# Satellite Wind Vectors from GOES Sounder Moisture Fields


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## ABSTRACT

Geostationary Operational Environmental Satellite (GOES) East and West sounders provide real-time retrievals of temperature and moisture in cloud-free regions on an hourly basis. The single field-of-view product has spatial resolution of about 10 km. The vertical profiles can be converted to images of temperature or moisture at all or selected pressure levels, which then serve as input image sequences for satellite wind retrieval algorithms. By their nature, the sounder generated moisture fields on constant pressure surfaces will overcome the existing problem of determining heights of the wind vectors. This work is an attempt to deduce winds from GOES-derived dew point temperature (*Td*) images using the current Cooperative Institute for Meteorological and Satellite Studies (CIMSS) automated feature-tracking algorithm (Velden at al., 2005). The potential applicability of GOES sounder moisture fields for retrieving winds is tested, and the limitations of the technique are assessed by comparisons with operational satellite-derived winds (GOES imager) and radiosondes.


## INTRODUCTION

Atmospheric motion vectors (AMV) have been derived operationally from geostationary satellite imagery ever since the 1970s (Nieman et al.,1997). Further development and refinement of the algorithms have been ongoing efforts (Menzel, 2001). More recent data assimilation and Numerical Weather Prediction (NWP) model impact studies have shown a positive impact of assimilating the satellite winds (Thepaut, this volume). However, one of the remaining issues of the wind retrievals from any satellite data, i.e. GOES, METEOSAT, MODIS, is the uncertainty in the height assignment attributed to each wind vector. Furthermore, it has been suggested that it is beneficial to spread the satellite wind information over multiple levels, particularly when a water vapor profile is used to define the vertical influence (Rao et al.,2002).

One approach to overcome the AMV height assignment ambiguities of the traditional methods was proposed by Velden et al.(2004), where it is suggested to utilize the current operational wind retrieval algorithm but applied to constant pressure level moisture analysis fields derived from hyper-spectral sounding data. The scheme was initially tested on simulated data using the Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) instrument characteristics, and on one case of NPOESS Airborne Sounder Testbed-Interferometer (NAST-I) airborne data to successfully illustrate the feasibility of such a concept (Velden at al., 2004).

In late 2005, NOAA/NESDIS implemented a new integrated GOES Sounder product processing system that derives atmospheric products such as clear sky radiances, temperature and moisture profiles, cloud-top pressure, and surface skin temperature at the full GOES sounder resolution of about 10km$^2$. These products have not only better geographical coverage, but also provide improved depiction of gradient information, which allow for constant pressure level moisture analysis fields of significant contrast to be extracted and used as input to a wind retrieval algorithm (Daniels et al.,2006).

This paper presents preliminary results from deriving satellite wind vectors from GOES sounder dew point temperature (*Td*) fields, their comparisons against RAOBs, and points out future directions for research, development and applications.

## DATA DESCRIPTION

The GOES full resolution sounder product processing system provides hourly Single-Field-Of-View (SFOV) retrievals of the atmospheric state in clear sky regions at nominal spatial resolution of 10 km (Daniels et al.,2006). The atmospheric profiles of temperature and moisture are derived using a nonlinear physical retrieval algorithm. First, the GOES sounder radiances are navigated and calibrated, and it is determined if a pixel is cloudy or clear. For each cloud-free pixel, a first guess temperature profile is obtained from a space-time interpolation of fields provided by NWS (National Weather Service) forecast models; currently the GFS (Global Forecast System) model is used. Hourly surface observations and sea surface temperature from AVHRR help provide surface boundary information. Sounder radiances are then used with a forward radiative transfer model to simultaneously retrieve temperature and moisture profiles as well as surface skin temperature. At this time, relative humidity (RH) and dew point temperature (Td) are provided at the same pressure levels as temperature, occupying 31 pressure levels between 1000 and 10mb.

GOES sounder vertical profiles can be easily converted to a set of images representing moisture on constant pressure levels by extracting the variable of interest (i.e., Td) from each profile at the desired available constant pressure level. The pressure levels are predetermined by the initial guess profile. These images then serve as input image sequences for the satellite wind retrieval algorithm. We used the Man-computer-Interactive-Data-Access-System (McIDAS) (Lazzara et al.,1999) environment to extract *constant pressure images* of *Td* at selected constant pressure levels.

