STATUS AND DEVELOPMENT OF OPERATIONAL GOES WIND PRODUCTS

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ABSTRACT

NOAA/NESDIS and the Cooperative Institute for Meteorological Satellite Studies (CIMSS) continue to be very active in improving the quality of Atmospheric Motion Vectors (AMVs) derived from the GOES-I/M series of satellites. The NOAA/NESDIS winds processing system continues to be incrementally upgraded with updated wind algorithms, new wind products, and new processing strategies. High quality visible cloud-drift (CD) winds are now being generated from GOES-8 and GOES-10 on an operational basis for the Northern and Southern Hemispheres. GOES sounder water vapor wind products have also been added to the operational wind production suite. The operational NESDIS wind products are now being distributed in the unified BUFR template. This development opens up opportunities for improved use of the wind products by the major numerical weather prediction centers. New operational processing strategies take advantage of the higher frequency interval imagery available to derive the wind products. These new strategies have resulted in improved wind products which, in turn, has resulted in improvements in their utility in numerous applications. These geostationary wind products serve as critical input to a wide range of applications that include assimilation into regional and global prediction systems, oceanic analyses, and tropical storm analyses.

1. Introduction

NOAA/NESDIS and the Cooperative Institute for Meteorological Satellite Studies (CIMSS) continue to be very active in improving the quality of Atmospheric Motion Vectors (AMVs) derived from the GOES-I/M series of satellites. The NOAA/NESDIS winds processing system continues to be incrementally upgraded with updated wind algorithms, new wind products, and new processing strategies. High quality visible cloud-drift (CD) winds are now being generated from GOES-8 and GOES-10 on an operational basis for the Northern and Southern Hemispheres. GOES sounder water vapor wind products have also been added to the operational wind production suite. The operational NESDIS wind products are now being distributed in the unified BUFR template. This development opens up opportunities for improved use of the wind products by the major numerical weather prediction centers. New operational processing strategies take advantage of the higher frequency interval imagery available to derive the wind products. These new strategies have resulted in improved wind products which, in turn, has resulted in improvements in their utility in numerous applications. These geostationary wind products serve as critical input to a wide range of applications that include assimilation into regional and global prediction systems, oceanic analyses, and tropical storm analyses.

2. Overview of the NOAA/NESDIS wind product system

An overview of the operational NOAA/NESDIS winds processing system is shown in Figure 1. The major components of the system include automated image registration quality control, target selection, wind target height assignment, target tracking, and automated quality control of derived winds.

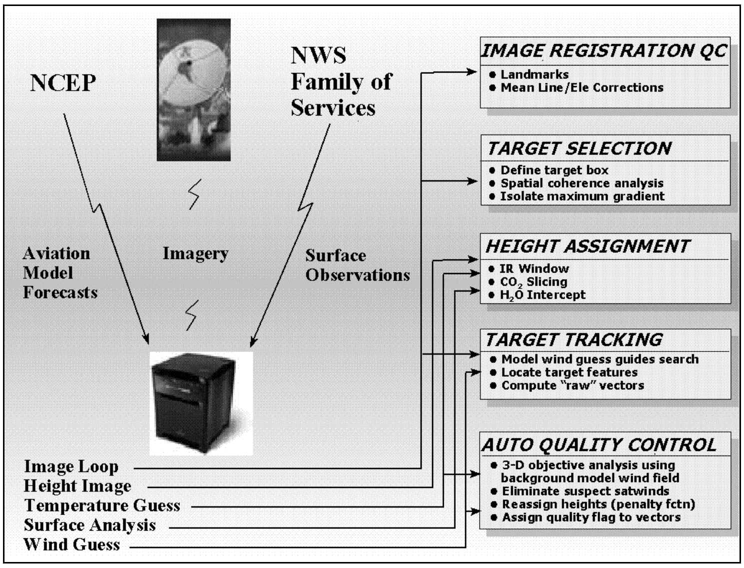


Figure 1. Overview of NOAA/NESDIS Winds Processing System

GOES imagery is acquired soon after ingest to build loops of imagery at the desired time intervals. Aviation model forecast data is made available at 3 hour forecast intervals and at 1^o x 1^o resolution by the National Centers for Environmental Prediction (NCEP)/ Environmental Modeling Center (EMC). Surface observations are made available every hour by the National Weather Service (NWS). The first image in the loop is currently used for the target selection and height assignments. Subsequent imagery is used during the tracking phase where a Euclidean distance pattern-matching technique is used. Automated quality control of the satellite winds is then performed. This step involves a three-dimensional objective analysis (Hayden and Purser, 1995) of the wind field using background information from the NCEP/EMC global aviation numerical weather prediction model.

