STATUS AND DEVELOPMENT OF GOES WIND PRODUCTS AT NOAA/NESDIS

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ABSTRACT

This paper summarizes advances to the derivation of operational GOES winds at NOAA/NESDIS. NOAA/NESDIS and the Cooperative Institute for Meteorological Satellite Studies (CIMSS) continue to work closely to improve the quality of Atmospheric Motion Vectors (AMVs) derived from the GOES-I/M series of satellites. Efforts have been aimed at improving the wind algorithms and processing strategies while developing new products. This paper will summarize work with rapid scan winds, 3.9um cloud-drift winds, clear-air water vapor winds, GOES-12 winds, and the encoding of the winds into BUFR. By participating in a number of field campaigns, NESDIS has demonstrated the capability of generating rapid scan winds on an hourly basis. This capability will lay the foundation for operational generation of such datasets in the future. Rapid scan winds generated in these field campaigns have shown utility both in numerical weather prediction models and the day-to-day forecasting process. The newest operational wind product is the low-level cloud-drift winds derived from 3.9um imagery. This is a nighttime product that supplements the current low-level cloud-drift winds derived from the infrared window channel. The newest GOES satellite, GOES-12, was successfully launched on July 23, 2001. Significant changes made to the imager aboard GOES-12 include the addition of a 13.3um channel at 8km resolution and improvement in the resolution of the 6.7um water vapor channel from 8km to 4km. The addition of the 13.3um channel affords the opportunity to use the CO2 slicing algorithm to assign heights to viable cloud tracers. The higher resolution of the water vapor channel offers the potential to improve the water vapor wind products. Results from wind tests run using these new and improved channels during the GOES-12 science checkout period will be presented. Finally, the status of the BUFR wind datasets made available over the Global Telecommunication System (GTS) and an FTP server will be discussed.

1. Introduction

NOAA/NESDIS and the Cooperative Institute for Meteorological Satellite Studies (CIMSS) continue a fruitful collaboration aimed at 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. Section 2 provides a status of NESDIS operations which includes a status report on the GOES satellites, operational wind products and dissemination plans for these products, and updates to the operational wind algorithms since the last winds workshop. Section 3 describes the new products, capabilities, and processing strategies undertaken by both NOAA/NESDIS and CIMSS. Participation in field experiments has provided opportunities to generate and validate cloud-drift winds derived from rapid scan imagery. Verification of winds from NOAA's newest geostationary satellite, GOES-12, are also presented in this section.

2. NESDIS Operations Status Report

2.1 Status of GOES Satellites

NOAA/NESDIS currently maintains a continuous stream of data from two geostationary environmental operational satellites. At the present time, these two operational satellites include GOES-8 at 75°W and GOES-10 at 135°W. To reduce the risk of a break in operational service, NOAA uses the on-orbit spare concept. To this end, the GOES constellation also includes GOES-9, a limited-capability on-orbit spare, and GOES-11 and GOES-12, which are two fully capable on-orbit spares. GOES-11 and GOES-12 were successfully launched on May 3, 2000 and July 23, 2001, respectively. Plans call for GOES-12 to be the next operational satellite in the event of a failure of either GOES-8 or GOES-10.

GOES-11 carries the same instrumentation as the previous three GOES satellites. GOES-12 carries redesigned instrument motors and carries the same instrument complement as the previous satellites, with two primary changes**.** Imager instrument changes made include the replacement of the 12.0um channel (4km resolution) with a 13.3um channel (8km resolution) and a spectrally modified water vapor channel with improved resolution. The water vapor channel is spectrally wider then its counterparts on the previous GOES satellites where its central wavelength is 6.5um instead of 6.7um. The resolution of the water vapor channel has improved from 8km to 4km at the sub-satellite point.