To assure tracking of features in the moisture fields, and not cloud edges and features, cloud pixels have been masked and a median 3x3 filter was then applied to remove remaining single cloudy pixels. Often under broken cloud conditions many initial moisture targets are not tracked, since the search box can not include cloudy pixels (a current limitation of the tracking code that will be addressed in a future version). Thus it is vital to set a proper search box size: small enough to not eliminate many targets under broken clouds, but also large enough to allow retrieval of the fastest winds at high altitudes. This will be discussed later in the paper. Also, as part of the image pre-processing step, an optimal histogram stretch was applied to every image triplet to achieve maximum brightness contrast and to increase the number of targets to be tracked. Figure 1 shows an example of an image generated from GOES-12 sounder derived dew point temperature profiles at 500mb. The different stages of image extraction, preprocessing and wind retrieval are illustrated. By their nature, the sounder generated moisture field images overcome the problem of assigning heights to the wind vectors. Atmospheric motion vectors were derived using a 5X5 pixel target box, a search box of size of 11x19 pixels, and a 10 m/s U and V component acceleration check quality control threshold.

## EXAMPLES AND DISCUSSION

The following section offers an example of GOES sounder winds from 5 December 2003. The triplet images used for deriving winds at all possible pressure levels are taken from scans between 10:46 and 12:46 UTC. Winds are derived for 20 pressure levels between 1000mb and 100mb, due to current limitations within the wind retrieval algorithm. The levels between 100mb and 0.1mb will be utilized in the next version of the software (under development). The raw winds are shown in Figure 2. As mentioned in the previous section, GOES sounder derived profiles exist only for cloud free areas and this is seen from the view from the top, see Figure 2(a). The vertical distribution of the derived wind vectors, as shown in Figure 2(b), is fairly even throughout the altitude range of 0-15 km. In this illustration, a climatologically derived atmospheric profile was used to convert the pressure levels to altitude.

The quality of the derived winds is assessed by first assigning quality indicators (QI; Holmlund, 1998). Figure 2(c) shows the top view of the AMVs with QI greater than or equal to 50. A threshold of 50 was chosen to represent a mid-point between commonly used thresholds in practice (30 to 70). The Auto Editor Recursive Filter, an important post-processing step in the CIMSS automated AMV tracking system, has not been implemented yet in the sounder wind retrieval code, but will be tested in the future. It is evident that the number of vectors is significantly reduced (see also Table 1), however, the AMV coverage over entire image seems to have been affected equally. Hence, no particular conclusion can be drawn as to why so many winds have QI less than 50. Due to the preliminary nature of the results presented here, we are not confident that the QI, with its current definition, is the best representation of the quality of the sounder moisture winds. This hypothesis will be investigated further in our work.

Statistics from comparisons of the GOES sounder winds against RAOBs are calculated for two examples (Table 1). The number of AMVs from GOES matches to RAOB winds within 100km distance and 50mb pressure, as well as the Mean Bias (MB) and Vector Root Mean Square (VRMS) error (Menzel et al., 1996) are computed for all winds, winds with QI ≥ 50 and winds with QI ≥ 70. Results are summarized by the following layers: low winds (1000-700mb), mid level winds (699-400mb), and high winds (399-100 mb).

