OPERATIONAL SATELLITE WIND PRODUCT PROCESSING AT NOAA/NESDIS: A STATUS REPORT

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ABSTRACT

This paper summarizes the status of the operational satellite wind product system at NOAA/NESDIS. Recent improvements, new additions, processing changes, future plans and product quality assessment of the Atmospheric Motion Vector (AMV) product suite will be discussed. GOES-12 continues to serve as the eastern operational geostationary satellite and GOES-10 continues to serve as the western operational geostationary satellite. In the spring of 2006, GOES-11 is scheduled to replace GOES-10 as the western operational satellite. GOES-N, the first in the new GOES-N/P series of satellites, is expected to be launched in the spring of 2006. An extensive science post-launch checkout of radiances and derived products, that includes AMVs, is planned. The capability to derive polar AMVs from measurements received from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard the National Aeronautical and Space Administration (NASA) polar orbiting Terra and Aqua satellites has been successfully transitioned into the operational NOAA/NESDIS AMV product suite. MODIS AMVs are being routinely validated against radiosonde wind observations and NCEP/GFS wind analyses; these results will be discussed. There has been an increased emphasis on improving the quality control of the operational GOES and MODIS AMVs. The Expected Error (EE) approach is being integrated within the operational winds processing stream. An expected error will be computed for each AMV and included in the BUFR template along with the other quality indicators already there.

1. INTRODUCTION

The NOAA/NESDIS winds processing system continues to be incrementally upgraded with updated wind algorithms, new wind products, and new processing strategies. NOAA/NESDIS and CIMSS maintain a close collaboration that allows continuous improvement of the quality of Atmospheric Motion Vectors (AMVs) derived from NOAA's Geostationary Operational Environmental Satellites as well as from NASA's Terra and Aqua polar orbiting satellites. Section 2 provides the status of the GOES satellites, current and new operational AMV products, product quality monitoring statistics and dissemination plans for these products, and AMV algorithm and processing updates. Section 3 briefly summarizes GOES and MODIS AMV research and development activities currently underway at both NOAA/NESDIS and CIMSS.

2. NESDIS OPERATIONS STATUS REPORT

2.1 Status of GOES Satellites

Many changes to the constellation of GOES satellites are planned in 2006. At the present time, NOAA/NESDIS maintains a continuous stream of data from two geostationary environmental operational satellites: GOES-12 at 75^{o}W and GOES-10 at 135^{o}W. On or around 27 June 2006, GOES-11 will replace GOES-10 as the western operational geostationary satellite. The spectral coverage of GOES-11 imager and sounder instruments are very similar to the spectral coverage on the GOES-10. Upon a successful checkout and transition to GOES-11, GOES-10 will then be repositioned to 60^{o}W as part the Earth Observation Partnership of the Americas (EOPA). Through EOPA, NOAA is exploring partnerships with countries and

scientific organizations in the Americas and the Caribbean to share Earth observations, develop and strengthen data networks, and enhance delivery of benefits to society. The scanning schedules for both the GOES-10 imager and sounder instruments at 60^{o}W have not yet been defined, but it is envisioned that continuous 15-min scanning over South America will be done. This will bring good opportunities for the generation of AMVs and other products over South America.