2.2 Operational GOES Wind Products and Dissemination Plans

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

Wind Product	***Frequency (Hours)***	***Image Sector(s)***	***Image Interval (minutes)***
IR Cloud-drift	3	RISOP	7.5
	3	CONUS	15
	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

Table 1. NOAA/NESDIS Operational 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 and compute verification statistics. 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.

The capability to routinely use higher frequency interval imagery in the operational derivation of visible CD satellite wind vectors has been extended to the operational derivation of the IR cloud-drift wind products. The GOES 15-minute CONUS and PACUS image sectors are now used routinely for the generation of IR 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 that are offered by the current GOES scanning schedules are illustrated in Figure 1.

All of the operational NESDIS wind products shown in Table 1 are 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, will continue to be encoded into the SATOB format and distributed over the GTS.

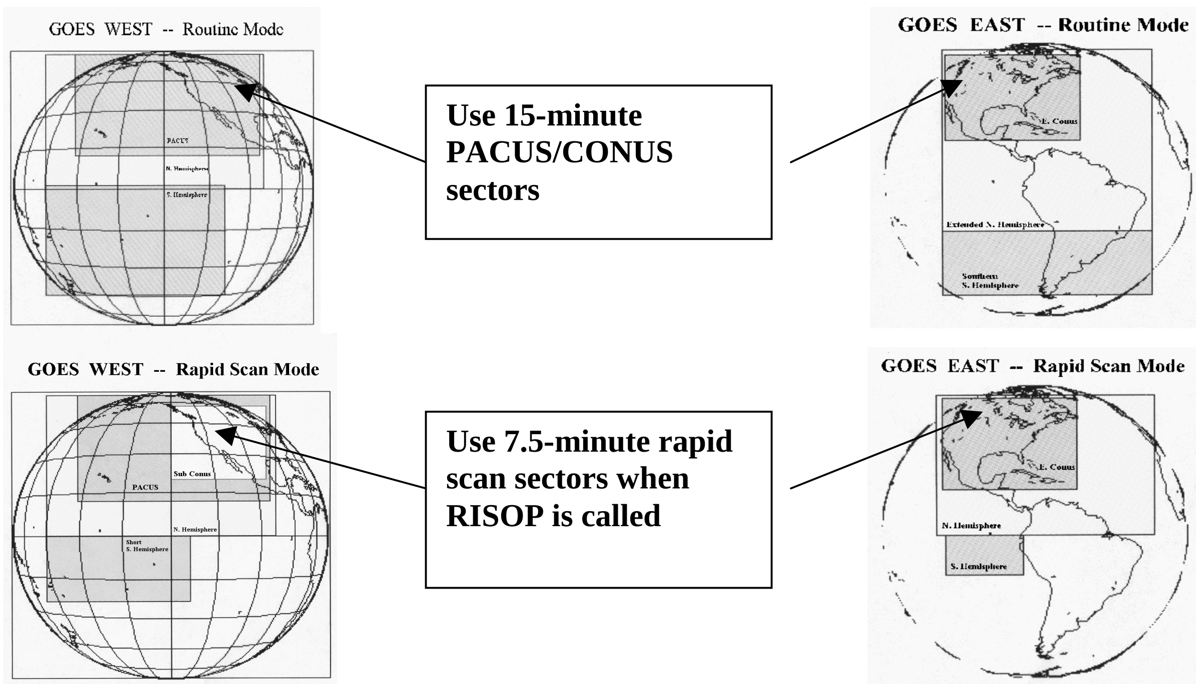

Figure 1: GOES East and GOES West Image Sectors. Use of CONUS, PACUS, and RISOP sectors have been extended to the operational GOES IR cloud-drift winds processing.

NOAA/NESDIS is planning to update its operational GOES satellite wind BUFR encoder to correct deficiencies noted by users of these data. The newly encoded GOES wind BUFR datasets will soon be distributed out over the GTS with new WMO bulletin headers. They are also available via an anonymous ftp server. The current NESDIS wind BUFR products will continue to be distributed over the GTS until the user community has fully tested their systems to ingest the updated datasets.