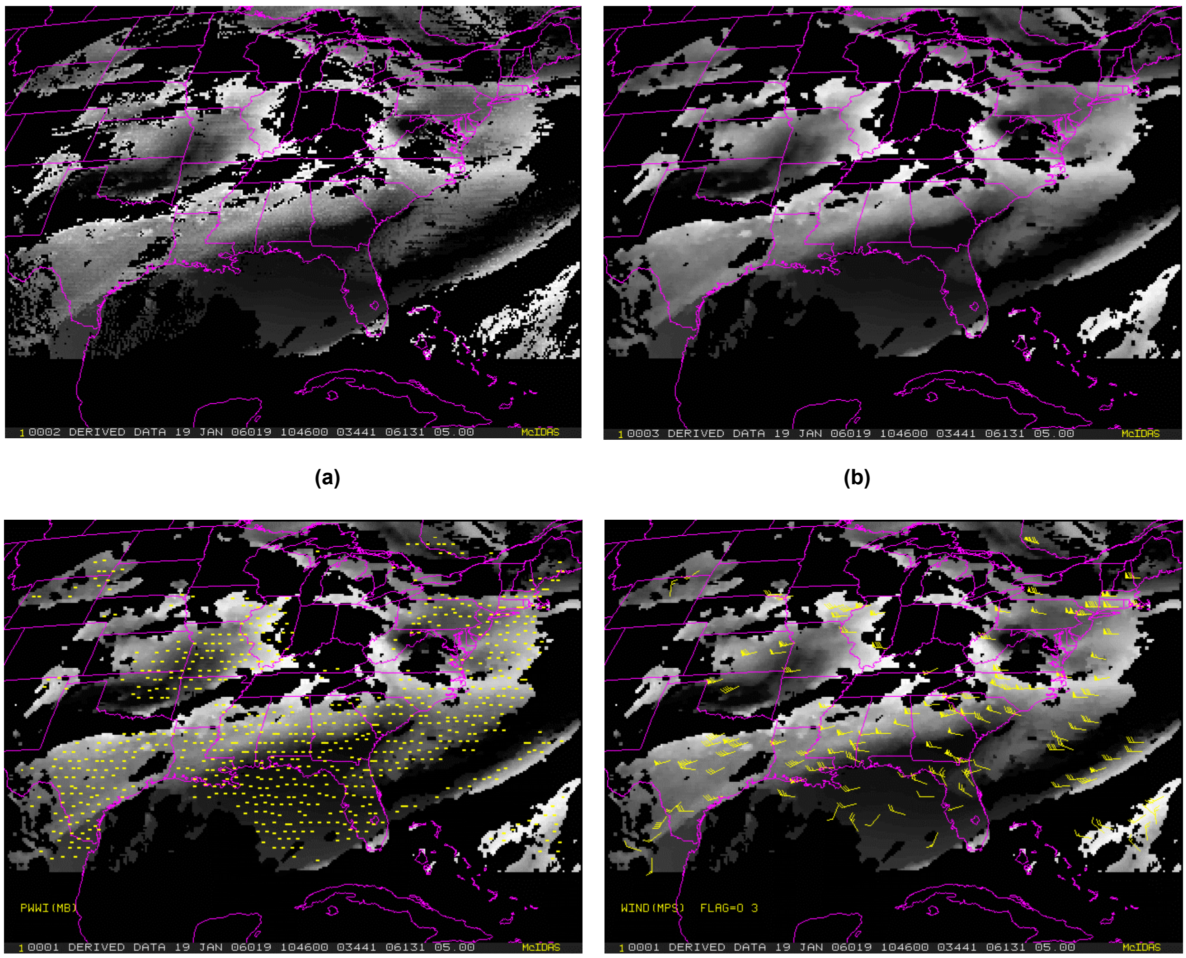
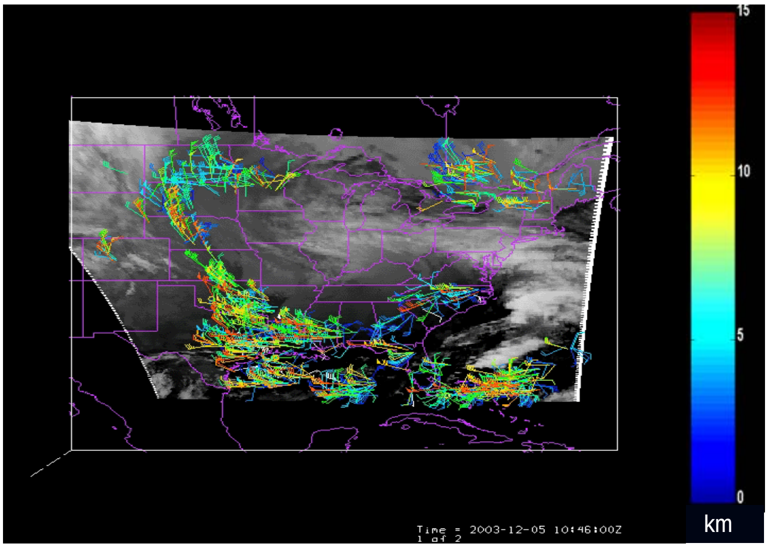
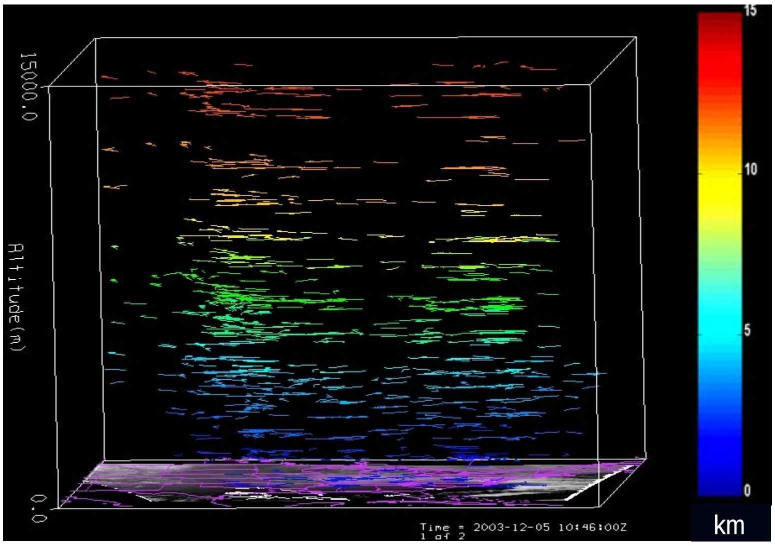



