GOES-R Progress Report for April - June 2006
University of Wisconsin-Madison
Cooperative Institute for Meteorological Satellite Studies

Project Title:	CIMSS Participation in GOES-R Risk Reduction
Principle Investigator:	Steve Ackerman
Co-Investigators:	Allen Huang (Algorithms), Chris Velden (Winds),
	Elaine Prins (Fires), Ralph Petersen (Nowcasting),
	Bob Knuteson (Data Systems), Dave Tobin (Validation)
Additional Contributors:	Jun Li, Xiolie Zhou (FSU), Ray Garcia
Program Manager:	Tom Achtor
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Remaining Funds:	$0

Topics Summary

Program Management and Coordination

Refer to the dedicated internal web site (**http://cimss.ssec.wisc.edu/goes_r/internal/alg_dev/**)
for information concerning management and coordination:

- GOES-R3 AD monthly meeting
- Monthly reports
- Group quarterly reports
- Meeting minutes, and
- Announcements.

Task 1. Algorithm Development

1.1 Soundings Algorithm Development

Handling surface emissivity in hyperspectral IR sounding retrieval
Handling surface IR emissivity properly is very important to hyperspectral IR sounding retrieval, especially the boundary layer moisture retrieval. Recently, we are using combined MODIS ecosystem classified emissivity measurements at 6 wavebands and the hyperspectral IR emissivity measurements from laboratory to generate the ecosystem classified hyperspectral IR emissivity database; this database is currently under testing for AIRS sounding retrieval. We are also developing an algorithm to simultaneously retrieve sounding and the hyperspectral IR emissivity spectrum. The hyperspectral IR spectrum is represented by Eigenvectors (EVs) derived from laboratory measurements. The eigenvector coefficients and soundings then can be retrieved simultaneously from hyperspectral IR radiance measurements. Our study shows that at least 20 EVs are needed in order to represent the spectral variation of an IR emissivity spectrum. Details of this work are reported in the web site "AD Quarterly Reports" Q2 2006 Report – Sounding.

Study on the First Guess

A good first guess is important for optimal solution of a physical inverse method. Usually we use the first guess from a regression retrieval. There are two types of regression approaches: EV based regression and selected channel based regression. Currently, the CIMSS International MODIS and AIRS Processing Package (IMAPP) uses a EV based regression technique. We have compared EV based and selected channel based regression approaches and found that EV based regression provides a better first guess than the selected channel based regression.

We also compared CIMSS and NASTI team (LaRC) retrievals; we found that both results are comparable. The algorithms are similar: using EV based regression as first guess followed by physical retrieval using selected channels. However, the NASTI team uses region training for case studies while the CIMSS version uses global training that can be used for global AIRS data processing.

Further details are reported in the web site "AD Quarterly Reports" Q2 2006 Report – Sounding.

Atmospheric Composition Algorithm Development

GOES-ABI has the capability of monitoring atmospheric dust properties. An algorithm has been developed for identifying dust and retrieving optical thickness, particle radius, and density. Aerosol physical parameters (complex refraction index and particle size distribution) were pre-selected. We have used the SEVIRI (Spinning Enhanced Visible and Infrared Imager) on MSG (Meteosat-8) for an ABI proxy.

Look-up tables (LUT) have been generated with a radiative transfer model to create a relationship between the dust microphysical properties and brightness temperature (BT) as well as that for the 11 and 12 µm channel difference (BTD).

The retrieval algorithm is based on the BT of 11µm and BTD between 11 and 12 µm calculated from the forward radiative transfer model. The BTD is controlled by underlying surface skin temperature T_s, effective dust layer top temperature T_c, dust aerosol loading, particle size distribution of dust aerosol and the refraction index of dust aerosol. When T_s, T_c and refraction index are fixed, the 11µm BT presents a quite linear relationship with dust optical thickness, while the BTD between 11 and 12µm presents a good linear relationship with the particle size. Based on this physical pattern, the optical thickness and particle effective radius of dust storm can be retrieved simultaneously.