The current timeline for testing and operational implementation of these changes is as follows:

- May 1, 2002: NESDIS makes updated GOES wind BUFR datasets available on anonymous ftp server
- May 15, 2002: NOAA/NWS begins experimental GTS distribution of updated GOES wind BUFR datasets under new WMO headers for a period of 45-60 days
- July 1, 2002: NOAA/NWS begins operational GTS distribution of updated GOES BUFR datasets under new WMO headers; original GOES BUFR wind datasets under old WMO headers terminated

A summary of changes made to the BUFR encoder include:

- Replace use of local descriptors with WMO-sanctioned descriptors
- Use of Version 10 of the BUFR Tables
- Quality control section contains Class 33 entries only
- Generate one BUFR message per file and increase the number of satellite wind observations per BUFR message. This will eliminate file segmentation problems encountered by users, particularly when processing larger NESDIS wind files.
- Newly defined WMO headers for GTS distribution

Table 2 shows the GOES satellite wind products that will be distributed in the updated BUFR format. The location indicator for NESDIS is KNES, and the new (soon to be operational) GTS bulletin headers for each of the products is defined in the table below. At any individual time, more or less bulletins may be available since the actual size of the product will vary depending on meteorological conditions.

Wind Product	Bulletin Header GOES West	Bulletin Header GOES East	Product Times (UTC)
	ii=01-50		
IR Cloud-Drift	ICCXii	IACXii	0,3,6,9,12,15,18,21
Water Vapor Motion	IGCXii	IECXii	0,3,6,9,12,15,18,21
Visible Cloud-Drift	IJCXii	IHCXii	0,3,6,9,12,15,18,21
Sounder Water Vapor Motion Winds (7.4um)	IMCXii	IKCXii	CONUS 0,3,6..21 Non-CONUS 0,6,12,18
Sounder Water Vapor Motion Winds (7.0um)	IPCXii	INCXii	CONUS 0,3,6..21 Non-CONUS 0,6,12,18
Picture-Triplet	ITCXii	ISCXii	0,3,6,9,12,15,18,21

Table 2: Operational GOES satellite wind products, and accompanying WMO bulletin headers, which will be distributed over the GTS.

In addition to transmitting the GOES wind products over the GTS, NESDIS will also be transmitting these products to the NOAA/National Weather Service's (NWS) Advanced Weather Interactive Processing System (AWIPS). This represents a significant milestone for NOAA, as this is the first time these products will be distributed via an operationally supported network to NWS field forecast offices. Once at the NWS field forecast offices, weather forecasters will be able to use existing AWIPS graphics capabilities to easily integrate these products with other data sources (model output, rawinsondes, aircraft reports) which, ultimately, will help them in preparing a better forecast.

2.3 Recent Implementations

A number of updates have been made to the operational GOES winds processing system since the last winds workshop. These are described below:

- Use of rapid scan imagery for IR cloud-drift winds as discussed in Section 2.2

- Middle image targeting

The middle image of the image triplet is now used for target selection and height assignment for all wind product types. Winds vectors are computed computed forward and backward in time and averaged in this approach. A larger percentage of targets selected result in good winds as a result of this approach.

- Speed bias correction limited to fast, high-level cloud-drift winds poleward of 25o latitude

Convincing evidence was provided by ECMWF (personal communication with Michael Rohn) that showed the GOES high-level cloud-drift winds had a fast speed bias.