The GOES-N spacecraft, the first in the GOES-N/O/P series, was successfully launched on 24 May 2006 and positioned at 95^{o}W where it will undergo a long-term post-launch checkout. The GOES-N/O/P instruments will be similar to the instruments on GOES-12, but will be on a new spacecraft that is expected to bring improvements to both the navigation/registration and radiometrics. Improved navigation will be achieved by the use of star trackers. While many products are expected to improve as a result of improved navigation, the AMV products may benefit the most from improvements to image-to-image navigation. The spectral coverage of the GOES-N imager and sounder instruments will be similar to the spectral coverage of the GOES-12 imager and sounder instruments on the previous satellites. Like the GOES-12 imager, the GOES-N imager will have a 8km resolution 13.3um channel that will allow for the computation of good height assignments for AMVs. The resolution of the 13.3um channel on the future GOES-O/P imagers will be 4km, which should bring further improvements to the AMV CO_2 height assignments. Radiances from the new GOES-N satellite are expected to be less noisy as a result of instituting a longer blackbody dwell time and operating the instrument with a colder patch (detector) temperature. In addition, the GOES-N/O/P series will be capable of providing imagery through the spring and fall “eclipse” or “keep out” periods. These “eclipse” periods occur around the time of the spring and fall equinoxes and can result in an interruption of imagery for as long as two hours centered approximately on 06 and 09 UTC for GOES-East and West, respectively. The post-launch checkout of GOES-N is expected to occur over a six month period. During the last three weeks of this checkout period, NOAA will lead and conduct a GOES-N science test. During this time, numerous imager and sounder scanning schedules will available to capture a variety of different weather events with different temporal and spatial scales. A wide variety of products, including AMVs, will be generated during this science test period. There will be many opportunities to further explore the use of rapid scan imagery for deriving AMVs. A comprehensive validation of instrument radiances and derived products, including AMVs, will be performed. Upon the completion of this post-launch checkout, GOES-N will be stored as an on-obit spare. GOES-N AMV experimental results and validations will be presented at the next International Winds Workshop.

2.2 Operational Wind Products, Dissemination, and Product Monitoring

The operational AMV products currently 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. All of the AMV products shown in this table are encoded into the World Meteorological Organization (WMO)-sanctioned Binary Universal Form for the Representation (BUFR) of meteorological data and distributed over the Global Telecommunication System (GTS). The last column of the table lists the WMO headers used to uniquely identify each of these NESDIS AMV products. All of the products, with the exception of the sounder water vapor winds, will continue to be encoded into the SATOB format and distributed over the Global Telecommunication System (GTS). Since IWW7, satellite-derived wind products added to the operational production suite at NOAA/NESDIS included the GOES night-time, low-level 3.9 µm shortwave infrared (SWIR) cloud-drift winds (Dunion and Velden 2002a) and the polar LWIR cloud-drift wind and water vapor wind products from the Terra and Aqua spacecraft (Key et al, 2003). On 17 March 2006, NOAA/NESDIS ceased production of the low-level “picture-triplet” cloud-drift wind products.

Operational production and distribution of the 3.9 µm SWIR AMV products began on 27 July 2004. Figure 1 shows an example of the GOES-W 3.9um winds over the Eastern Pacific at 06Z on 20 April 2006. The 3.9um AMV products are being distributed to both the GTS and to NOAA’s National Weather Service’s (NWS) Advanced Weather Interactive Processing System (AWIPS). Distribution to the NWS AWIPS gives NWS field forecasters digital access to these AMV products, that allows them to make use of AWIPS graphics tools and capabilities to easily integrate the AMV products with other data sources that include model output, rawinsondes, and aircraft reports.

Beginning on 19 September 2006, NOAA/NESDIS began distributing the Terra and Aqua MODIS AMVs over the GTS. This gives operational Numerical Weather Prediction (NWP) centers easy access to these AMV products. Given the sparsity of wind observations in the polar regions, satellite-derived polar wind

information have been demonstrated by all of the NCEP centers to improve forecasts in polar and sub-polar areas

(Velden et al, 2005). At the present time, the following NWP centers are assimilating the MODIS winds in their operational forecast systems:

- European Center for Medium-Range Weather Forecasts (ECMWF)
- NASA Global Modeling and Assimilation Office (GMAO)
- (UK) Met Office
- Canadian Meteorological Centre (CMC)
- Japan Meteorological Agency (JMA)
- US Navy, Fleet Numerical Meteorology and Oceanography Center (FNMOC)
- National Centers for Environmental Prediction (NCEP)
- Deutscher Wetterdienst (DWD)