3. Current and new operational wind products and new processing strategies

The current operational wind products being generated at NOAA/NESDIS are shown in Table 1. The frequency at which each product is produced, together with the GOES image sector used, and image interval is presented in this table.

Table 1. NOAA/NESDIS Operational Wind Products

Wind Product	*Frequency (Hours)*	*Image Sector(s)*	*Image Interval (minutes)*
IR Cloud-drift	3	Extended NH; SH	30
Water Vapor	3	Extended NH; SH	30
Vis Cloud-drift	3	RISOP	7.5
	3	PACU/CONUS	15
	3	Extended NH; SH	30
Sounder WV (7.4um)	3,6	CONUS/Tropical	60
Sounder WV (7.0um)	3,6	CONUS/Tropical	60

The newest operational wind products include the visible cloud drift and GOES sounder water vapor motion winds. The visible cloud-drift wind products are generated routinely for GOES-8 and GOES-10 every three hours during daylight hours over the Northern and Southern Hemisphere. The GOES sounder water vapor winds are generated every three hours over the Continental United States (CONUS) and every six hours over the adjacent oceanic regions. An example of the GOES-10 visible wind product at 23Z on February 14, 2000 is shown in Figure 2 where the low level flow around a cyclonic weather system approaching the western United States is well depicted. Figure 3 illustrates the GOES sounder water vapor winds and the sounder coverage offered over CONUS and nearby oceans from both GOES-8 and GOES-10 at 12Z on February 14, 2000. As discussed in Velden et. al., 1997, the 7.0um and 7.4um sounder water vapor channels can be used to track water vapor features radiating from lower layers of the atmosphere. While there may be some redundancy between the imager water vapor winds and sounder water vapor winds in terms of vertical coverage, additional information is gained from the sounder channels, especially in the cloud-free regions.

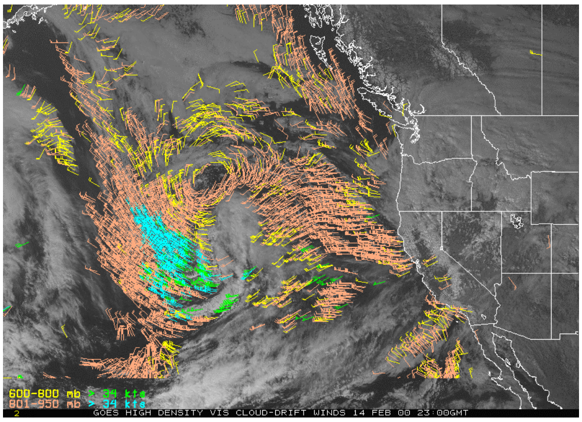


Figure 2. GOES-10 low-level visible cloud-drift winds at 23Z on February 14, 2000.

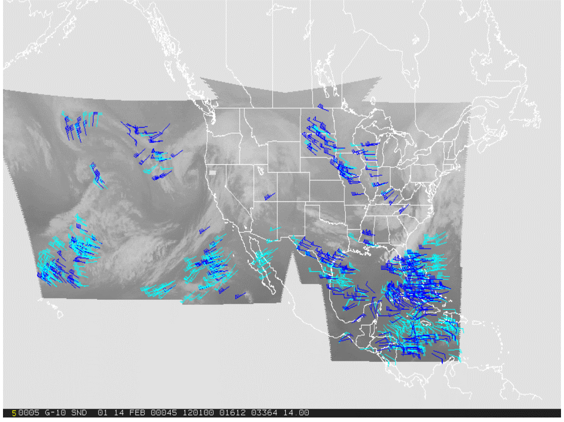
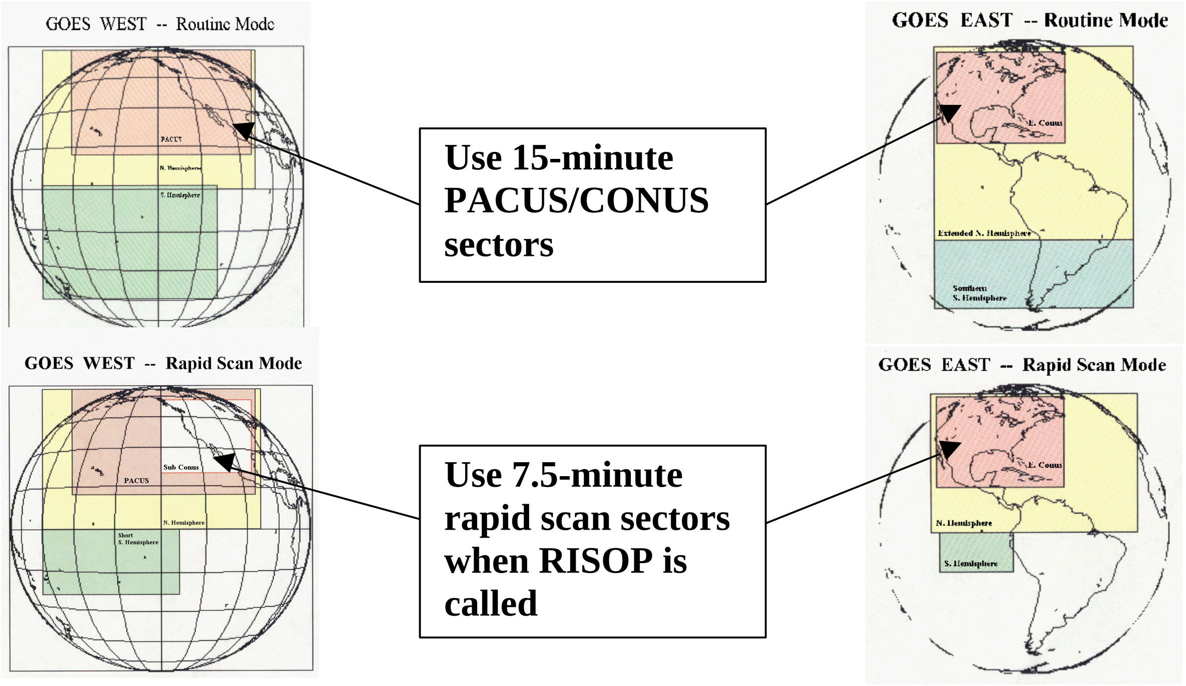


