CHARACTERIZATION OF TRACER HEIGHT ASSIGNMENT ERRORS: A RECURRING THEME FOR ATMOSPHERIC MOTIONS VECTORS

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ABSTRACT

Atmospheric Motion Vectors (AMVs) derived from geostationary, and now polar satellites, provide invaluable information regarding the atmospheric wind field that has been successfully leveraged within operational Numerical Weather Prediction (NWP) data assimilation systems over the past ten years. AMVs derived from geostationary satellites continue to be indispensable over the world oceans and in the tropics. More recently, AMVs derived from the Terra and Aqua polar orbiting satellites, have been shown by the NWP community to be invaluable in improving analyses of the polar wind field, and at the same time, improve the quality of forecasts in the polar regions. The satellite wind community has worked together over the past ten to fifteen years to improve the quality of the AMVs and certainly can take a significant portion of the credit for the success that these observations continue to make on NWP. The NWP community can certainly take its share of this success given improved utilization of the AMV observations as well as improvements made to operational data assimilation schemes. However, despite these successes, the NWP community continues to ask the satellite wind community for some fundamental information regarding the quality of the AMVs. Specifically, what portion of the AMV error can be attributed to height assignment? Height assignment errors associated with the AMV data have long concerned the members of the wind producing and NWP communities alike. Tracer height assignment remains a key issue because, in many cases, it is the largest contributor to the total AMV error that can render them useless or cause significant problems for a NWP data assimilation system. The goal of this work is to characterize the errors of the height assignments assigned to the AMVs generated at NOAA/NESDIS. Results from a “Level-of-Best-Fit” analysis, that involves the utilization of collocated rawinsonde observations, GOES AMVs, and MODIS AMVs, to characterize tracer height assignment errors as a function of height assignment method, latitude, and season, will be presented. Only after this analysis is completed can we begin to answer the fundamental questions being asked by the NWS community regarding what component of the AMV error is attributed to errors in tracer height assignment. Results of this analysis may also provide the necessary information that should lead to further improvements in the height assignment algorithms currently in use today.

1. INTRODUCTION

Atmospheric Motion Vectors (AMVs) derived from geostationary, and now polar satellites, provide invaluable information regarding the atmospheric wind field that are now being successfully leveraged within operational Numerical Weather Prediction (NWP) data assimilation systems (Velden et al, 2005). AMVs derived from geostationary satellites continue to be indispensable over the world oceans and in the tropics. More recently, AMVs derived from the Terra and Aqua polar orbiting satellites, have been shown by the NWP community to be invaluable in improving analyses of the polar wind field, and at the same time, improve the quality of forecasts in the polar regions (Key et al, 2003).

Despite all of the successes achieved with operational AMVs, further improvements in their quality, together with a more comprehensive characterization of their errors, are being requested by the NWP community. This is a fair request which forces operational satellite AMV producers to take a closer look at every step of their AMV derivation process to identify and quantify possible error sources.

In the absence of navigation and registration errors, it is generally assumed that errors in height assignment are the largest single contributor to the total AMV error. The issue of height assignment is not a new one and is one that was addressed at the First International Winds Workshop in 1991. It remains a key issue today.

Height assignment errors can render AMVs useless and can negatively impact operational NWP data assimilation systems.

The goal of this work is to characterize the errors of the height assignments assigned to operational GOES-12 AMVs generated at NOAA/NESDIS. Wind observations from the NOAA Wind Profiler network and rawinsondes are used to evaluate the GOES-12 AMV height assignments. Section 2 provides information and discussion on general GOES height assignment characteristics that include: i) The typical distribution of height assignment methods used for GOES-10 and GOES-12 AMVs; ii) The impact that the CO_2 (13.3um channel) has on the quality of the GOES-12 AMVs ; and iii) The autoeditor and its role and impact in AMV height assignments. In Section 3, the methodology and results from a Level of Best-Fit (LBF) analysis using collocated GOES-12 AMVs, NOAA wind profiler observations, and rawindonde wind observations are discussed.