Wind Product	*Frequency (Hours)*	*Image Sector(s)*	*Image Interval (minutes)*	*GTS WMO Header*
GOES IMAGER				
LWIR (11um) Cloud-drift	3	RISOP	7.5	JACX11- GOES-E JCCX11- GOES-W
	3	CONUS	15	
	3	Extended NH: SH	30	
SWIR (3.9um) Cloud-drift	3 (Night-time)	RISOP	7.5	JQCX11- GOES-E JRCX11- GOES-W
	3 (Night-time)	CONUS	15	
	3 (Night-time)	Extended NH: SH	30	
Water Vapor (6.7um)	3	Extended NH; SH	30	JECX11- GOES-E JGCX11- GOES-W
Vis Cloud-drift (0.65um)	3 (Daytime)	RISOP	7.5	JHCX11- GOES-E JJCX11- GOES-W
	3 (Daytime)	PACU/CONUS	15	
	3 (Daytime)	Extended NH; SH	30	
GOES SOUNDER				
Sounder WV (7.4um)	3,6	CONUS/Tropical	60	JKCX11- GOES-E JMCX11- GOES-W
Sounder WV (7.0um)	3,6	CONUS/Tropical	60	JNCX11- GOES-E JPCX11- GOES-W
TERRA/AQUA MODIS				
LWIR (11um) Cloud-drift	2	NH; SH (Poleward of 65^{o} Lat)	100	JBCX11- Terra JICX11 - Aqua
Water Vapor (6.7um)	2	NH; SH (Poleward of 65^{o} Lat)	100	JFCX11- Terra JILX11 - Aqua

Table 1. **NOAA/NESDIS Operational Satellite Wind Products**

In the near future, NOAA/NESDIS will begin testing the generation of AMVs on an hourly basis instead of a three hourly basis. In anticipation of establishing this capability, a computer system architecture change was made within NOAA/NESDIS' computing environment for the production of GOES and MODIS AMVs. SGI workstations, running the IRIX operating system, were replaced by Dell servers, running the LINUX Redhat operating system. The operational AMV product processing software was successfully ported and tested within this new architecture. Reduced AMV product latency times, of up to 40%, are observed as a result of the faster processors. With this new computing architecture now successfully in place, experimental production and distribution of hourly GOES AMV products can be done. Present plans call for experimental production and distribution of hourly GOES AMV product files in BUFR in July 2006. The AMV user community will be notified when these files are made available.

Like other satellite producers, NOAA/NESDIS continues to rely on collocated AMVs, rawinsonde observations, and/or NCEP GFS analyses to assess and monitor the quality the AMVs. Time series of verification statistics can be found at: http://www.orbit.nesdis.noaa.gov/smcd/opdb/goes/winds/html/tseries.html. Figure 2 (left) shows time series of daily (at 00Z and 12Z) verification statistics (satellite-rawinsonde mean vector difference and wind speed bias) for upper level (100-400mb) GOES-12 LWIR cloud- drift winds and water vapor winds in the Northern and Southern Hemispheres for the period January 2004 – August 31, 2005. Figure 2 (right) shows a time series of verification statistics for low level (700-100mb) GOES-12 SWIR and LWIR cloud-drift winds. The verification statistics for GOES-10, while not shown, show similar results.