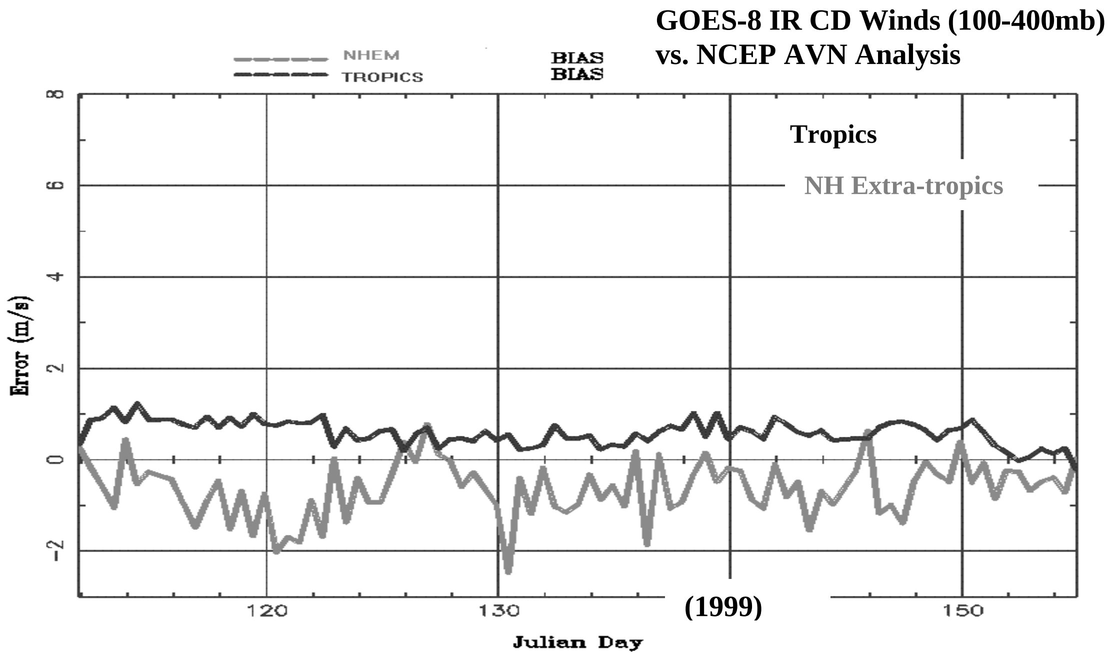

Figure 2: Speed bias (m/s) between GOES-8 IR cloud-drift winds (100-400mb) and collocated NCEP Aviation model analysis wind for tropical (25N-25S) and Northern Hemisphere extra-tropics (25N-60N).

Figure 2 illustrates the speed bias between the between GOES-8 IR cloud-drift winds and collocated NCEP Aviation model analysis wind for tropical (25N-25S) and Northern Hemisphere extra-tropics (25N-60N) for Julian Days 99110 – 99152. Note that the satellite wind speeds in the tropics are consistently faster than the analysis winds and that the reverse is true in the Northern Hemisphere extra-tropics. In light of these findings, the speed bias correction was turned off in the tropics. Note the drop in GOES-8 IR cloud-drift speed bias, from ~ 1m/s to 0 m/s in the tropics on Julian Day 99151 which is when the speed bias correction was turned off in the tropics.

- Quality control changes

Numerous changes relating to quality control of the GOES wind products were made since the last winds workshop. First, the EUMETSAT quality control indicator (Holmlund et al., 2000) has been implemented and passed into the final BUFR wind product datasets. The second change involved correcting tracer height assignments placed above the tropopause. The correction involved placing the tracer height at the tropopause level. The third change involves a small, but important change to the operational procedure (Velden et al., 1998) used to reassign heights to thin cirrus tracers. The water vapor intercept height technique fails at times for thin cirrus tracers. In these cases, the IR window method must be relied on to provide an estimate of the tracer height. The procedure involves checking neighboring vectors where the water vapor intercept method was successful. If a neighboring vector is found, and is in general agreement with the vector in question, then the vector in question is assumed to be tracing undetected thin cirrus and its height is reassigned to the water vapor intercept of its neighbor. The change made to this procedure was to pass on the target temperature from the neighboring vector so that it would be consistent with the reassigned pressure. The final change made involved the reinstatement of fast (> 60m/s) cloud-drift winds at high levels (100-300mb) in jet streak regimes that may not agree with the guess wind speed. An example of such reinstated winds are illustrated in Figure 3.