2. GENERAL GOES HEIGHT ASSIGNMENT CHARACTERISTICS

The compliment of channels available on the GOES-10 and GOES-12 imager instruments allows for feature tracking at a variety of different wavelengths (LWIR at 10.7um, SWIR at 3.9um, Visible at 0.64um, and water vapor at 6.5um (GOES-12) or at 6.7um (GOES-10). In addition, this compliment of channels allows for the computation of numerous AMV heights using a number of different height assignment methods. For each tracer, all possible height assignment methods are attempted. The height assignment method chosen for each tracer follows a pre-determined order according to the expected performance of each height assignment algorithm (Daniels et al, 2004). For each tracer then, a CO_2 height is selected first (if available), then the H_2O-intercept height (if the CO_2 height is not available), and then the window height (if neither the CO_2 height nor the H_2O-intercept height are available). Figure 1 shows the height assignment distribution for GOES-10 (left) and GOES-12 (right) AMVs.

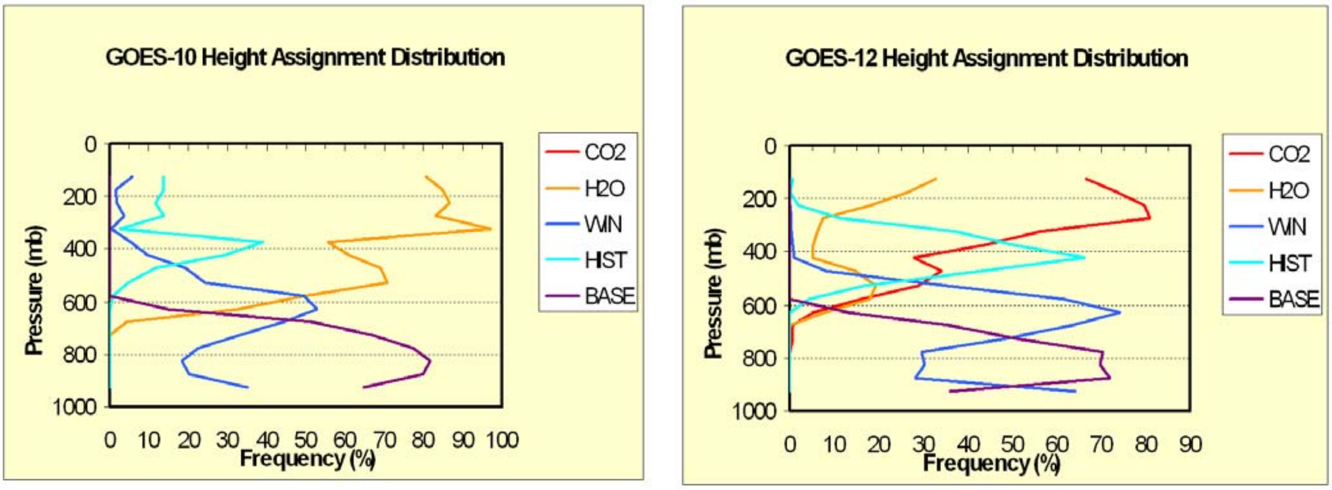

***Figure 1.* Frequency distribution of height assignment methods assigned to GOES-10** (left) **and GOES-12 AMVs** (right)**.**

In the case of GOES-12 which has a 13.3um channel, more than 80% of the cloud-drift AMVs above 300hPa are assigned CO_2 heights. The remaining cloud-drift AMVs are assigned H_2O-intercept heights or IR window (IRW) heights. In the case of GOES-10 IR cloud-drift AMVs above 300hPa, 85-90% of them are assigned H_2O-intercept heights; the remaining AMVs at these levels are assigned IRW heights. At low levels ($P >$ 700hPa), the cloud-drift IR AMVs are assigned IRW heights or cloud base heights. In the case of water vapor AMVs, a histogram (HIST) approach applied to the water vapour radiances is taken to assign heights to clear-sky water vapor tracers. The distribution of these histogram heights is similar for GOES-10 and GOES-12 and clearly reflects the weighting function of the respective water vapour channels.