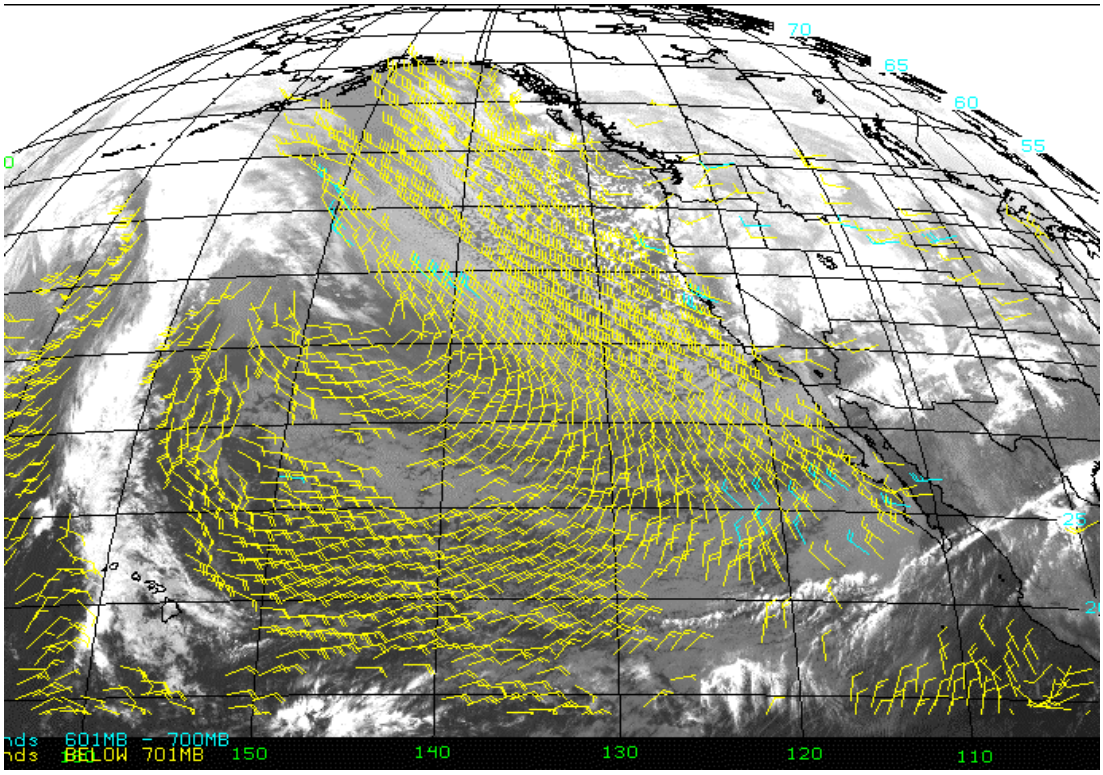


Figure 1. **GOES-10 3.9um low level cloud-drift winds over the Eastern Pacific at 06Z on 20 April 2006**

Like the GOES AMV wind products, the quality of the Terra and Aqua MODIS wind products are monitored via comparisons with collocated rawinsonde observations. While the number of rawinsondes observations in the Arctic and Antarctic regions is limited, the comparison statistics that are generated still provide useful information on the quality of the MODIS AMVs. Figure 3 (left) shows time series of daily (at 00Z and 12Z) verification statistics (satellite-rawinsonde mean vector difference and wind speed bias) for mid level (400-700mb) Aqua LWIR cloud-drift winds and water vapor winds in the Northern Hemisphere for the period January 2004 – August 31, 2005. Figure 3 (right) shows the time series of verification statistics but for mid-level (400-700mb) Aqua LWIR cloud-drift winds and water vapor winds in the Southern Hemisphere. The verification statistics for Terra MODIS AMVs, while not shown, show similar results.

