correlation technique in winds software was not able to track features. Therefore, custom McIDAS applications were developed to smooth the gradients, by increasing the resolution of the images by a factor of four using a bi-linear interpolation. These swath slices are then reprojected to a polar stereographic projection at four km resolution. The cross correlation technique in the winds algorithm performed much better using the smooth gradient images.

AIRS Winds Software

The winds software package was developed at CIMSS/SSEC for use with geostationary and polar orbiting satellite imagery. Applying this software to AIRS became a new challenge due to its low spatial resolution (13.5 km) compared to MODIS (one km) and geostationary infrared images (four km). The above image processing and adjustments to the configuration of the winds software were needed to extract reasonable AMVs.

DATA COVERAGE

The AIRS AMVs were extracted from a time sequence of three images. In order to achieve overlapping images, the AMVs could only be derived in high latitudes (poleward of 70º latitude). The geographic coverage of AMVs from polar orbiting satellites is over small regions at any particular time. Figure 1 illustrates the swath overlap for three consecutive passes for MODIS (left) and AIRS (right). Because the AIRS instrument has a narrower swath width than MODIS, the spatial coverage of the AIRS AMVs is also reduced. An entire day is needed to get complete AMV coverage over the polar regions.

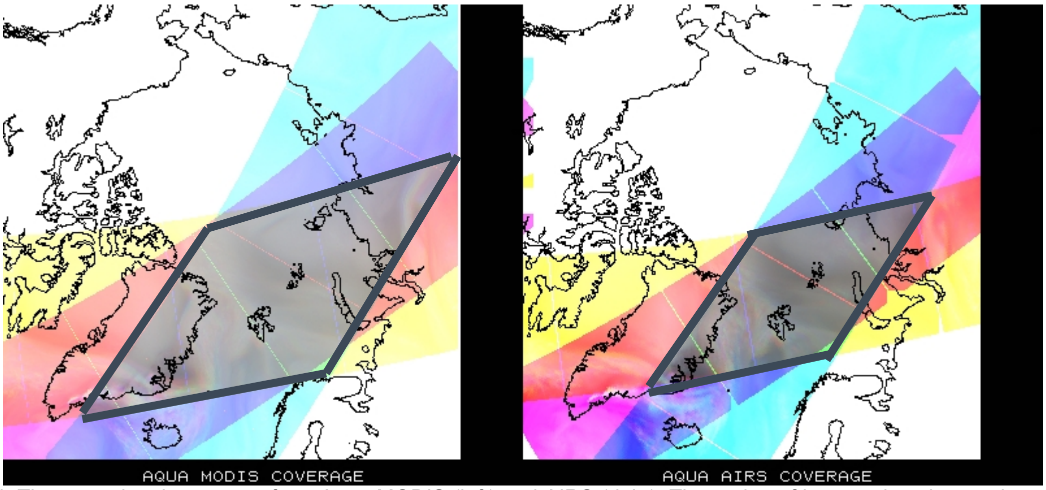

Figure 1: Three overlapping passes from Aqua MODIS (left) and AIRS (right). The region of intersection shows where features can be tracked.

The AMVs were derived on pressure surfaces away from the tropopause and the Earth's surface. Specifically, we used moisture levels from 359 to 616 hPa (17 levels) and ozone levels from 103 to 201 hPa (12 levels).

COMPARISON TO MODIS WINDS

For the 14 June to 13 July 2012 time period (summer), 650 wind sets were generated, resulting in 164,000 AIRS moisture and 135,000 ozone AMVs (see Figure 2 for an example spatial distribution of one wind set). During the same time period, nearly three million Aqua MODIS winds were generated (see Figure 3 for an example of a MODIS wind set).