The addition of the CO2 (13.3um) channel on the GOES-12 spacecraft has a definite, measurable impact on the quality of the high-level cloud-drift AMVs. This is illustrated in Figure 2 which shows a comparison of GOES-12 high level (100-400 hPa) AMVs and radiosonde winds where the AMVs were computed with and without the 13.3um channel. The quality of the high level cloud-drift AMVs is clearly improved with the addition of the 13.3um channel. This is a direct result of improved height assignments for thin cirrus tracers.

Without the 13.3um channel, the AMV heights for such cirrus tracers must be calculated using the H_2O-intercept or IR window height assignment methods. In these cases, the failure rate of the H_2O-intercept method is high and the default IRW height assignment method does not perform well. In the absence of a 13.3um channel, the overall quality of these high level AMVs is worse.

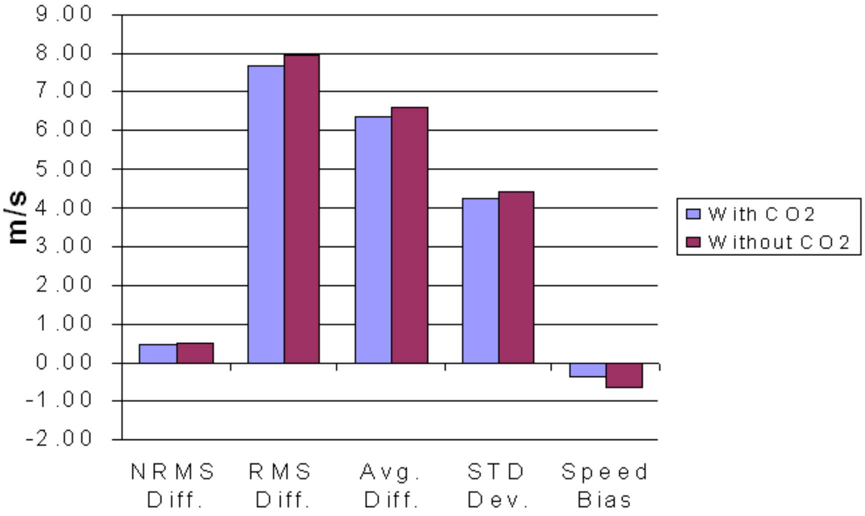

Figure 2. **Comparison statistics for GOES-12 high level (100-400 hPa) AMVs (with and without the 13.3um CO2 channel) versus radiosondes.**

All of the AMVs are subjected to the autoeditor (AE), which is the automated procedure used at NOAA/NESDIS for quality control and objective editing of these data (Hayden, 1993; Hayden and Purser, 1995). A well known function of the autoeditor is to reassign the heights of AMV tracers. This height reassignment function is of particular relevance to the problem of characterizing the AMV height assignment errors. Through the assimilation of other data (ie., model background and neighboring AMVs), the AE reassigns each AMV where it is representative. If an AMV is nowhere representative, it is rejected. Figure 3 shows a scatter plot of the original pressure assignments versus the AE pressure re-assignments for a sample of GOES-12 cloud-drift AMVs on 28 March 2006. Color coding is used to indicate the different height assignment method used for each AMV tracer. The scatter plot shows that, in general, the AE performs small pressure reassignments (+/- 50hPa).