**Figure 1. GOES 12 sounder-derived constant pressure Dew Point Temperature (*Td)* images at 500mb, on 19 January 2006, 10:46 UTC. Blacked-out regions indicate where the retrieval cloud-mask was applied. (a) extracted image from the SFOV profiles after histogram stretch; (b) same as (a) but after a median 3x3 filter to smooth out single cloudy pixels; (c) distribution of targets identified from the moisture fields; (d) atmospheric motion vectors derived at 500mb from triplet images between 10:46 and 12:46 UTC.**

**Figure 2. (on the following page) GOES sounder derived moisture (Td) winds from 5 December 2003, 12 UTC:**
**(a) Raw (unedited) winds - view from the top; (b) Vertical distribution of raw winds; (c) Quality controlled winds with QI≥50 – view from the top.**


15
10
5
0
km
Time = 2003-12-05 10:46:00Z
1 of 2

**(a)**


15000.0
Altitude(m)
0.0
15
10
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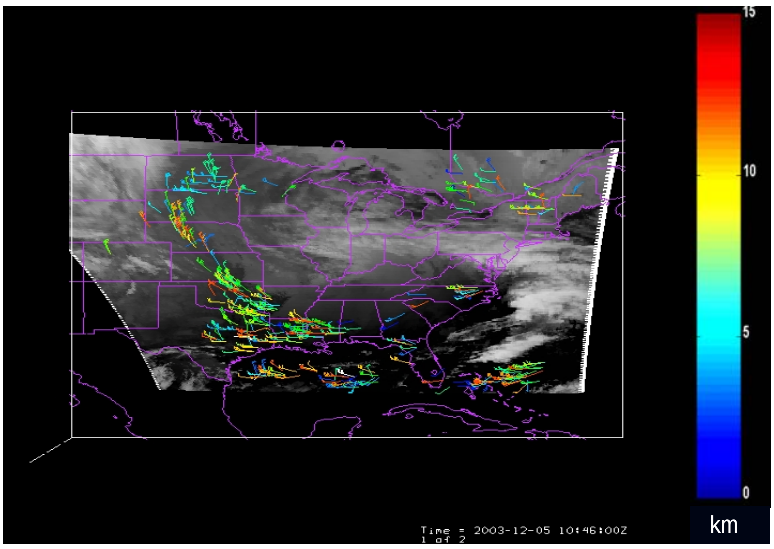
km
Time = 2003-12-05 10:46:00Z
1 of 2