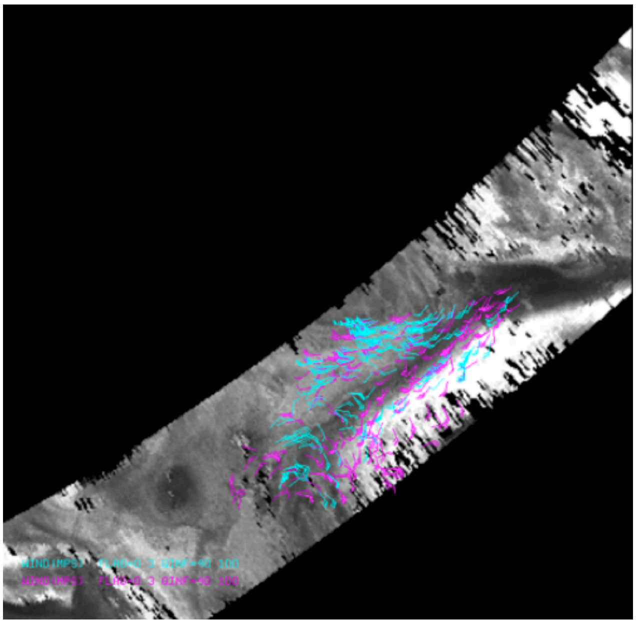

Figure 2: AIRS retrieval AMVs over a 400 hPa AIRS retrieved moisture field from 20 July 2012 0551 UTC. The North Pole is in the center of the picture, with Greenland in the lower left region (not visible). These wind barbs are all moisture and ozone tracked AMVs color coded by pressure level: yellow 700 to 1000 hPa; cyan 400 to 699 hPa; magenta above 399 hPa.

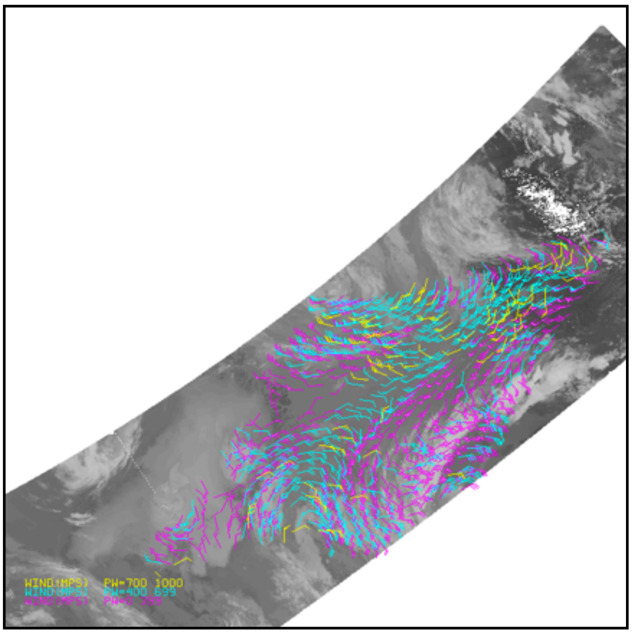

Figure 3: Same geographic region and time as Figure 2, with the Aqua MODIS AMVs displayed over a MODIS 11 µ image. The AMVs are from tracking clouds and features in both infrared and water vapor channels.

To inter-compare the AIRS and MODIS AMVs, vectors were co-located using this criteria: vectors had to be located within 25 km and their assigned pressure levels had to be within 15 hPa. These requirements resulted in approximately 25,000 matches, or only about 8% of the total AIRS winds. The percentage appears low because the AIRS AMVs are distributed vertically while the MODIS AMVs are at a single level at a specific geographic region and the AIRS dataset contained winds in the stratosphere as well.

Figure 4 depicts the distribution of the speed differences between the 25,000 matched AIRS and MODIS AMVs for the northern hemisphere summer. There is no bias (mean difference is -0.06 ms^{-1}) and it is an approximate Gaussian distribution.

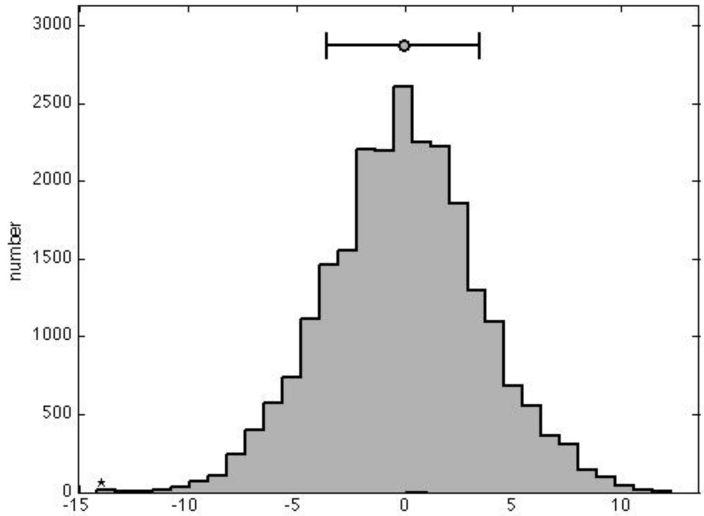

Figure 4: Histogram of the speed difference between co-located Aqua MODIS and AIRS retrieval AMVs: northern hemisphere summer: 14 June to 31 July 2012. Mean=-0.06 m/s;, Standard Deviation=3.54 m/s.

