JP1.6   STATUS AND DEVELOPMENT OF GOES WIND PRODUCTS AT NOAA/NESDIS

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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.

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 being distributed in BUFR. This opens up opportunities for improved use of the wind products by the major numerical weather prediction (NWP)

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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 that, in turn, have 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, tropical storm analyses, and real-time forecasting.

2.   NESDIS OPERATIONS STATUS REPORT

2.1   Status of GOES Satellites

NOAA/NESDIS currently maintains a continuous stream of data from two operational geostationary satellites. At the present time, these two satellites are GOES-8 at 75°W and GOES-10 at 135°W. To reduce the risk of a break in operational service, 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.

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

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.

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-et.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 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

GOES WEST -- Routine Mode

GOES EAST -- Routine Mode

Use 15-minute PACUS/CONUS sectors

GOES WEST -- Rapid Scan Mode

GOES EAST -- Rapid Scan Mode

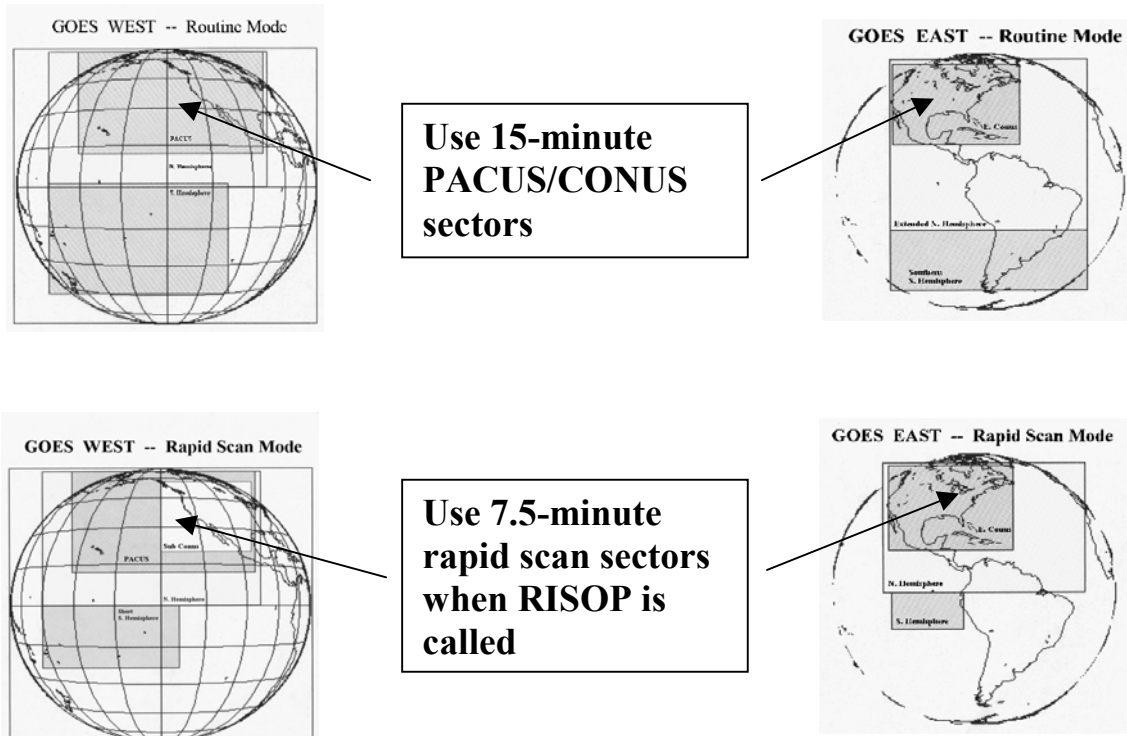**Use 7.5-minute rapid scan sectors when RISOP is called**

Figure 2: 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.

Hemisphere. These image sectors that are offered by the current GOES scanning schedules are illustrated in Figure 2.

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.

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 are being routinely generated and 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.

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 GTS users, particularly when processing larger NESDIS wind files.