**(b)**


15
10
5
0
km
Time = 2003-12-05 10:46:00Z
1 of 2

**(c)**

**Table 1. GOES Sounder winds statistics from comparison against RAOB winds**

| 5 Dec. 2003, 12 UTC | Number AMV | Mean Bias (m/s) | VRMS (m/s) |
|---|---|---|---|
| ***Raw winds*** | | | |
| All levels | 207 | -7.2 | 17.0 |
| Low winds | 36 | -2.8 | 14.7 |
| Mid level winds | 108 | -7.2 | 16.0 |
| High winds | 63 | -9.6 | 19.8 |
| ***QI ≥ 50*** | | | |
| All levels | 57 | -2.3 | 14.9 |
| Low winds | 7 | -2.3 | 16.0 |
| Mid level | 35 | -3.9 | 14.0 |
| High winds | 15 | 1.2 | 16.2 |
| ***QI ≥ 70*** | | | |
| All levels | 30 | -1.5 | 12.4 |
| Low winds | 3 | -2.0 | 12.1 |
| Mid level | 17 | -3.9 | 12.1 |
| High winds | 10 | -2.8 | 13.0 |
| | | | |
| **19 Jan. 2006, 12 UTC** | **Number AMV** | **Mean Bias (m/s)** | **VRMS (m/s)** |
| ***Raw winds*** | | | |
| All levels | 336 | -2.9 | 14.7 |
| Low winds | 114 | -0.2 | 12.6 |
| Mid level winds | 143 | -0.7 | 13.4 |
| High winds | 79 | -10.7 | 19.2 |
| ***QI ≥ 50*** | | | |
| All levels | 178 | -0.5 | 14.8 |
| Low winds | 42 | 2.5 | 13.8 |
| Mid level | 91 | 2.8 | 12.7 |
| High winds | 45 | -9.9 | 19.1 |
| ***QI ≥ 70*** | | | |
| All levels | 87 | 1.3 | 12.3 |
| Low winds | 9 | 0.5 | 10.9 |
| Mid level | 50 | 5.3 | 11.8 |
| High winds | 28 | -5.6 | 13.5 |

A negative bias, i.e. satellite winds appear slower than the RAOB winds, is evident for virtually all levels of the raw winds, with largest mean bias for the high winds reaching -10m/s for the case from January19 2006. A maximum improvement of 3m/s and 5m/s in VRMS is observed after applying QI thresholds of 50 and 70 respectively. However the VRMS values are still high as compared to typical values from operational imager water vapor winds. At this time. the cause of the slow bias and the large VRMS is not known. The sounder profiles providing moisture analyses for the two examples are generated by identical algorithms. However, in the 2003 case, the first guess profiles were available at a resolution of 3x3 pixels, while for the case from 2006, first guesses were available on a single pixel basis. Thus the images from 19 January 2006, are expected to have better contrast. A comparison between the two cases (5-Dec-2003 and 19-Jan-2006) suggests the homogeneity of the moisture fields could be contributing to the AMV quality. Hence, a better image preprocessing approach would need to be developed.