The algorithm has been applied successfully to SEVIRI data over a dust storm on 3 March 2004. The SEVIRI [Schmetz et al 2002] has 12 spectral bands covering 0.4 to 13.4 µm with spatial resolution of 1 km for visible bands and 3 km for IR bands with high radiometric precision of 0.25 K. The quantitative evolution of dust development is well depicted from SEVIRI data with 15 minute temporal resolution. The optical thickness retrieval agrees with the TOMS (Total Ozone Mapping Spectrometer) aerosol index.

We are also developing an ozone algorithm for ABI, again, SEVIRI is used as proxy, and results of ozone retrieval are expected in the next quarterly report.

Further details are reported in the web site "AD Quarterly Reports" Q2 2006 Report – Composition.

Surface Emissivity Study & Modeling
The work in this quarter focused on 1) continuing to develop the high spectral resolution emissivity database using principal component analysis (termed internally "versions B and C", PCA regression method), 2) improving upon and writing a paper detailing the moderate spectral resolution emissivity database ("version A", baseline spectral fit to MOD11 points) and its application to AIRS and MODIS temperature and moisture retrievals.

The approach to deriving a high spectral resolution emissivity database is based upon a regression relationship between the observed MOD11 emissivity data and the first 1-6 principal components of the laboratory spectra. In this quarter, a Fortran 95 version of the PCA regression algorithm was written because of memory problems with the existing Matlab version.

Other details of this work are reported in the web site "AD Quarterly Reports" Q2 2006 Report – Surface Property.

NWP Modeling for Geostationary hyperspectral resolution measurement simulation
During this period of time the following activities were conducted:

- Finished the first set of revisions for the journal article entitled "Mesoscale numerical weather prediction models used in support of infrared hyperspectral measurements simulation and product algorithm development", which was initially submitted to the Journal of Atmospheric and Oceanic Technology in February. Reviewer comments for this article were generally favorable.
- Attended the GOES-R User's Conference in Broomfield, CO, WRF User's Workshop in Boulder, CO, 2nd Annual Summer Community Meeting in Boulder.
- Presented three posters.
- Wrote a flexible utility capable of generating clear-sky brightness temperatures and radiances for each of the current GOES sounder and imager channels using output from WRF model simulations. WRF-simulated water vapor and temperature profiles and surface skin temperature, together with climatological ozone data, are passed through a clear-sky forward model to generate simulated GOES imagery.
- Prepared a 45-minute presentation that will given at the CIMSS colloquium in July. This presentation documents the numerical modeling work that performed during the last year in support of GOES-R research activities.

Details of the above work is documented in the web site "AD Quarterly Reports" Q2 2006 Report – NWP.

Cloudy Fast Forward Model Development
- Significant modifications were made to the F90 version of the GIFTS fast model code:
  - Improved reflection of downwelling radiance by the surface under clear skies
  - Incorporated new ice cloud radiative properties into the two-layer model, which are based on the latest ice scattering property databases developed by Baum et al.
  - Incorporated land surface emissivity database and associated interpolation code
- GIFTS fast model code was executed successfully on our new cluster (38 dual core nodes) using both the gnu 95 and Intel f90 compilers.

- Attended GOES-R User's Conference in Broomfield, CO. Presented a poster that summarized our forward modeling capabilities in support of GOES-R measurement simulations.

Soundings Summary of Significant Inputs in the last three months
- Optimization of HES sounding retrieval through the analysis of initial guess and surface emissivity treatment.
- Begin to develop composition retrieval algorithm using ABI proxy data – SEVIRI.
- Continue to refine global emissivity database and made public presentations about the progress and results.
- Improving and incorporate new features to enhance version 1 of GIFTS cloudy sky forward model
- Making public presentation about the use of WRF model in support of GOES-R work.
- Continue to revise sounding ATBD.
- Two significant efforts on GOES-R risk reduction in regards to wind derivation from sounder-derived moisture fields were presented by CIMSS Co-I's at the recent WMO International Winds Workshop in Bejing. The extended abstracts for the workshop volume neatly summarize these two efforts and preliminary results

Soundings Plans for Next Three Months
- Continue to optimize the use of new features of WRF model and performing FULL disk and high spatial resolution model calculation to simulate ABI and HES data.
- Continue to improve and incorporate new features to improve cloudy forward model for sounding algorithm development and related simulation.
- Continue to improve and refine cloudy sounding algorithm and update sounding retrieval strategy in handing 1st guess and surface property modeling.
- Continue to develop atmospheric composition retrieval algorithm for future testing and demonstration.
- Continue to refine ATBDs for GOES-R3 annual review.
- Continue to refine approaches to improve high spectral resolution global gridded emissivity database and make relevant publication and presentation.
- Preparing presentation material for GOES-R Risk Reduction annual review.