Figure 3. GOES-8 and -10 sounder 7.0 um and 7.4 um water vapor winds at 12Z on February 14 2000.

a) Use of Higher Frequency Interval Imagery

New processing strategies have been developed for operational wind processing to take advantage of the higher frequency interval imagery offered by the current GOES scanning schedules. The capability to routinely use higher frequency interval imagery in the operational derivation of visible CD satellite wind vectors has recently been added to the wind production suite at NOAA/NESDIS. The GOES 15-minute CONUS and PACUS image sectors are now used routinely for the generation of low level visible cloud-drift wind vectors for GOES-8 and GOES-10, respectively. In addition, the more frequent 7.5-minute imagery rapid scan imagery is automatically utilized when the GOES imager is placed in rapid scan mode. The Northern Hemispheric image sectors, which are scanned every 30 minutes, are used to generate wind products outside the CONUS, PACUS, and RISOP domains in order to achieve full Northern Hemispheric coverage. The Southern Hemispheric image sectors, which are scanned every 30 minutes, are used to achieve coverage in the Southern Hemisphere. These image sectors are illustrated in Figure 4.

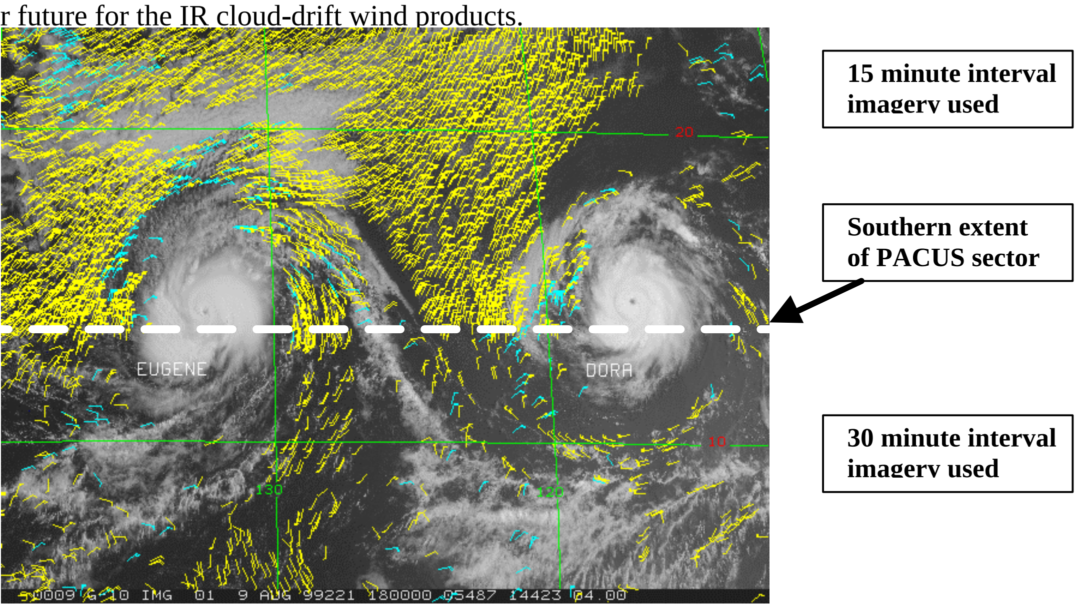


Use 15-minute PACUS/CONUS sectors

Use 7.5-minute rapid scan sectors when RISOP is called

Figure 4. GOES East and GOES West Image Sectors. Use of CONUS, PACUS, and RISOP sectors offer benefits to wind processing.

The importance of image frequency in target selection for tracking is well recognized. Successful tracking of features such as cumulus over land, whose lifetimes can be considerably less than 30 minutes, demands the use of visible imagery whose time interval is in the 5-15 minute range. Velden et al, (2000) investigated the impact of using GOES rapid and super rapid scan imagery on the coverage and quality of various derived wind products. The authors presented validation statistics to help identify the optimal image frequency for various wind product types. An example showing the impact of using higher frequency interval imagery on the GOES-10 visible wind product is shown in Figure 5. This figure shows GOES-10 low level cloud-drift winds around Hurricanes Dora and Eugene, where 15-minute PACUS and 30-minute Northern Hemisphere imagery were used. Note the dramatic increase in vector coverage and the more uniform flow associated with the 15-minute wind field. As noted above, the operational NESDIS winds production cycle includes the processing of both image sectors to produce a combined visible wind product. A similar processing strategy will be implemented in the near future for the IR cloud-drift wind products.