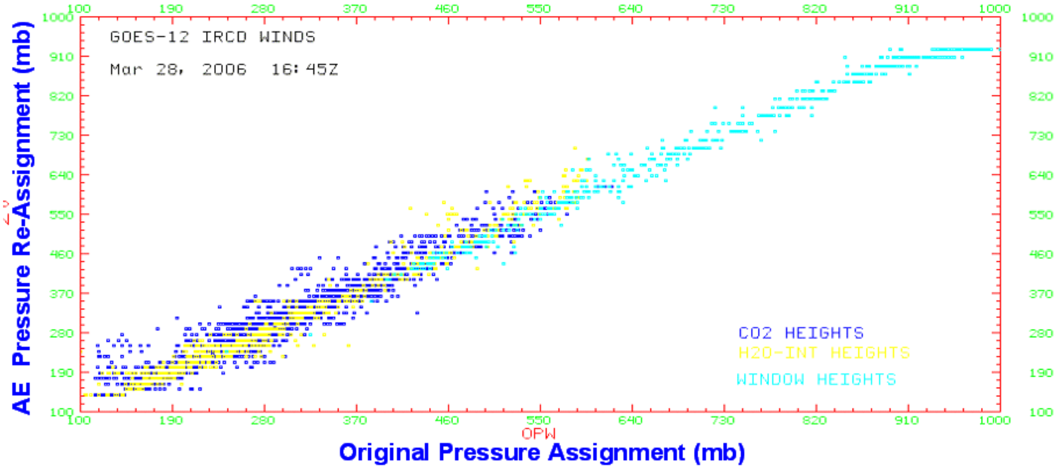

Figure 3. **GOES-12 AMV original pressure assignments versus autoeditor pressure re-assignments at 16:45Z on 28 March 2006**

3. DATA ANALYSIS AND RESULTS

In order to understand and quantify the height assignment characteristics of the GOES-12 AMVs, a Level of Best-Fit (LBF) analysis using collocated operational GOES-12 AMVs, NOAA wind profiler observations, and rawinsonde wind observations was performed. The approach taken is to compare each GOES-12 AMV to an entire wind profile observation. In this way, the AMV height assignment can be compared to the pressure level in the atmosphere where the AMV fits best. This approach is similar to the approach taken in a study of GOES-8 AMV height assignments by Rao and Velden, 2002. The results of these analyses are discussed in the following subsections 3.1-3.2. Just as important as these LBF analyses is an analysis of the spatial (vertical and horizontal) variability of atmospheric wind. Through the use of collocated NOAA wind profiler and rawinsonde observations, estimates of this variability can be made. Understanding and quantifying this variability is important for properly arriving at more realistic error estimates for satellite-derived AMVs. Results from this analysis are presented in subsection 3.3.

3.1 Level of Best-Fit Analysis: Operational GOES-12 AMVs to Wind Profiler Comparison

Figure 4 illustrates a LBF comparison between collocated operational GOES-12 AMVs (IR, WV, and VIS) and NOAA Wind Profiler (at Lamont, OK) observations for the period 12 April 2005 to 31 November 2005. GOES-12 AMVs are binned into 50 hPa layers and are then compared to profiler wind observations within +/- 150hPa of the AMV height assignment. The mean height assignments for eight such layers are plotted as colored horizontal lines in Figure 4. For each AMV height layer, a vector RMS profile is computed and similarly color coded. By comparing the mean height of each AMV bin against the height (pressure) in the atmosphere where the minimum exists in the vector RMS profile, one can deduce in a mean sense how good the AMV height assignments. If the minimum in the RMS vector profile falls below (above) the mean height (pressure) of the AMV bin, then the AMV in that bin are systematically assigned heights that are too high up (low) in the atmosphere. For example, GOES-12 AMVs assigned to 200 hPa are typically misassigned too high up in the atmosphere by ~ 15-20 hPa. Conversely, GOES-12 AMVs assigned to 300 hPa, are typically assigned too low in the atmosphere by ~ 25 hPa. Closer inspection of Figure 4 also reveals that the shape of the vector RMS profiles differs as a function of height. Sharp (broad) peaks in the vector RMS profiles are observed at higher (lower) levels which are indicative of more rapid wind speed changes with height at these levels. Overall, these data show that in the mean, the GOES-12 AMV heights differed from the LBF height by about 16 hPa. Further analysis was done to assess how much the vector RMS could be reduced if the AMVs in these samples were assigned the corresponding mean LBF heights. Doing this resulted in only a minimal improvement (0.4-0.9 m/s) in vector RMS, suggesting that satellite-derived AMVs are more representative over a layer, and as a result, should be treated and used as such. More assessment of these data along these lines is planned so that this may be more understood.