The results are encouraging, as:

- The MODIS and AIRS co-located AMVs are similar and without bias. The standard deviation of the speed difference was several meters per second, as expected, due to the different spatial resolution (2 km for MODIS vs. 16 km for AIRS)

- Only 8% of the MODIS and AIRS AMVs are co-located within 25 km and 15 hPa, therefore the AIRS AMVs should provide additional observations over the MODIS-only dataset.

GEOS-5 IMPACT EXPERIMENTS

We ran the GEOS-5 Atmospheric Global Climate Model (AGCM) on the NCCS 'discover' system, with the following features and configurations:

- Gridpoint Statistical Interpolation (GSI) analysis at ~½° resolution with 72 vertical levels.
- 3DVar
- 6-h assimilation cycle
- 7-day forecasts, adjoint-based 24 hour observations
- Impacts at 0000 UTC (dry energy norm, sfc-150 hPa)

Experiments

Three experiments were run utilizing the northern hemisphere summer time period (14 June – 31 July 2012). The input AIRS AMVs were from 103 to 201 hPa (ozone) and 359 to 616 hPa (moisture)

- Control: The Control run contained all of the standard data sources, including the MODIS IR and WV AMVs.
- Exp. 1 (AIRS AMVs): Exp. 1 was run identically to the Control, with the addition of the AIRS moisture and ozone AMVs. This allowed the incremental impact due to the addition of AIRS winds to be highlighted, as all other data sources remained constant.
- Exp. 2 (ex2): Exp. 2 was run identically to Exp. 1, with the removal of the MODIS WV winds. The experiment replaces the MODIS WV winds with the AIRS WV winds, which were in similar clear sky regions, testing the usage of sounder winds instead of AMVs from the water vapor channel on MODIS. This is important as the Terra MODIS WV winds were turned off in mid-2013 due to a degraded band 27 channel. Also, VIIRS on S-NPP does not have a water vapor channel, which may be compensated by using sounder AMVs from CrIS.
- Exp. 3 (ex3): Exp. 3 was run identically to the Control, however with all MODIS winds removed. This tests the impact of AIRS winds (only from Aqua) as a complete replacement of MODIS winds (from Aqua and Terra).

Assimilation Impact

The measure of how the AIRS AMVs behaved in the GEOS-5 was to compare the winds with the GEOS-5 background and analysis fields. Figure 5 depicts the moisture AMV speed departure from the northern hemisphere background (blue) and northern hemisphere analysis (yellow). Since there is very little moisture in the southern hemisphere during winter (green and red curves), they were not considered for this time period. However, the results of the northern hemisphere analysis are favorable:

- The distribution bias is small (approximately 0.2 ms^{-1}), and
- The standard deviation was reduced from 3.2 (background) to 3.0 ms^{-1} (analysis), indicating that the AIRS AMVs that were assimilated had an impact on the analysis.

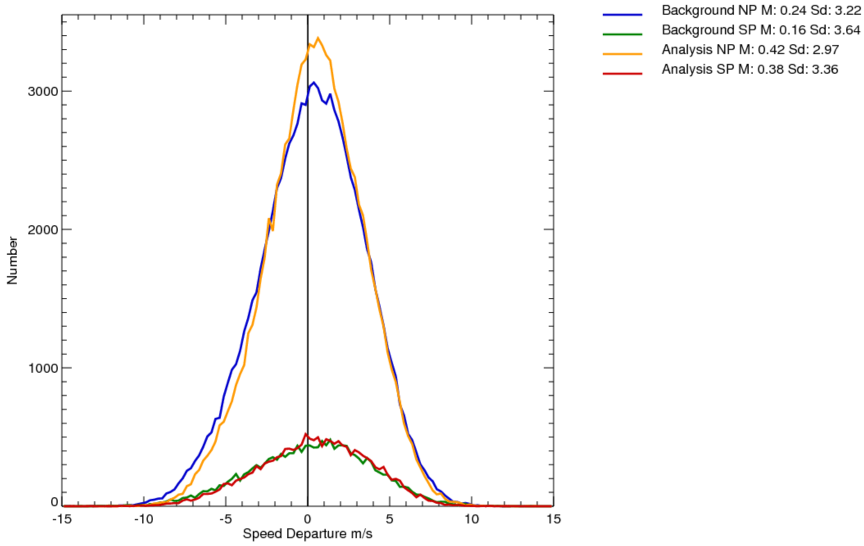

Figure 5: Distribution of speed departure for 01-29 July 2012 for the AIRS moisture AMVs. Compared to background (northern hemisphere=blue; southern hemisphere=green) and analysis (northern hemisphere=yellow; southern hemisphere=red).