15 minute interval imagery used

Southern extent of PACUS sector

30 minute interval imagery used

Figure5. GOES-10 low level visible cloud-drift winds around hurricanes Dora and Eugene using 15-minute and 30-minute interval visible imagery.

b) Low Level Cloud Tracer Height Assignments

Low-level cloud tracer height assignments are typically based on IR window methods which use a coincident model temperature profile to assign the tracer height at cloud top. Numerous studies, however, have indicated that low level cumuliform cloud motion is best estimated by assigning the derived wind vector at cloud base (Hasler et al, 1979). Since cloud base temperature cannot be measured directly from satellite measurements, a reasonable estimation technique is needed. Such a technique has been developed at the Australian Bureau of Meteorology. The technique involves constructing a histogram of IR pixels in the target scene, applying a Hermite polynomial expansion to the histogram, and taking the second derivative of the polynomial expansion to identify/estimate where the cloud base is. This technique has been implemented within the NESDIS tracer height assignment algorithm. Results indicate that this approach lowers the vector height assignments some 40-50mb. Verification statistics, using rawinsondes as ground truth, show a reduction in vector rms error of nearly 0.5 m/s.

c) Product Distribution

All of the operational NESDIS wind products shown in Table 1 are now encoded into the unified BUFR format and available on a NESDIS server. All of the products, with the exception of the sounder water vapor winds, continue to be encoded into the SATOB format and distributed over the GTS. The BUFR wind product datasets will be disseminated out over the GTS once NESDIS and the National Weather Service (NWS) work out the communication interfaces associated with the new NWS computer system.

4. Quality of GOES satellite wind products

The traditional means of assessing the accuracy of satellite derived winds at NOAA/NESDIS is to collocate satellite derived winds with rawinsondes. Time series of daily verification statistics for visible and IR CD and WV winds for GOES-8 is shown in Figure 6. Figures 7 shows the daily verification statistics for GOES-8 sounder band 10 (7.4um) and band 11 (7.0um) water vapor winds for the same period. It should be noted that the visible CD winds include only low level winds below 600mb. Updated time series of these wind verification statistics can be found online on the NESDIS web page: http://orbit-net.nesdis.noaa.gov/goes/winds/html/tseries.html