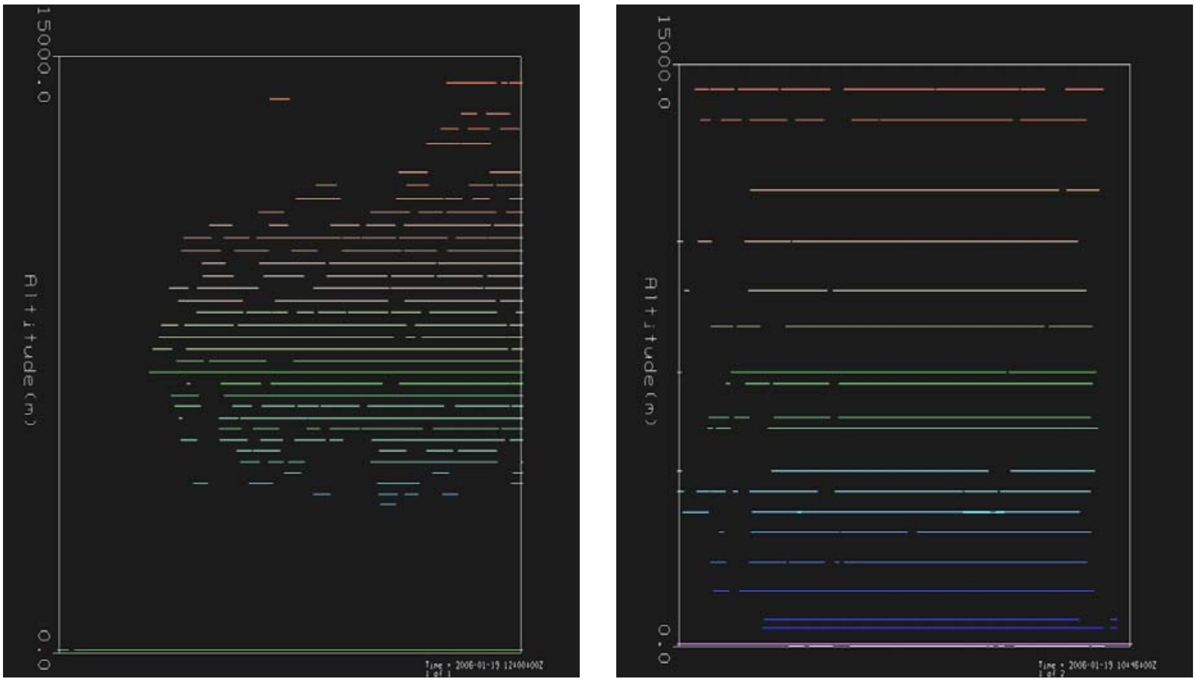
As mentioned earlier, the winds are derived using a 5x5 pixel target box, and a 11x19 pixel search box. The size of the search box was selected to allow measurement of the fastest jet-stream winds of 120 m/s. Given that the winds at lower altitudes are not reaching such high speeds, we will be able to reduce the size of the search box, thus improving the mean bias and the VRMS. The results (for raw winds) in Table 2 suggest that it may be beneficial to apply different size search boxes depending on the pressure level of the moisture fields being analyzed. The statistics are produced for the winds from 19 January 2006. The mean bias is not greatly improved, but it has relatively low values even with the

11x19 search box. The VRMS however has been reduced significantly by employing a smaller search box, as much as 50% for the high winds.

**Table 2. Effect of search box size on wind accuracy. Collocated RAOBs are used for validation.**

| **19 Jan. 2006, 12 UTC** | **Number AMV** | **Mean Bias (m/s)** | **VRMS (m/s)** |
|---|---|---|---|
| ***Search box size 7x11*** | | | |
| All levels | 468 | -1.8 | 8.5 |
| Low winds | 157 | -1.5 | 8.5 |
| Mid level winds | 209 | -0.5 | 8.0 |
| High winds | 102 | -4.7 | 9.7 |
| ***Search box size 11x19*** | | | |
| All levels | 336 | -2.9 | 14.7 |
| Low winds | 114 | -0.2 | 12.6 |
| Mid level | 143 | -0.7 | 13.4 |
| High winds | 79 | -10.7 | 19.2 |

The plots in Figure 3 allow a visual comparison of the vertical distribution of the operationally-derived CIMSS water vapor (WV) tracked winds (on the left) to the AMVs from the GOES sounder-derived product dew point temperature fields (on the right). The sounder winds are currently derived and shown at 20 pressure levels, hence they look sparser compared to the operational output, however another 11 pressure levels will be added in the future. Hence, the vertical resolution will improve. The main advantages of the sounder approach are the even distribution of winds in altitude, and that there is no height assignment involved due to the fact that the moisture fields already have a known pressure. Spatially, the operational WV winds are retrieved over both cloudy and clear areas, thus the comparison against the clear-sky-only sounder winds in this figure should not be misinterpreted.