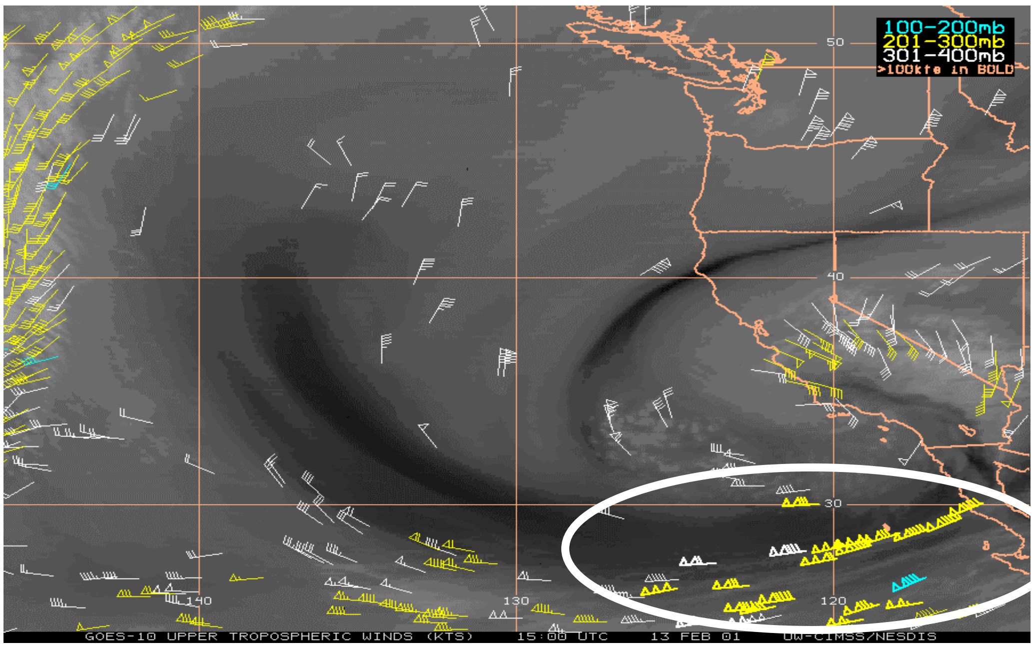

Figure 3: Reinstating high (100-300mb), fast (> 60m/s) cloud-drift winds that do not agree with the model forecast in the quality control step provide useful information to weather forecasters in the field.

3. New Products, Capabilities, and Processing Strategies

3.1 Rapid Scan Winds

Several field experiments afforded NESDIS and CIMSS the opportunity to further demonstrate improvements in both the quantity and quality of satellite cloud drift winds using 7.5 minute rapid scan imagery. These field experiments included the 2001 and 2002 Pacific Landfalling Jets Experiments (PACJET) and the 2001 Convection and Moisture Experiment (CAMEX). Special GOES schedules were coordinated for each of these experiments that provided an hourly rapid scan (7.5 minute) image triplet. Hourly rapid scan wind datasets were generated in real-time and made available to participants in the various experiments. An example of the high spatial and temporal resolution cloud-drift wind products generated is shown in Figure 4. Inclusion of these hourly rapid scan winds in the Rapid Update Cycle (RUC) mesoscale model has resulted in improved short-range (0-12 hour) wind predictions by up to 10% (Weygandt, et al., 2001).