Figure 6 shows the speed departure for the ozone AMVs. The distributions are skewed (non-Gaussian distributions) and shifted to the right of zero, indicating a fast bias in the AMVs of 1.7 ms^{-1} for the northern hemisphere, as compared to the background. With very few observations in the stratosphere, it was not possible to determine if the ozone AMVs truly had a fast bias compared to an independent measure of wind speed.

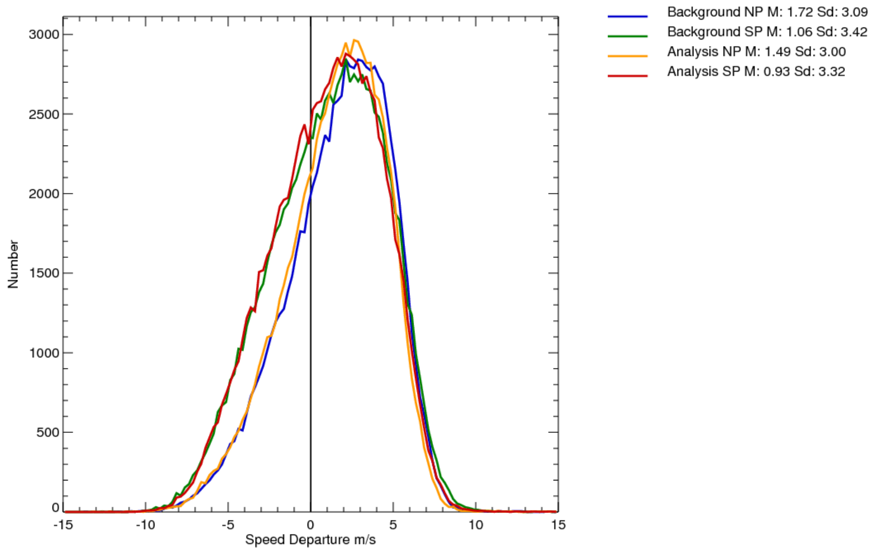

Figure 6: Distribution of speed departure for 01-29 July 2012 for the AIRS ozone AMVs. Compared to background (northern hemisphere=blue; southern hemisphere=green) and analysis (northern hemisphere=yellow; southern hemisphere=red).

The impact per observation (Figure 7) is very good for the AIRS moisture AMVs, as they are ranked higher than all other satellite-derived wind datasets. However, the AIRS ozone AMVs have a negative impact, which is likely due to the speed bias noted in Figure 6.

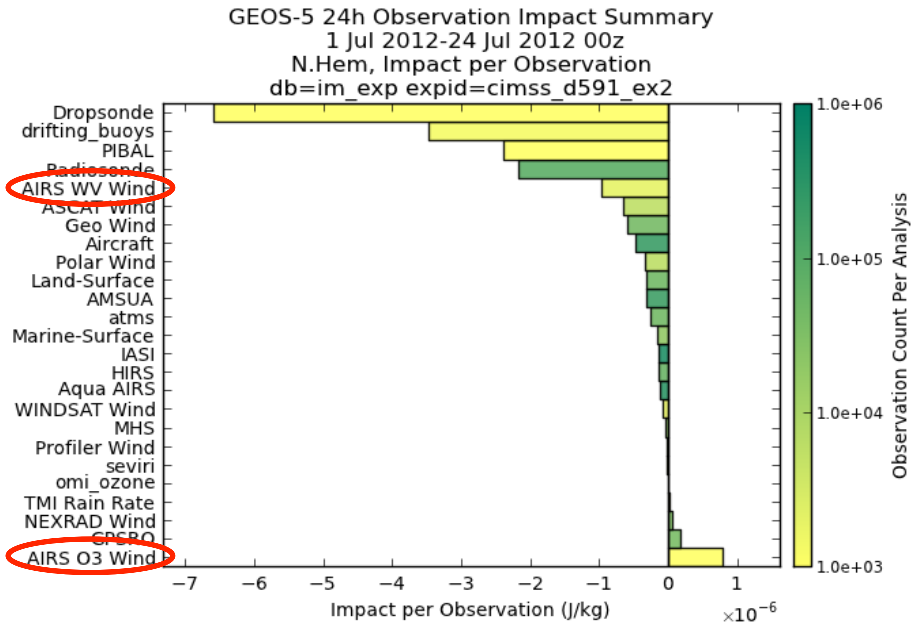

Figure 7: Impact per observation for 01-24 July 2012 0000 UTC for the AIRS WV (moisture) and O3 (ozone) AMVs.