(a) (b)

**Figure 3. Vertical distribution of AMVs for 12 UTC on 19 January 2006: (a) operational GOES Water Vapor tracked winds; (b) from GOES sounder derived product moisture fields**

Finally, Figure 4 illustrates the correlation between the amount of moisture per constant pressure level, and the number of derived wind vectors. The top left panel shows the variation in the number of AMVs per pressure level. On the top right is the mean dew point temperature per pressure level (averaged over the entire scene); it decreases monotonically with lowering pressures. Nevertheless, the bottom left plot shows that the Td standard deviation (STD) for each image does not necessarily follow the same trend. The Td standard deviation is used as a measure of contrast (available gradients) in the moisture fields. Notice that the STD is in agreement with the trend of the curve on the top left panel, i.e. number of AMVs. Finally, the plot of the number of vectors versus the dew point temperature STD, on the bottom right, confirms that when the contrast is higher, more vectors are derived independently of the amount of moisture.

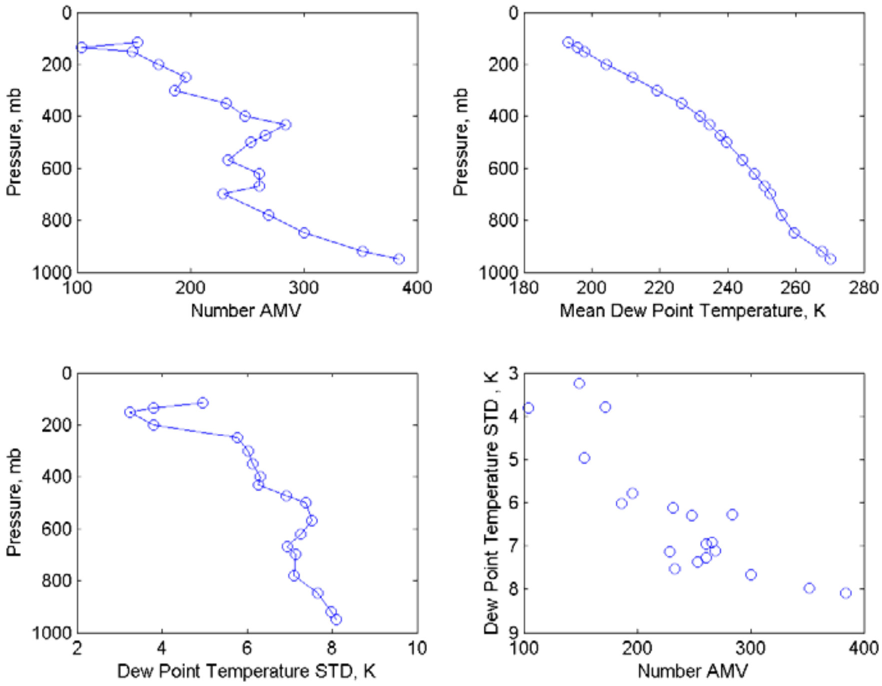



**Figure 4. Correlation between dew point temperature variation with altitude and number of AMVs, 19 January 2006, 12 UTC.**

## CONCLUSIONS AND FUTURE WORK

In this investigation, the automated CIMSS feature tracking algorithm has been applied to GOES sounder moisture fields to produce AMVs. The sounder profiles, and hence the derivative images, are available at 31 constant pressure levels on an hourly basis and at 10km nominal spatial resolution. Thus, the resulting AMVs overcome the height assignment uncertainties associated with traditional wind retrievals from imagers. Preliminary results from this study demonstrate the feasibility of the approach despite the existing slow bias and large VRMS. Certainly the coarse spatial resolution and limited vertical resolution of the current GOES sounder moisture data is a limiting factor on the AMV quality. However, future GOES sounders that are being considered will improve on these two factors, so our study is relevant to future GOES risk reduction and demonstration issues.

Future research toward improving the GOES sounder moisture winds will address the following topics: improving the image extraction scheme; applying dynamic search box size with altitude; extracting mixing ratio fields; further algorithm verification with RAOBs and wind profiling radar data; implementing the approach in real time; producing long term statistics; performing model impact studies; and initiating data assimilation efforts.

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