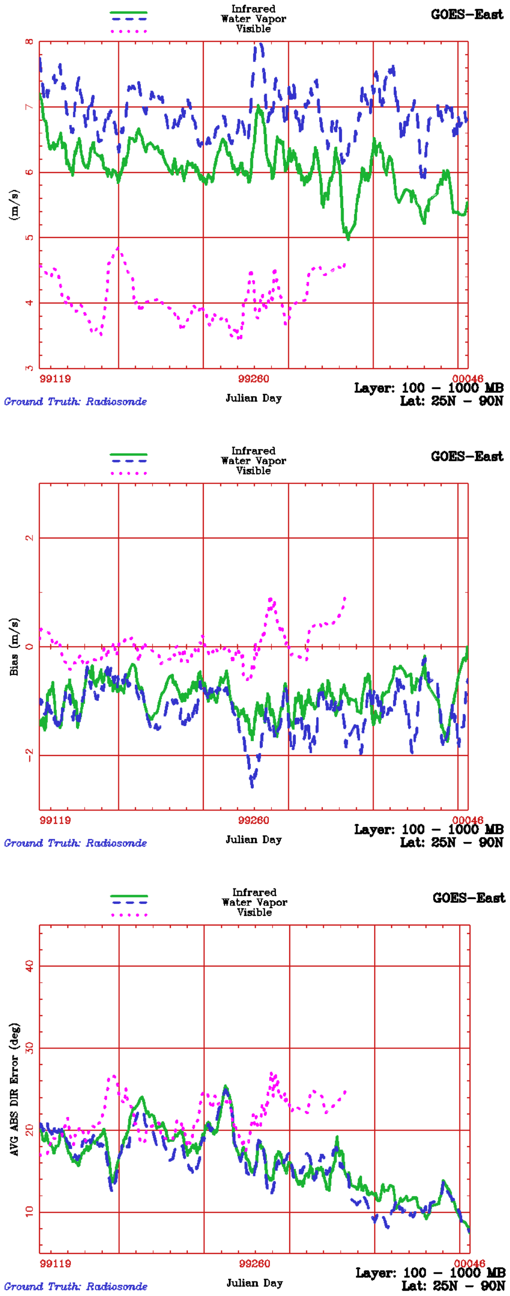


Figure 6. Mean vector difference (top), bias (middle), and directional difference (bottom) for IR,WV,VIS winds.

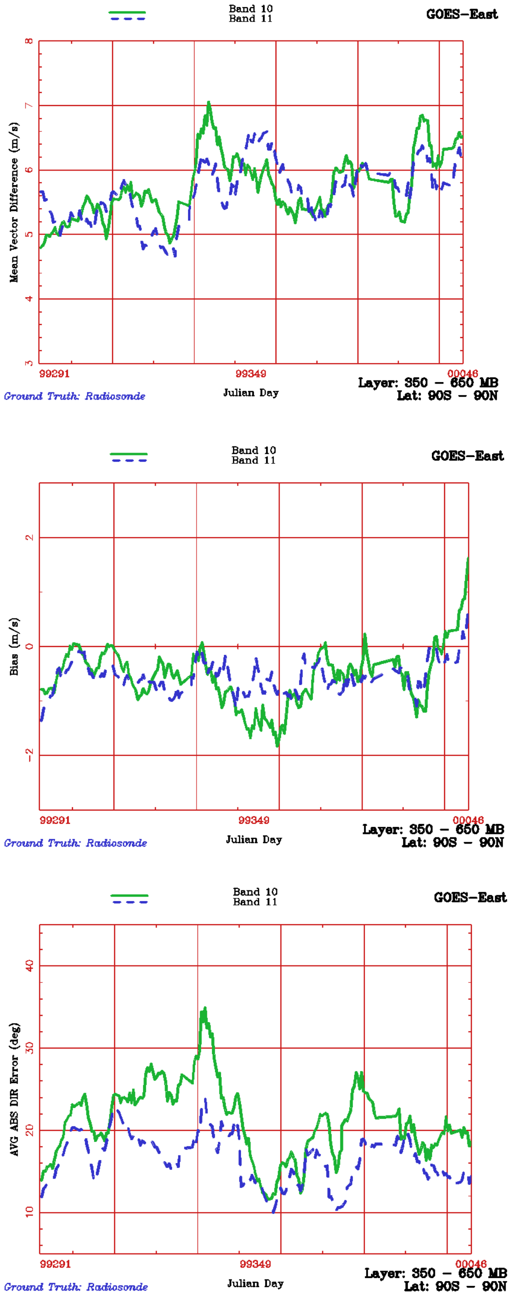


Figure 7. Mean vector difference (top), bias (middle), and directional difference (bottom) for sounder WV winds

Addressing the Slow Bias for GOES Water Vapor Winds at Middle (400-700mb) Levels

The above time series show that the water vapor winds exhibit a considerable slow bias. In this section we address possible causes for this bias and present a proposed solution.

The mid-level slow bias evident in the water vapor winds has been observed for some time by the major numerical weather prediction centers. Given their observed quality, most if not all, of the major NWP centers exclude the use of these wind products in their data assimilation schemes. Water vapor winds at these middle levels of the atmosphere are predominantly tagged as "clear-air", indicating that moisture features having some finite depth are being tracked. The "cloud-top" WV winds fall predominantly in the high level category. These winds are treated much like the IR (10.7um) cloud-drift winds in that the cloud tracers are provided the benefit of using the multi-spectral water vapor intercept height assignment technique and are afforded the opportunity of a speed bias correction providing they meet certain criteria.