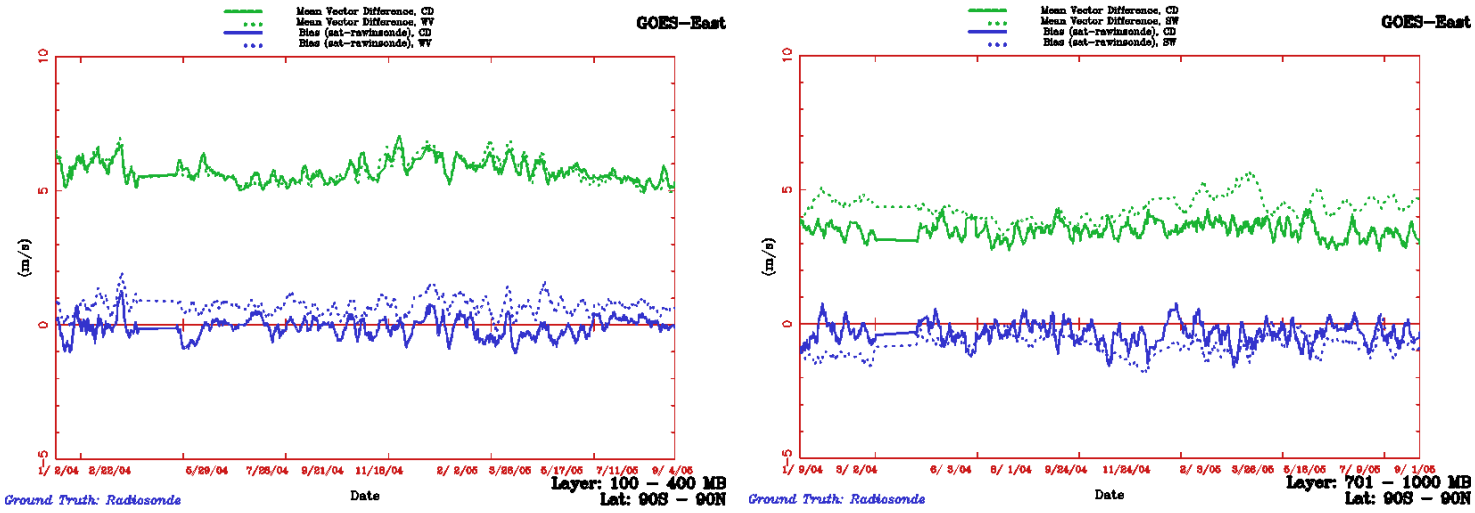


Figure 2. **Mean vector difference and speed bias (sat-rawinsonde) for GOES-12 upper level (100-400mb) LWIR cloud-drift and WV winds** (left) **and lower level (700-1000mb) LWIR and SWIR cloud-drift winds** (right)**.**

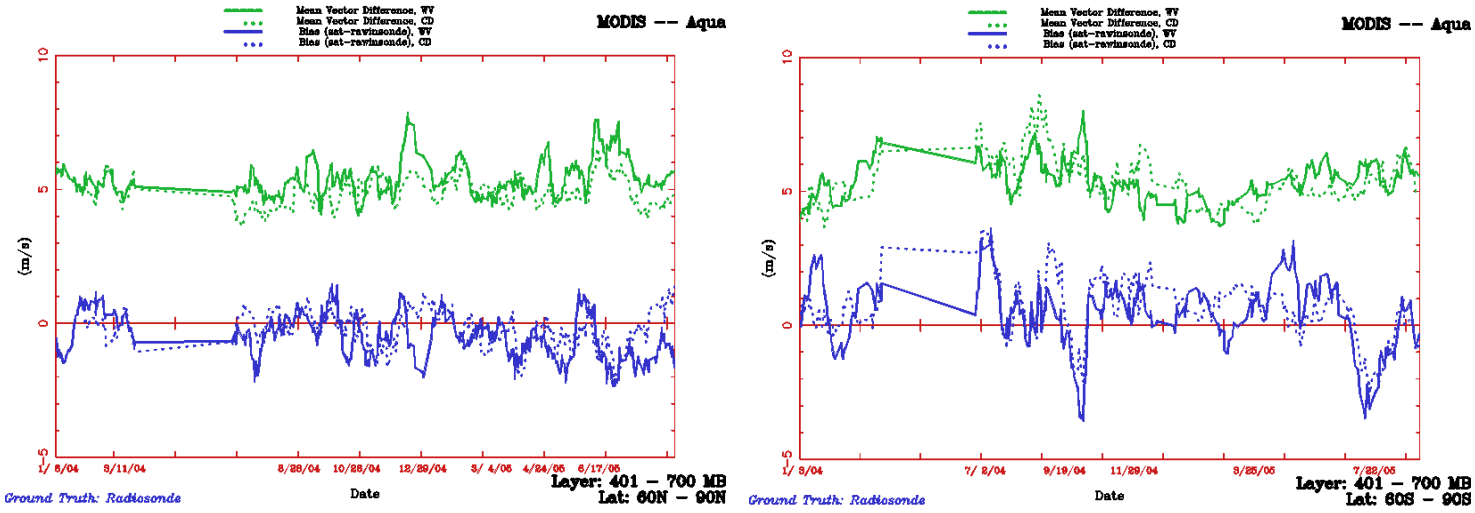


Figure 3. **Mean vector difference and speed bias (sat-rawinsonde) for NHEM Aqua MODIS mid level (400-700mb) LWIR cloud-drift and WV winds** (left) **and SHEM Aqua mid level (400-700mb) LWIR and WV winds** (right)

3. RESEARCH AND DEVELOPMENT ACTIVITIES

Numerous AMV research and development activities are underway at CIMSS and NOAA/NESDIS. A number of these activities are short-term activities that will bring additional capability to AMV processing at NOAA/NESDIS over the next year. Others are ongoing or longer term activities where the goal is to demonstrate proof-of-concept. A brief description of some of these activities is presented below with an emphasis on those activities that will bring added capability within the next year.