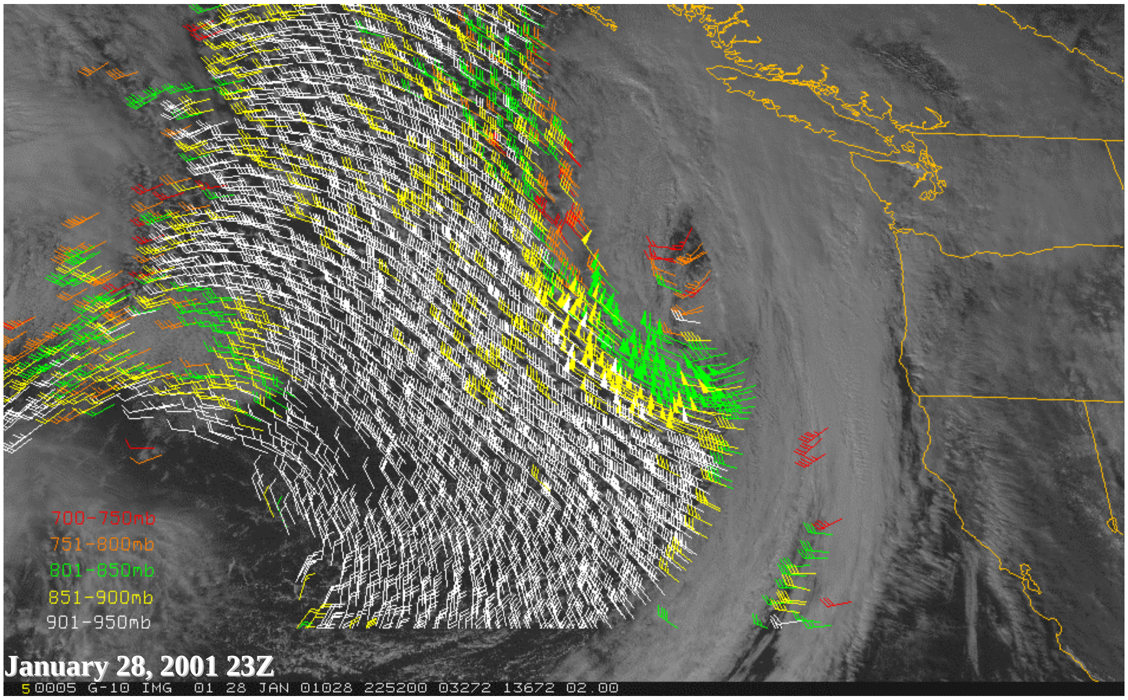

Figure 4: GOES-10 low level cloud-drift winds generated from rapid scan imagery during the 2001 PACJET Experiment.

While such experiments have allowed for the creation of special GOES schedules that provide routine rapid scan imagery, operational implementation of such schedules in a two GOES satellite operation, is more difficult because of the limited time budget offered by the current GOES schedules and the competing requirements for the GOES imagery which is available. A possible solution would be a three GOES satellite operation where one satellite is dedicated to providing routine rapid scan imagery.

3.2 Cloud-Drift Winds Derived from 3.9um Measurements

Low-level cloud drift winds are traditionally generated from visible imagery and 10.7um longwave infrared imagery. However, it is possible to use the GOES imager 3.9um channel over non-sunlit areas to track low-level cloud motion. Selective enhancement of the 3.9um imagery brings out gradient information in the imagery that results in better target selection and tracking. This product will supplement the low-level visible and 10.7um cloud-drift wind products being generated operationally at NESDIS. More details regarding the development and verification of the 3.9um cloud-drift wind product is described in Velden et al, 2002. Dunion (2002) discusses the utility of this new product, together with other conventional surface wind observations, for analyzing the surface wind field around tropical storms. NOAA/NESDIS plans to incorporate this product into its operational data stream by the end of 2002.

3.3 New Capabilities with GOES-12

NOAA/NESDIS conducted a GOES-12 Science Test which allowed for the characterization of the quality of GOES-12 measurements and routine generation and validation of derived products including winds. The official time period of the science test was September 23, 2000 - October 27, 2001, but the GOES-12 data continued to be available until December 16, 2001.