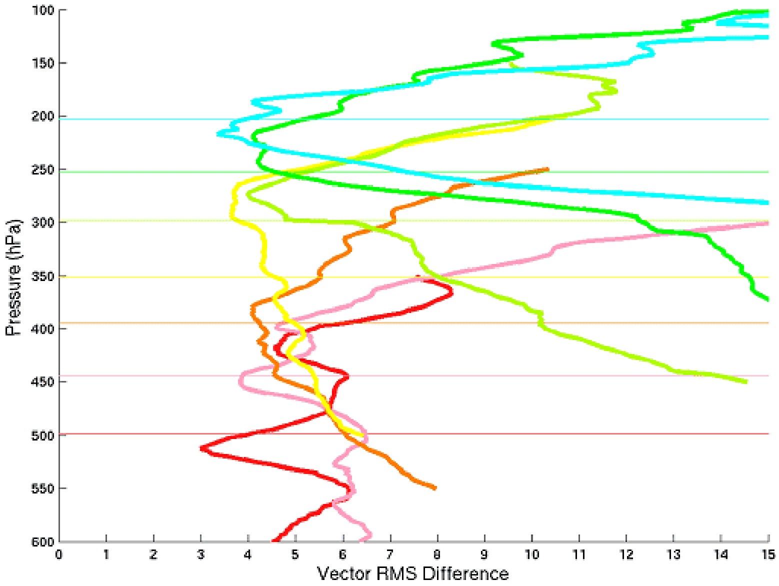

Figure 4. **Vertical vector RMS profiles between GOES-12 AMVs and collocated NOAA wind profiler observations. Vector RMS profiles are color coded according to AMV heights which are placed into 50 hPa bins.**

3.2 Level of Best-Fit Analysis: Operational GOES-12 AMVs to Rawinsonde Comparison

A LBF analysis, similar to the one described in Section 3.1, was done using spatially (150km horizontal; 20 hPa vertical) and temporally (60 min) collocated operational GOES-12 IR cloud-drift AMVs and rawinsondes over the one year period Jan 2004 to Jan 2005. GOES-12 AMV heights (post autoeditor) were binned into 10 hPa layers and compared to rawinsonde profiles (interpolated to 10 hPa vertical resolution) over the vertical range 150hPa – 900 hPa. The analysis results were stratified by the various height assignment methods applied to GOES-12 IR cloud-drift AMVs. LBF results at 200hPa, 300hPa, and 500hPa for the CO_2 slicing, H_2O-intercept, IRW height assignments are shown in Figure 5. The solid green curve is the vector RMS vector profile, the dashed green line is the speed bias (AMV-rawinsonde) profile, and the red line is the mean rawinsonde speed profile. These figures indicate that, in general, reasonably accurate height assignments are given to the GOES-12 AMVs. The typical absolute difference between the level of best fit and the actual height assignment is in the range of 20-50hPa. Larger differences exceeding 60hPa occur for the CO_2 slicing and H_2O-intercept height assignment methods. This is not unexpected as it is well known that the performance of these methods degrades toward increasing pressure. However, closer inspection of each of the vector RMS curves in Figure 5 reveals that nearly all of the GOES-12 AMVs are assigned heights that are too high up in the atmosphere. This result is found for each height assignment method. The only exception is the GOES-12 300hPa winds where the IRW height assignment method was used. Here the minimum in the vector RMS profile occurs just above 300hPA. Table 1 summarizes all of these differences. There is a clear systematic tendency to assign the GOES-12 AMVs too high up in the atmosphere. For the CO_2 heights, it has been found that application of a radiance bias correction to the 11um and 13.3um channels improves the specification of the clear-sky radiances used in the CO_2 slicing algorithm resulting in improved CO_2 height assignments. This is illustrated in Figure 6 which shows the level of best-fit results for a sample of winter time (Dec 2004 – Jan 2005) GOES-12 AMVs that been assigned CO_2 heights where a radiance bias correction was not applied (Figure 6a) and where it was applied (Figure 6b). In the case where a radiance bias correction was not applied, it can be seen from Figure 6a that the CO_2 heights were