3.1 Quality Control

The Expected Error (EE) quality control approach developed at the Australian Bureau of Meteorology (LeMarshall et al, 2004) , has been tested for GOES and MODIS at the Joint Center for Satellite Assimilation

(JCSDA), NOAA/NESDIS/STAR, and at CIMSS. The EE quality flag, which is an estimate of the AMV root mean square error in meters per second, is calculated from the wind speed components, the wind shear, the pressure and the elements that make up the Quality Indicator (QI) (Holmlund, 1998, Holmlund et al, 2001). The coefficients for each of these terms are generated using least squares regression and are tuned for each AMV type using colocated radiosonde observations. Results are encouraging and indicate that the EE approach does quite well in estimating the error associated with the real-time GOES and MODIS AMVs. These results are described in more detail in LeMarshall et al, 2006 and Berger et al, 2006. At the present time, the EE quality control approach is being integrated within the operational winds processing system at NOAA/NESDIS. In addition, the EE flag has been added to the AMV BUFR template. The addition of this new AMV quality flag, together with the AMV quality flags that already exist in the BUFR template, are expected to allow NWP users to improve their ability to preferentially select the highest quality AMVs that will be used in their operational data assimilation schemes. Current plans call for the EE approach to be implemented within the operational processing systems in July 2006. The JCSDA is planning AMV impact studies with NCEP's global NWP model soon after this implementation.

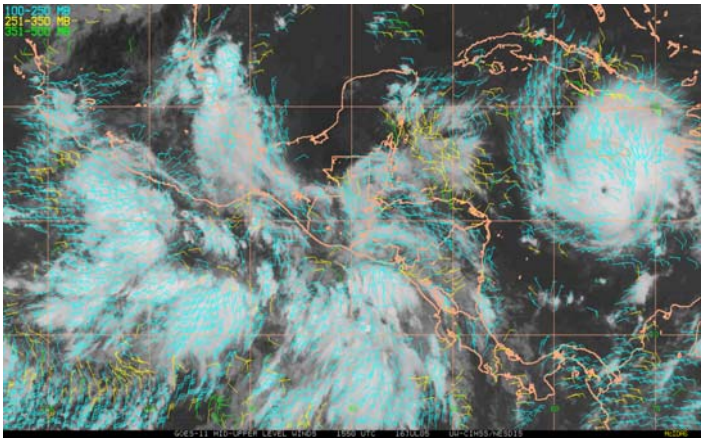
3.2 Upgrades to MODIS AMV Processing

At present, MODIS AMVs are generated separately for the Terra and Aqua satellites. Through combined use of imagery from both Terra and Aqua, improvements in the quality and timeliness of the MODIS AMVs are expected. Utilizing mixed Terra and Aqua MODIS imagery to derive AMVs will require that imagery be corrected for parallax, as the two satellites will view the same cloud or water vapor features from different angles. Without a parallax correction, errors in location, and therefore wind speed and direction, can be significant. A parallax correction method has been developed and tested at CIMSS (Santek et al, 2004). Plans call for the parallax correction method to be implemented within the operational AMV processing system at NOAA/NESDIS by the end of 2006. Routine experimental MODIS wind production and validation using mixed Terra and Aqua imagery remains to be done.

3.3 Winds from Rapid-Scan Imagery

In the United States, GOES has been used in operational forecasting for quite some time. Forecasters recognize the additional detail that can be captured from more frequent imaging in events associated with rapidly changing cloud structures. The value of more frequent imaging is evidenced by the inclusion of a 15-minute update cycle over the Continental United States (CONUS) sector in the current GOES schedule, and by the multitude of special National Weather Service (NWS) operational requests for more frequent sampling at 7.5 minute intervals (Rapid-Scan OPerations, RISOP). On occasion, special periods of Super-Rapid-Scan Operations (SRSO) have been requested by the research community. The SRSO allow limited-area coverage of one-minute interval sampling over meteorological events of interest.