Forecast Impact

The forecast impact was statistically neutral as measured by the ACC score for the first 24 days of July 2012. Figure 8 depicts the 500 hPa die-off curves for the control (blue) and the three experiments:

- Although not statistically significant, the addition of the AIRS AMVs (red) shows a slight improvement in the ACC score after Day 4.
- The removal of the MODIS AMVs (blue) shows a decrease in the ACC score, as the AIRS AMVs are unable to offset the loss of the MODIS AMVs, indicating that the AIRS AMVs complement the MODIS AMVs and should not be considered a replacement. This was expected as the AIRS AMVs are in clear sky or above cloud regions, while the MODIS AMVs include cloud-tracked features.
- Note: The arbitrary ordering of the placement of the curves makes it more difficult to observe some of the experiment's curve if they are "below" a different curve.

The neutral, or slightly positive, impact due to the addition of the AIRS retrieval AMVs is encouraging as these AMVs are poleward of 70º latitude, but they still have an impact in the longer range forecast over the northern hemisphere (20º – 90º latitude).

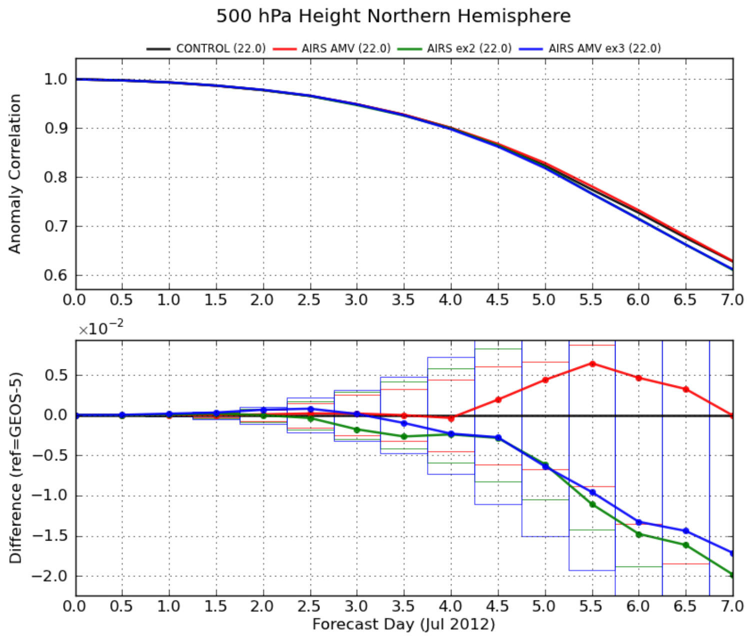

Figure 8: The 500 hPa Northern Hemisphere ACC die-off curves (top) for 1-24 July 2012 00 UTC. The control (black) and three experiments (red, green, and blue) are shown. The lower figure shows the difference between the control and the experiments. Positive difference is an improvement in the forecast; to be statistically significant, the curve must lie outside of its threshold rectangle.

CONCLUSIONS

There are three positive results from this study:

1. The AIRS AMVs compare favorably to co-located MODIS AMVs for a six-week period, as evidenced by a zero speed bias with a standard deviation of 3.5 ms^{-1}.
2. The impact per AIRS moisture AMV is very good, as they are ranked higher than all other satellite-derived wind datasets.
3. The neutral, or slightly positive, impact due to the addition of the AIRS retrieval AMVs is encouraging as these AMVs are only in the polar region, but they have an impact in the longer range forecast over the northern hemisphere.

In order for other NWP centers to evaluate the AIRS AMVs, we were recently awarded a new grant from NASA to generate this product in real-time. These will be available via ftp in the last quarter of calendar year 2014. The format will be as text files in a format similar to other AMV products provided by CIMSS, such as those from MODIS, AVHRR, and Leo/Geo.

ACKNOWLEDGMENTS

Funding for this research was provided by NASA Grants NNX11AE97G and NNX14AI77G.