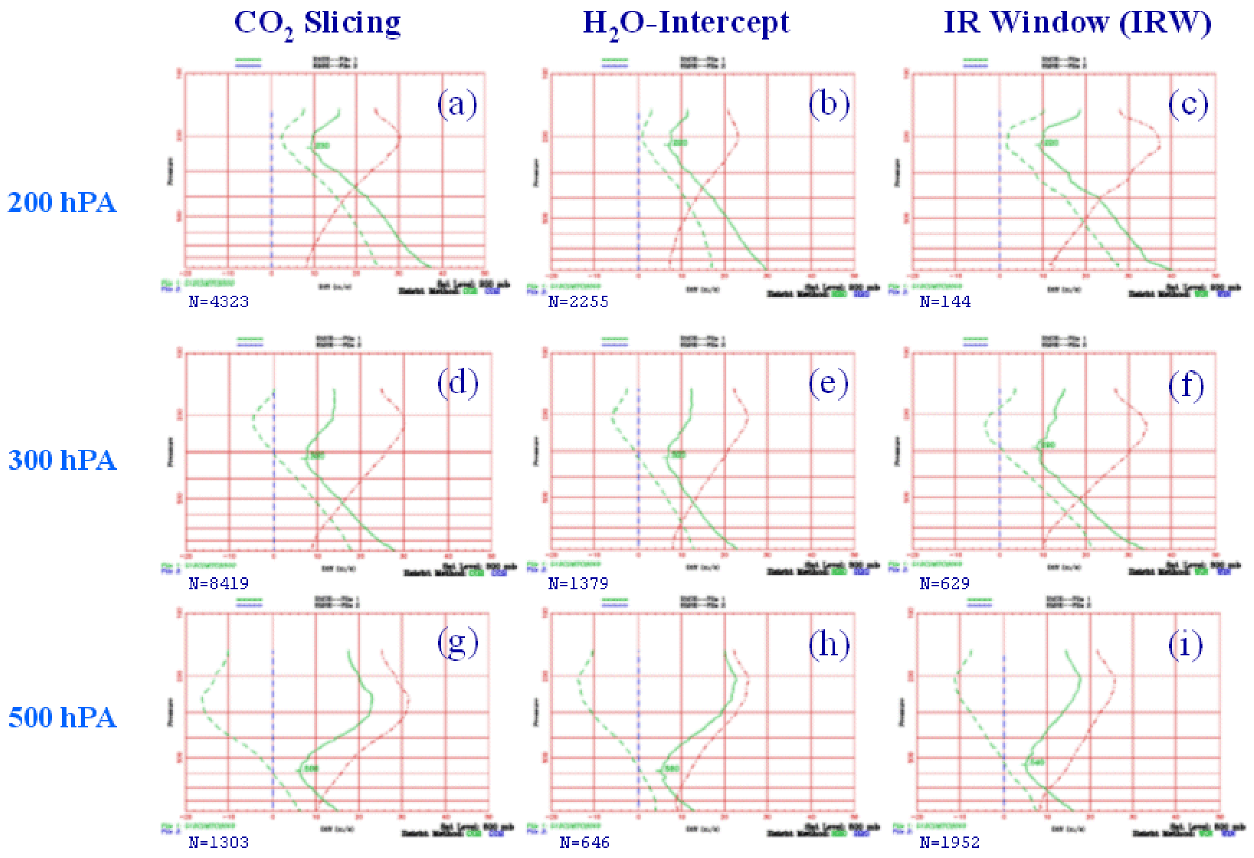

Figure 5. **Vertical vector RMS profiles between GOES-12 AMVs (at 200, 300, and 500 hPa) and collocated rawinsonde observations for different height assignment methods. Solid green curve is the vector RMS profile, the dashed green line is the speed bias (AMV-rawinsonde) profile, and the red curve is the mean rawinsonde speed profile.**

assigned 30hPa too high up in atmosphere. When a radiance bias correction is applied, Figure 6b shows that the difference between the level of best fit and the actual height assignment is within 10hPa. This result is consistent with results discussed in Daniels et al, 2004, where CO_2 heights were placed lower in the atmosphere some 30-50hPa as a result of applying a radiance bias correction. Work is underway at NOAA/NESDIS to build the capability so that radiance bias corrections can be dynamically updated and applied to the 11um and 13.3um channels for use in the CO_2 height assignments.