- Newly defined WMO headers for GTS distribution

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). Current plans call for the GOES high density wind products to be included in the June 2003 AWIPS build. Inclusion of these products into AWIPS will represent a significant milestone for NOAA, as this will be 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 recent updates have been made to the operational GOES winds processing system. 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 25° 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 3 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.
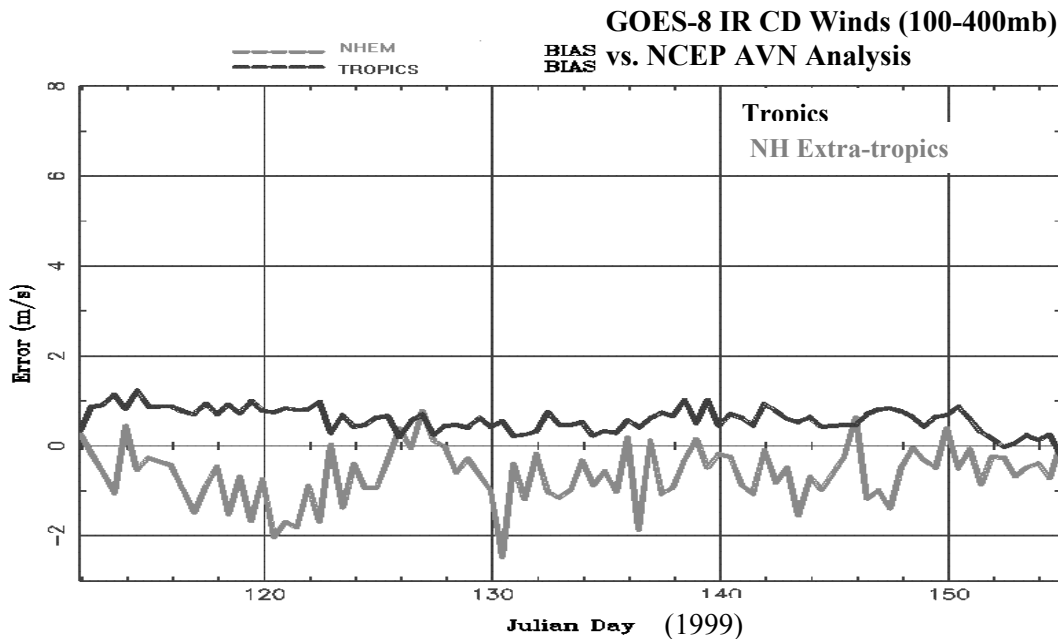
Figure 3. Speed bias (m/s) between GOES-8 IR cloud-drift winds (100-400mb) and collocated NCEP Aviation model analysis wind for tropical (25N-25S) and Northern Hemisphere extra-tropics (25N-60N).

- 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 4.
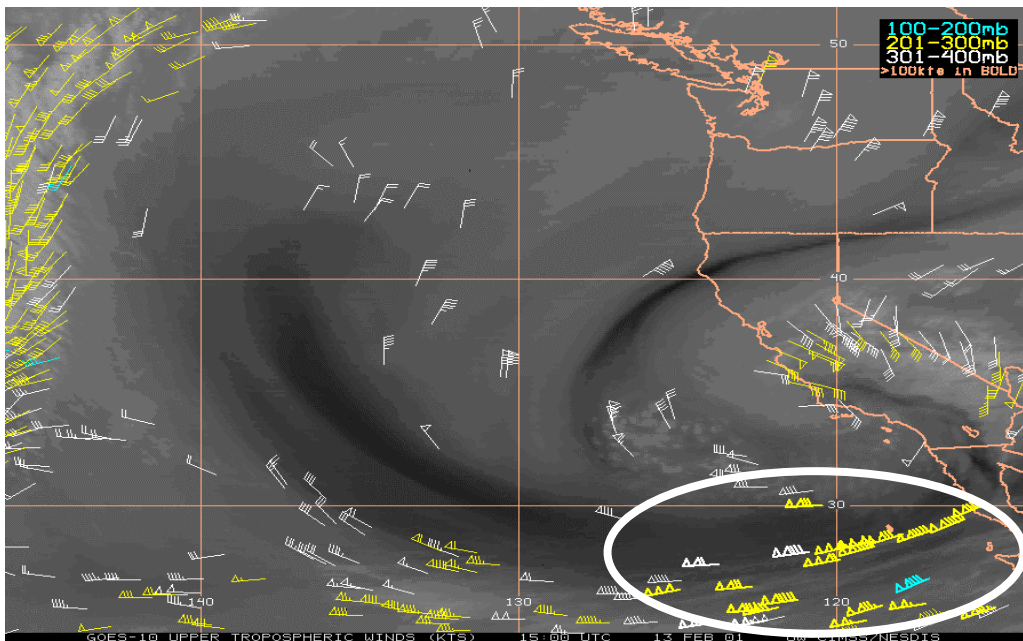
Figure 4. Reinstating high (100-300mb), fast (> 60m/s) cloud-drift winds that do not agree with the model forecast in the quality control step provide useful information to weather forecasters in the field. Reinstated winds are in bold.