Tables 2 and 3 show our statistics at high (100-400mb) and mid-levels (400-700mb) levels derived from collocated WV winds (cloud-top and clear-air) and radiosonde winds over approximately a two year period (1998-2000). While a slow bias exists for both layers, it is much more pronounced in the mid-level layer. In addition to the usual set of statistics that get generated (mean vector difference, speed bias, etc) we computed the mean magnitude of the u-component and v-component for the satellite WV winds and the collocated radiosonde winds. We took the absolute value of each individual component when constructing the mean. We then computed the percent difference between the satellite WV winds and radiosonde for each component. At high levels, both satellite wind components are approximately 8% too slow relative to the radiosonde wind. At mid levels, however, the statistics indicate that the WV wind v-component is more than twice as slow as the u-component relative to the radiosonde wind. To investigate whether there was a dependence on direction we further stratified our statistics by radiosonde wind direction and computed these statistics for 30 degree bins (345deg-15deg; 15-45 deg, etc). These results are shown in Figure 8.

Table 2. Collocation statistics for High Level (100-400mb) GOES-8 Water Vapor Winds for the period 1998-2000. Radiosondes serve as ground truth.

Statistic	*SAT*		*GUESS*	*RAOB*
RMS Difference (m/s)	7.60		7.19	
Mean Vector Difference (m/s)	6.36		5.94	
Standard Deviation (m/s)	4.17		4.04	
Speed Bias (m/s)	**-1.03**		-1.73	
Mean | u-component | (m/s)	**17.81**	(-8.0 %)		**19.24**
Mean | v-component | (m/s)	**9.51**	(-8.6 %)		**10.33**
|Directional Difference|(deg)	13.47		13.87	
Speed (m/s)	22.31		21.62	22.91
Sample Size	282317		282317	

Table 3. Collocation statistics for mid-level (400-700mb) GOES-8 Water Vapor Winds for the period 1998-2000. Radiosondes serve as ground truth.

Statistic	*SAT*		*GUESS*	*RAOB*
RMS Difference (m/s)	8.49		7.14	
Mean Vector Difference (m/s)	7.07		5.67	
Standard Deviation (m/s)	4.70		4.33	
Speed Bias (m/s)	**-2.50**		-1.41	
Mean | u-component | (m/s)	**14.32**	(-11.4 %)		**15.96**
Mean | v-component | (m/s)	**7.19**	(-25.2 %)		**9.00**
|Directional Difference|(deg)	18.02		18.24	
Speed (m/s)	17.21		18.29	19.70
Sample Size	37755		37755	

The v-component line shows that the satellite WV wind v-component is slower than the corresponding radiosonde v-component in all bins except for two. The wind directions for these two bins are 90 deg (easterly) and 270 deg (westerly). Similarly, the u-component line shows that the satellite WV wind u-component is slower than the corresponding radiosonde u-component in all bins except for two. Not surprising, they are at 0 degrees (northerly) and 180 degrees (southerly). The behavior of the two curves at these angles is indicative of the problem of estimating small displacements with discrete observations. Clearly, it will be extremely difficult to determine the v-component of a tracer moving in a nearly easterly or westerly direction. The horizontal resolution of the imagery used becomes increasingly important for being able to resolve such component motion where slower speeds are prevalent. What is bothersome in our statistics in Table 3 is the fact that the mid-level satellite WV wind v-component difference is nearly twice that of the u-component difference.