	Mean Height Assignment Pressure – LOBF Pressure (mb)		
Press(mb)	**CO2**	**H2O-Int**	**IR Win**
200	**-30**	**-20**	**-20**
300	**-20**	**-20**	**+10**
400	**-30**	**-60**	**-20**
500	**-80**	**-80**	**-40**
600	**-90**		**-40**
700			**-60**
800			**-40**
850			**-20**

Table 1. **Differences between the level of best-fit and the actual height assignment for GOES-12 AMVs at different pressure levels and for the various height assignment methods used for GOES-12 AMVs.**

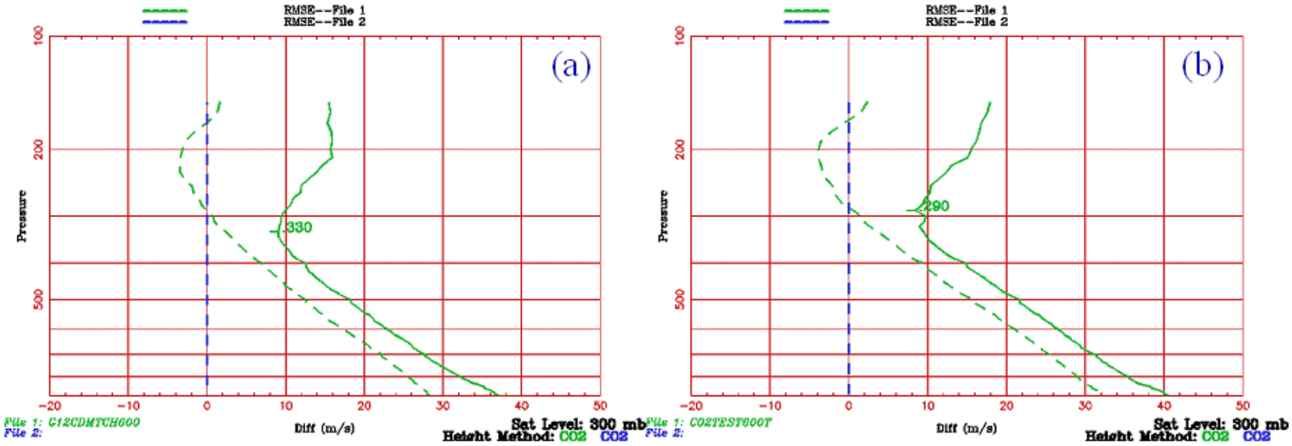

Figure 6. **Vertical vector RMS profiles between GOES-12 AMVs assigned at 300 hPa via the CO_2 slicing method and collocated rawinsonde observations for the period Dec 2004 – Jan 2005. A bias correction was not applied to the 11um and 13.3um radiances used to derive CO_2 heights in Figure 6a. A radiance bias correction was applied in the case of Figure 6b.**

3.3 Rawinsonde to Wind Profiler Comparison

Six-minute resolution data from the NOAA Wind Profiler site in Lamont, OK was utilized in this study. The rawinsonde observations used in this comparison were obtained from rawinsondes launched 4x daily at the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) program Southern Great Plains (SGP) Central Facility at Lamont, OK. These two wind observations were collocated in time and space over the time period 12 April 2005 to 30 November 2005. Wind profiler observations within +/- 3 minutes of the rawinsonde observation and 2hPA in the vertical were considered matches. In the horizontal, a spatial distance of up to 125km was used. More details can be found in Bedka et al, 2006.