The changes made to the GOES-12 imager offer potential benefits to the derivation of cloud-drift and water vapor motion winds. First, the addition of the 13.3um channel will allow, for the first time since

GOES-7, the use of the well-known CO2 slicing algorithm to assign heights to viable cloud tracers. The resultant CO2 slicing algorithm height assignments will supplement the height assignments provided by the water vapor intercept algorithm (Schmetz et al., 1992). Second, the improved resolution of the water vapor channel is expected to aid and improve the water vapor motion wind product through improved tracking of water vapor features.

The GOES high-density winds software has been significantly modified to prepare it for the GOES-12 imager instrument changes and for the adoption and use of a new radiative transfer model. The RTTOVS radiative transfer model, which has been used since the launch of GOES-8, was successfully replaced with the Pressure-Layer Optical Depth (PLOD) radiative transfer model. Wind verification statistics, for high-level tracers whose primary height assignment method is the water vapor intercept method, indicate no significant differences in wind quality when switching from the RTTOVS to PLOD radiative transfer model.

An effort was first made to investigate the state of the CO2 slicing algorithm and how it was implemented with GOES-7. It was determined that a “cold sampling” procedure was used to obtain the observed 11um and 13.3um radiances used in the algorithm. In this procedure, a histogram of the 11um channel radiances is constructed and the coldest 25% of the 11um pixels are determined. The coldest 11um radiances and accompanying 13.3um radiances are used to form an average radiance for each channel that is then input to the CO2 algorithm.

As an experiment, a new approach was attempted for arriving at a CO2 solution. In this approach, a CO2 solution was attempted at every single-field-of-view (SFOV) in the target scene and a histogram was constructed from all viable CO2 solutions. Viable CO2 solutions were those which passed several quality control tests which require that the target temperature be < 253K and cloud amount be > 10%. If at least 30% of the target scene contained viable CO2 solutions, then a final CO2 solution is determined by averaging the CO2 pressures in the histogram bin containing the maximum frequency. This approach was run in parallel with the “cold-sampling” procedure described above (ie., the control run) using GOES-12 imagery for the period December 11–16, 2001. The cloud-drift winds generated at 00Z and 12Z in both the control runs and the test runs were collocated in space and time with radiosonde winds and validation statistics were generated. An effort was made to ensure that the control and test satellite winds were collocated to the same radiosonde data so that a intercomparison could be made between verification statistics generated for each. Table 3 shows these verification statistics. These statistics show a significant improvement in the average vector difference statistic by about 1 m/s, and an improvement in the speed bias by approximately 0.2 m/s.

	CO2 Winds Cold-Sampling	**CO2 Winds SFOV Histogram**
RMS Difference (m/s)	9.82	8.15
Normalized RMS (m/s)	0.27	0.23
Average Difference (m/s)	7.64	6.58
Std Deviation (m/s)	6.17	4.80
Speed Bias (m/s)	0.51	0.33
ABS Directional Diff (deg)	7.18	7.52
Speed (m/s)	37.40	36.47
Sample Size	72	72

Table 3: High-level (100-400mb) GOES-12 IR CO_2 Cloud-Drift Wind and Radiosonde Wind Difference Statistics. The column shows statistics for the CO2 winds where the cold-sampling procedure was used. The second column shows statistics for the CO2 winds where the single-field-of-view (SFOV) histogram approach was used.

The normalized root mean square (RMS) vector difference for the SFOV histogram approach of 0.23 is an improvement over the normalized RMS vector difference of 0.27 for the “cold-sampling” procedure. It is surmised that the SFOV histogram approach leads to more representative target height assignments since it accounts for the expected variability of the cloud heights at each pixel within the target scene. The “cold-sampling” procedure, on the other hand, favors the coldest pixels and then averages them, which may act to reduce any cloud height variability present in the target scene. This approach also tends to assign cloud targets higher up in the atmosphere.