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 5. 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., 2002).

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.
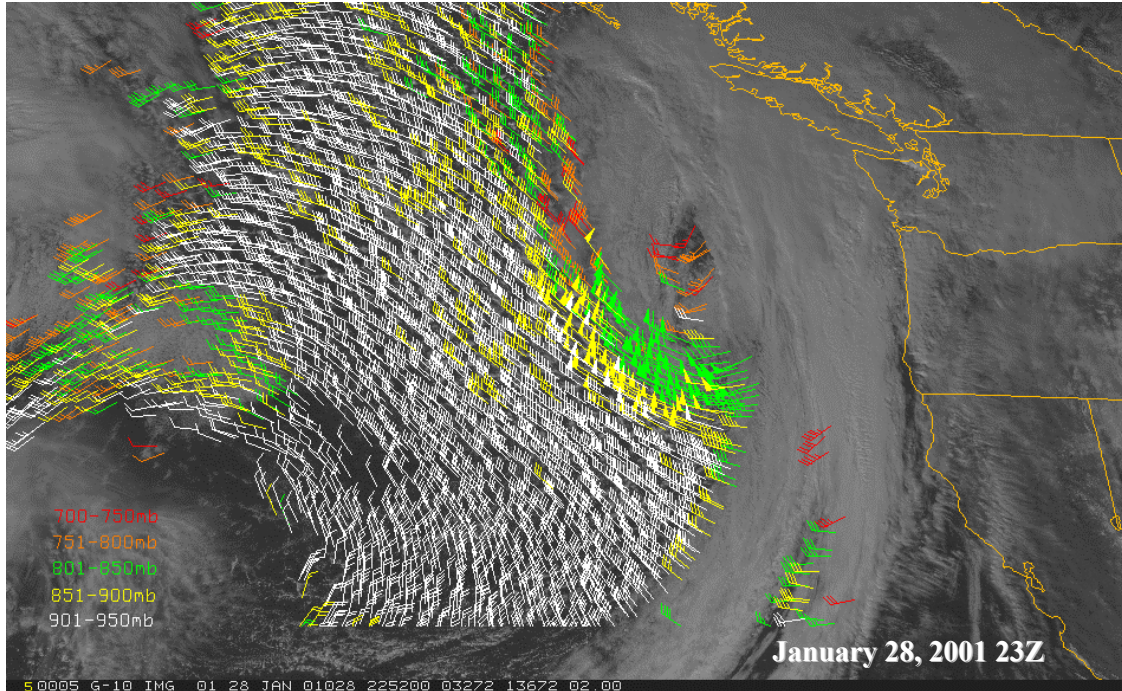
Figure 5. GOES-10 low level cloud-drift winds generated from rapid scan imagery during the 2001 PACJET Experiment.

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 CO_2 slicing algorithm to assign heights to viable cloud tracers. The resultant CO_2 slicing algorithm height assignments will supplement the height assignments provided by the water vapor

intercept algorithm (Schmetz et al., 1993). 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 CO_2 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 CO_2 algorithm.

As an experiment, a new approach was attempted for arriving at a CO_2 solution. In this approach, a CO_2 solution was attempted at every single-field-of-view (SFOV) in the target scene and a histogram was constructed from all viable CO_2 solutions. Viable CO_2 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 CO_2 solutions, then a final CO_2

solution is determined by averaging the CO_2 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.

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 CO_2 Heights and Water Vapor Intercept Heights

With GOES-12, the CO_2 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.

	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.

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.

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.

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 was 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.

	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.

	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. All of the NOAA/NESDIS wind products are being encoded in the BUFR template. Updates to the BUFR encoder, which corrects deficiencies and problems noted by users, are now in place. The newly encoded GOES wind BUFR datasets are now being distributed out over the GTS under new WMO bulletin headers. Users are currently modifying their systems to decode these datatsets. 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. 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 and is expected to improve tracking of clouds and moisture features.

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