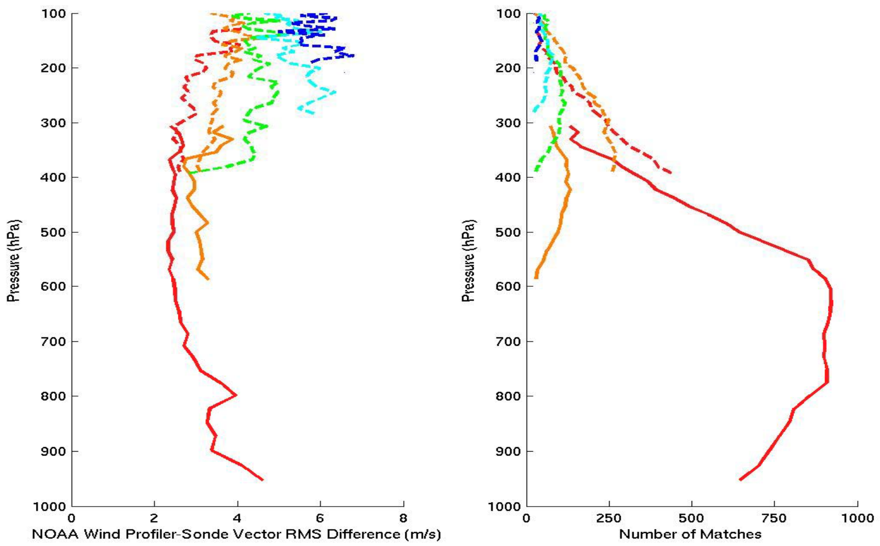

Figure 7. **Profiles of vector RMS** (left) **and speed bias** (right) **differences at varying horizontal spacing between the collocated NOAA Wind Profiler and rawinsonde wind observations. See text for color and line type explanations.**

Figure 7 shows profiles of vector RMS (left) and speed bias (right) differences at varying horizontal spacing between the collocated NOAA Wind Profiler and rawinsonde wind observations, respectively. In this way, one can analyze the atmospheric spatial variability that exists at varying distances; that is as the rawinsonde advects away from the Profiler site. The curve in red includes matches when the rawinsonde was 0 to 25 km away from the Profiler, orange is 26-50 km, green is 51-75km, cyan is 76-100, and blue is 101-125 km. The solid lines are the Profiler "low mode", the dashed are the Profiler "high mode". What can be observed from this figure is that the profile/rawinsonde difference near the surface is larger than difference in the mid-troposphere near 500 hPa. This difference increases further up, above 200 hPa, where the RMS climbs to the difference value near the surface ~4 m/s. By comparing the curves at increasing distance, one can see how much atmospheric motion fields vary over a relatively short distance of ~100 km or ~ 1 degree of lat/lon.

From these data, a 3-5m/s measurement uncertainty between the two observing systems is indicated. This is an important consideration that must be taken into account before assigning error estimates to satellite-derived AMVs. More realistic AMV error estimates would not include this variability.

4. SUMMARY

A Level of Best-Fit (LBF) analysis using collocated operational GOES-12 AMVs, NOAA wind profiler observations, and radiosonde wind observations was done in order to better understand and quantify the height assignment characteristics of the GOES-12 AMVs. The results suggest that, in general, the GOES-12 AMV height assignments are reasonable. In the case of the level of best fit analysis of collocated GOES-12 AMVs and NOAA wind profiler observations, assigning AMVs to the mean level of best fit showed only minimal improvement to the vector RMS. This seems to indicate that the major error may lie in the representativeness of the height assigned. It may be more important to define the layer of the wind that is being tracked, as this will better represent the AMV that results from the feature tracking process. Results from the level of best fit analysis of involving collocated GOES-12 AMVs and rawinsondes indicated a strong tendency to assign GOES-12 AMVs too high up in the atmosphere, regardless of what height assignment method is used. This suggests the need to interrogate every aspect of our height assignment methodology used at NOAA/NESDIS. It was also shown that application of a radiance bias correction to the 11um and 13.3um channels is necessary to improve the GOES-12 CO2 height assignments. These improvements were attributed to an improved specification of the clear-sky radiances used in the CO2 slicing algorithm. The net effect of applying a radiance bias correction is these channels is to place the GOES-12 AMVs lower in the atmosphere by some 30-50hPa which appears to be in the proper direction. NOAA/NESDIS is working to build the capability to dynamically compute and apply these corrections. Finally, an analysis of collocated winds observations from a NOAA wind profiler and rawinsondes showed a 3-5m/s measurement uncertainty between the two observing systems. This is an important consideration that must be taken into account before assigning error estimates to satellite-derived AMVs.

5. REFERENCES

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