Comparison of CO2 Heights and Water Vapor Intercept Heights

With GOES-12, the CO2 slicing (SFOV-histogram approach) and the water vapor intercept algorithms are used to assign heights for semi-transparent or sub-pixel cloud tracers. Both methods are attempted for each cloud tracer. If both methods are successful in deriving a cloud height for a particular cloud tracer, then an inter-comparison of the heights derived from each method can be made. Table 4 presents results for about 1000 targets on November 29, 2001.

	Mean cloud-top Pressure (mb)	Scatter wrt mean (mb)	Root Mean Square Deviation (mb) Wrt	
			CO2 Slicing	***WV Intercept***
CO2 Slicing	281	68	-	83
WV-intercept	250	88	83	-

Table 4: CO2 slicing and water vapor intercept cloud tracer height statistics using GOES-12 data on November 29, 2001.

In the mean, the CO2 height assignment is about 31mb lower in the atmosphere than the corresponding H2O intercept height assignment. These results for this day are fairly representative and do agree with results from a similar comparison done by Nieman et al, 1993 where GOES-7 Visible Infrared Spin Scan Radiometer Atmospheric Sounder (VAS) data were used. In this study the authors noted that the CO2 heights were about 30mb lower in the atmosphere than the corresponding H2O intercept heights. The standard deviation in the heights of the clouds with respect to the mean heights is 68mb and 88mb for the CO2 and water vapor intercept heights, respectively. The root mean square error between the two height assignment methods is 83mb. Schreiner et al., 2002 discuss results from a similar analysis involving GOES-12 data.

Verification of Winds Assigned CO2 Heights and Water Vapor Intercept Heights

Two sets of GOES-12 winds were generated where the CO2 slicing technique (SFOV-histogram approach) exclusively used for the first set and the water vapor intercept technique was used exclusively for the second set. Each wind set were collocated to the same radiosonde data so that a intercomparison could be made between verification statistics generated for each. Table 5 shows these verification statistics.

	CO2 Winds	H2O Intercept Winds
RMS Difference (m/s)	7.62	7.90
Normalized RMS (m/s)	0.23	0.23
Average Difference (m/s)	5.24	5.50
Std Deviation (m/s)	4.38	4.49
Speed Bias (m/s)	0.56	0.25
ABS Directional Diff (deg)	7.07	7.26
Speed (m/s)	34.03	34.01
Sample Size	1783	1783

Table 5: High-level (100-400mb) GOES-12 IR CO_2 Cloud-Drift Wind and Radiosonde Wind Difference Statistics. The first column shows statistics when the CO2-slicing algorithm was used. The second column shows statistics when the H2O intercept method was used.

These statistics show comparable quality regardless of which height assignment is used. A slight reduction in RMS and mean vector difference is observed for the CO2 winds, but these same winds exhibit a slightly larger speed bias. More work is needed to characterize these differences.

4. Summary

NOAA/NESDIS, together with its CIMSS partner, continue to improve the operational wind product suite at NOAA/NESDIS. This will continue. New capabilities and techniques will continue to be shared with our international counterparts. New products and techniques include the utilization of available 15-minute and 7.5 minute imagery for the derivation of IR cloud-drift winds and low-level cloud-drift winds derived from 3.9um imagery. All of the NOAA/NESDIS wind products are being encoded BUFR template. Updates to the BUFR encoder, which correct deficiencies and problems noted by users, are now in place. The newly encoded GOES wind BUFR datasets will soon be distributed out over the GTS with new WMO bulletin headers. Every opportunity was taken to demonstrate the impact that rapid scan imagery has on both the quantity and quality of satellite cloud drift winds using 7.5 minute rapid scan imagery. New opportunities in the future will also be taken. NOAA's newest geostationary satellite, GOES-12 was successfully launched on July 23, 2001. The imager onboard GOES-12 contains a 13.3um channel that allows use of the CO2 slicing height assignment technique for the first time since GOES-7. A higher resolution water vapor channel is also available on this satellite that is expected to improve tracking of clouds and moisture features.

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