Recently, special GOES RISOP periods have been collected during several field programs and research initiatives designed to maximize observational abilities in regions of high-impact weather events. Some examples include the NASA Tropical Cloud Systems Program (TCSP) in Figure 4 (left), the Atlantic Thorpex Regional Campaign (ATReC) in Figure 4 (right), and the TROpical Predictability EXperiment (TROPEX) in Figure 5. In ATReC and TCSP, the datasets were used in real time in mission planning and/or directing aircraft to targets of opportunity. In TROPEX, the datasets will be used in targeted observing strategy experiments run by modelers at the Naval Research Laboratory. In all three cases, it is expected the enhanced datasets will be employed in case study analyses and numerical model impact studies. Further details on the use of rapid scans, and other recent satellite-derived winds innovations can be found in Velden et al. (2005).



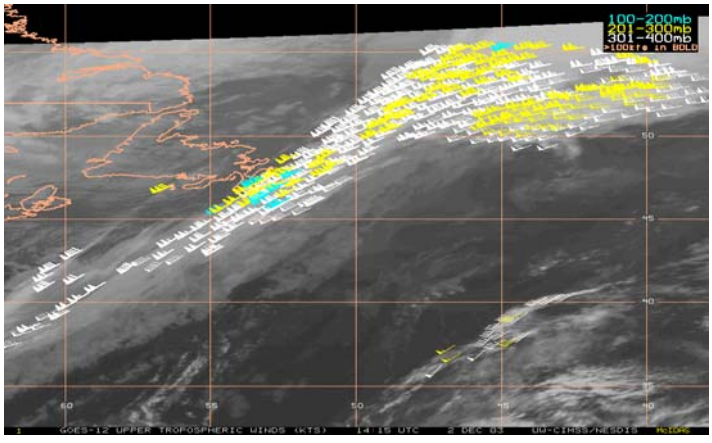


Figure 4. **GOES-11 rapid-scan Upper-level winds during TCSP, 16 July, 2005. (left) and GOES-12 upper-level rapid-scan winds during ATReC, 2 December, 2003 (right).**

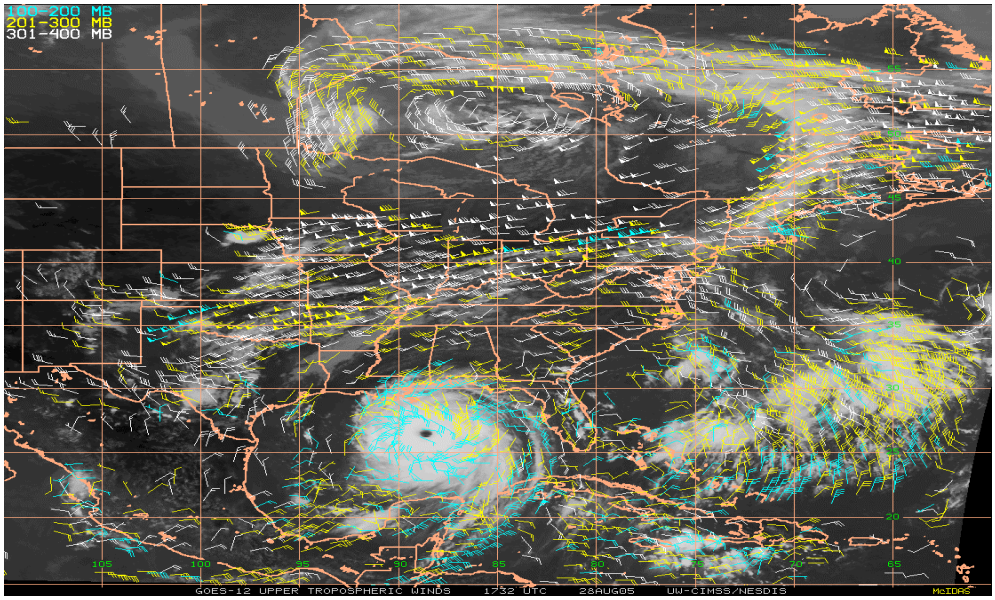


Figure 6. **GOES-12 upper-level rapid-scan winds during TROPEX, 28 August, 2005 during Hurricane Katrina.**