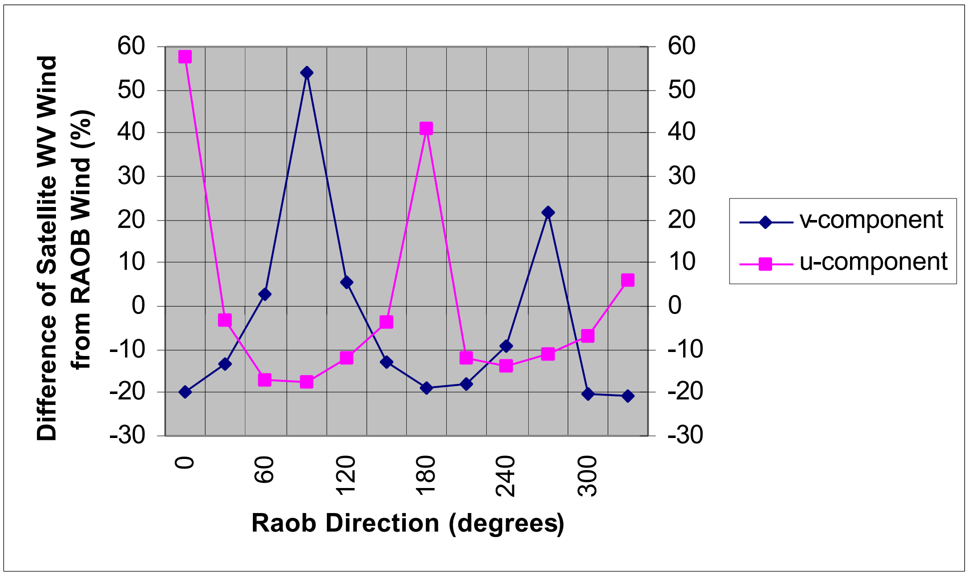


Figure 8. Percent difference between GOES-E WV wind (mid and high levels) u and v-components and corresponding u and v-components of RAOB wind as a function of RAOB wind direction.

We believe that the lower north/south resolution of the GOES water vapor imagery is likely to be a contributing factor for the mid-level slow bias. The resolution of the GOES water vapor imagery in the north-south (N/S) direction is 8km versus 2.3km in the east-west (E/W) direction where the data is over-sampled. This implies that small N/S displacements are not being resolved as well as E/W displacements in the water vapor imagery. At middle levels, where wind speeds are slower, it is logical to assume that the resolution of the data becomes even more important.

In order to bring out the impact of wind speed on the behavior we are observing in the u- and v-components, we plotted the component absolute difference (satellite – radiosonde) versus the component magnitude. This is shown in Figure 9. From this figure we conclude the following:

1) The smaller slope of the v-component line shows that the v-component is less sensitive to increases in speed. This is most likely a result of the lower N/S resolution of the WV imagery.
2) The coarser N/S resolution of the WV imagery, coupled with the slower overall magnitude of the v-component, contributes to larger relative differences.
3) Our acceleration checks tend to remove the largest "resolution" errors, while leaving the smaller (slower) errors. As such, the remaining error is biased (ie.,non-random) in the slow direction.

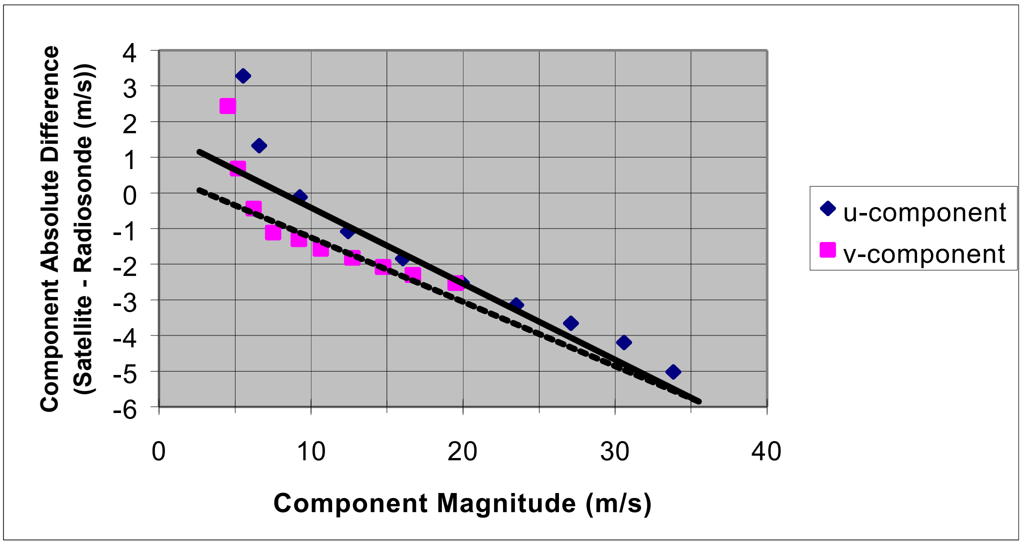


Figure 9. Component absolute differences (GOES-E WV satwinds – radiosonde) versus component magnitude.