3.4 GOES-R AMV Activities

Two programs, the GOES-R Risk Reduction (R3) and the GOES-R Algorithm Working Group (AWG), are underway at NOAA/NESDIS in order to prepare for the next generation of GOES-R sensors. Initiated in October 2004, the GOES-R Risk Reduction (R3) program purpose is to: i) Prepare for the evaluation of the GOES-R instrumentation that includes the Advanced Baseline Imager (ABI), Hyperspectral Environmental Suite (HES), HES-Coastal Waters (CW), Geostationary Lightning Mapper (GLM), and space environment sensor measurements; ii) Develop advanced products; and iii) Assess and demonstrate the impact of these improved measurement capabilities. The GOES AWG, initiated in November 2005, will manage and coordinate the development of GOES-R product algorithms and validation activities that will directly lead to the smooth transition of these science developments into day one operations. One GOES-R3 AMV development activity being done at CIMSS (Wanzong et al, 2006, Genkova et al, 2006 and Velden et al, 2004) involves the development and demonstration of new approaches to passive wind tracing in clear-sky conditions that will be possible from hyperspectral sounders to be flown on future GOES-R satellites. The GOES-R AWG AMV development activity involves the selection and development of GOES-R AMV algorithms from heritage approaches used operationally today and from potential scientific algorithms/approaches from the GOES-R3 program and other scientific communities. Relevant AMV algorithm developments and results that come out of both the GOES-R3 and GOES-R AWG programs will be presented at future International Winds Workshops.

4. SUMMARY

The status of the NOAA/NESDIS satellite wind product system has been discussed. While GOES-12 and GOES-10 continue to serve as the eastern and western operational geostationary satellites, respectively, many changes to the constellation of GOES satellites are planned in 2006. On or around 27 June 2006, GOES-11 will replace GOES-10 as the western operational geostationary satellite. By October 2006, the GOES-10 spacecraft will be repositioned to 60^{o}W that will allow for continuous coverage for South America. The GOES-N satellite, the first in the GOES-N/O/P series of GOES spacecrafts, was successfully launched on 24 May 2006. Modifications made to the GOES-N spacecraft bus are expected to lead to radiometric and navigational improvements that should directly lead to improvements in the quality of GOES-N AMVs. A comprehensive post-launch checkout of GOES-N imagery and products is planned to occur over a six month period. Satellite-derived AMV products added to the operational production suite at NOAA/NESDIS included the GOES night-time, low-level 3.9 µm shortwave infrared (SWIR) cloud-drift winds and the polar LWIR

cloud-drift wind and water vapor wind products from the Terra and Aqua spacecraft. Operational production and distribution of the 3.9 µm SWIR AMV products began on 27 July 2004. Beginning on 19 September 2006, NOAA/NESDIS began distributing the Terra and Aqua MODIS AMVs over the GTS. On 17 March 2006, NOAA/NESDIS ceased production of the low-level "picture-triplet" cloud-drift wind products.

Vibrant research and development activities for current and future GOES satellites continue at NOAA/NESDIS and CIMSS. There has been an increased emphasis on improving the quality control of the operational GOES and MODIS AMVs. The Expected Error (EE) approach is being integrated within the operational GOES and MODIS winds processing stream. The utility of GOES rapid scan winds continues to be demonstrated in field experiments designed to maximize the observational abilities in regions of high-impact weather events. These demonstrations will continue. Active work is underway to improve the quality and timeliness of the MODIS AMVs. These improvements are expected to bring further improvements in the accuracy of operational global NWP forecasts. Finally, the GOES-R Risk Reduction (R3) and the GOES-R Algorithm Working Group (AWG) programs are now underway at NOAA/NESDIS and CIMSS in order to prepare for the next generation of GOES-R instruments. These programs will put NOAA/NESDIS and its user community in a position to quickly reap the benefits that the new sensors offer.

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