So, what have we concluded from this exercise and where do we go from here? The coarser resolution of the water vapor imagery is a contributing factor to the differences observed in the water vapor wind u and v-component statistics. As pointed out by Merrill (1989), one must consider the temporal resolution of the imagery being used in relation to its spatial resolution. Given this, we must consider whether 30-minute temporal resolution is optimal for generating GOES water vapor winds. Using 60-minute interval imagery to derive GOES water vapor winds may be a possible answer to minimizing the resolution effects and improving the overall quality of these winds. In fact, doing this may actually make more physical sense given the nature of this data and the scale of motion which can adequately be resolved with it. We have in fact tried this and the results are quite striking. Figures 10 and 11 illustrate the raw (pre-autoeditor) water vapor winds using 30-minute and 60-minute interval data, respectively. Using the 60-minute interval imagery has resulted in a more coherent wind field. At the same time, the vector coverage at middle levels has increased by over 50% in this one case. When comparing these raw water vapor winds (30-minute and 60-minute) against radiosondes, the mean vector difference improved by 1.5-2.0 m/s. Absolute directional differences improved by over 5 degrees overall. Given these findings, we may be on the right track.

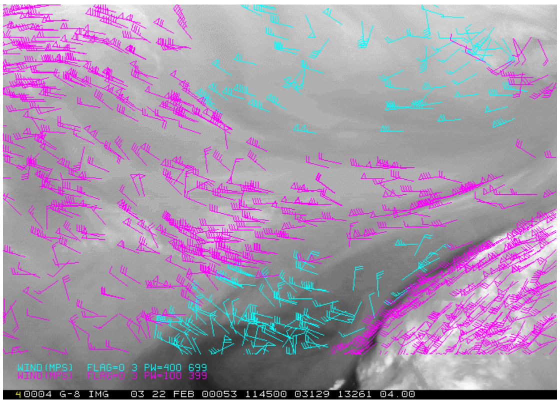


Figure 10. Raw WV winds derived from 30-min imagery

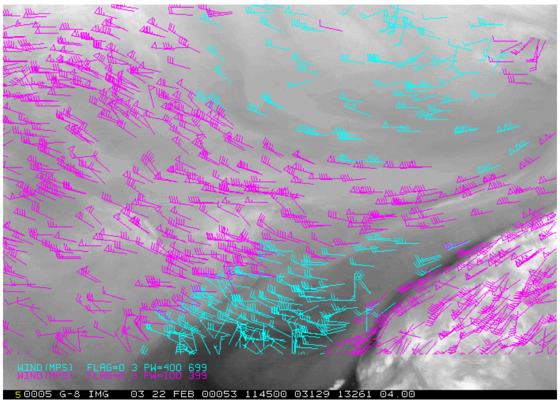


Figure 11. Raw WV winds derived from 60-minute imagery

Of course, other factors can also contribute to the observed slow bias. One is the "image aperture problem" (Jaehne, 1991) where uncertainties in tracking features along "edges" of an image are prevalent; flow can only be estimated perpendicular to an edge. This is a known problem and can be observed routinely in the water imagery where water vapor structures tend to have their strongest gradient features perpendicular to the wind direction. The coarser resolution of the WV imagery in the N/S direction will only enhance this problem. Typical cases involve the tracking of an elongated cloud or WV feature in the vicinity of jet streams. Another contributing factor is possible source contributing to the observed slow bias in the WV winds involves mis-assigning the height to tracers. Often times, lower level features are tracked and assigned too high up in the atmosphere. Tracking features in transverse bands in high shear environments can also lead to large slow biases.

5. Summary

NOAA/NESDIS, together with its CIMSS partner, continue to improve the wind product suite at NOAA/NESDIS. New wind products now operationally supported include the high density visible cloud-drift winds from the GOES imager and water vapor motion winds derived from the GOES sounder 7.0um and 7.4um moisture channels. All of the NOAA/NESDIS wind products are now being encoded into the unified BUFR template. This opens up opportunities for improved use of these products by the major NWP centers.

Recent emphasis has been placed on better utilization of higher frequency interval imagery for the derivation of satellite winds by the satellite wind community. In response to this, NOAA/NESDIS has enhanced its processing strategies to utilize available 15-minute and 7.5-minute for the derivation of visible cloud-drift winds. These new processing strategies will be applied to the IR cloud-drift winds in the very near future. Existing GOES image scanning schedules need to re-examined to determine if more optimal scanning strategies can be employed which will benefit the wind products for use in mesoscale models and by our NWS severe storm forecasters.

Statistics regarding the quality of our wind products have been presented. The quality of the products continues to look good. The slow bias observed in the imager WV winds, particularly at middle levels (400-700mb) of the atmosphere has been addressed. The coarser North/South resolution of the GOES water vapor imagery is being considered as a significant contributor to this slow bias. One potential solution involves the use of 60-minute interval imagery; preliminary results are promising. Other factors contributing to the slow bias problem include the image aperature problem, tracer height assignment, and vertical shear. More work is planned to better characterize this problem.

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