Recent presentations & publications:
Li, J., P. Zhang, T. J. Schmit, J. Schmetz, and W. P. Menzel, 2006: Quantitative monitoring of a Saharan dust event with SEVIRI on Meteosat-8, *International Journal of Remote Sensing* (revised manuscript submitted, minor revision is required).

Eva Borbas, PCA and Surface Emissivities" poster presentation at the 3rd Annual Advanced High Spectral Resolution Infrared Observations Workshop, Madison, WI. in April 2006.

Eva Borbas, "A global infrared land surface emissivity database" oral presentation at the 1st Emissivity Workshop in Paris, France in June, 2006.

Jason Otkin, CIMSS NWP and forward model activities in support of GOES-R research and development, GOES-R User's Conference in Broomfield, CO.

Jason Otkin, Poster Presentations, The uses of WRF model for the performance of several numerical studies, at the WRF User's Workshop in Boulder, CO.

1.2 Winds Algorithm Development

Two significant efforts on GOES-R Risk Reduction in regards to wind derivation from sounder-derived moisture fields were presented by CIMSS scientists at the recent WMO International Winds Workshop in Bejing, China. The extended abstracts for the workshop volume neatly summarize these two efforts and preliminary results (see appendices at the end of this report).

Plans for Next Three Months
A new simulated case is being prepared by the modeling and retrievals groups that will simulate full-disk GOES-R sounder coverage over a 24-hour period. The winds group will attempt to derive wind vector fields from this case once we are provided with the retrieval moisture fields.

1.3 Biomass Burning Research

Research and development activities in 2006 center primarily on active fire product development and validation. Development will focus on active fire detection and sub-pixel characteristics for emission estimates, including the investigation of fire radiative power. This effort will involve the use of multiple data sources (geo and leo) that take advantage of the strengths of each system to create improved fused fire products. This risk reduction activity will ensure enhanced future fire detection, monitoring and characterization. Initially CIMSS will investigate GOES ABI fire monitoring capabilities by simulating ABI with MODIS, MSG (METEOSAT Second Generation), and MTSAT-1R (Multi-functional Transport SATellite) multispectral data.

Accomplishments:
CIMSS GOES-R Risk Reduction biomass burning efforts began in April 2006 and have focused on simulation of GOES-12 Imager and GOES-R ABI data from higher spatial resolution MODIS data to better understand the differences between current and future geostationary fire detection and characterization capabilities. MODIS observations of the large destructive fires in Southern California in October 2003 were used to simulate GOES-12 Imager and GOES-R ABI 3.9 and 11 μm data and fire characterization capabilities. In order to more accurately simulate Imager and ABI data, appropriate point spread functions were applied in the simulation process. Figure 1.1 shows the spatial response and sampling differences between GOES-R ABI and GOES-I/M Imagers. The figure shows the spatial response of each instrument with each grid point representing 1km at the sub-satellite point. The scanning pattern represents an approximation of the size and sampling for both sensors overlaid on the MODIS 3.9 μm image of the Verdale fire. GOES-R is expected to have minimal oversampling compared to the current GOES, which oversamples by a factor of 1.75 in the East/West direction. The red boxes on the point spread function plots represent the nominal 4 km and 2 km fields of view for GOES-12 and GOES-R respectively.

A modified version of the GOES Wildfire Automated Biomass Burning Algorithm (WF_ABBA) was applied to the simulated GOES-12 Imager and GOES-R ABI data to determine Dozier estimates of instantaneous sub-pixel fire size and temperature. GOES-12 and GOES-R were assumed to be located directly over the fires to limit issues introduced by remapping data. Fire Radiative Power (FRP) was derived from the Dozier output. Figure 1.2 provides a comparison of MODIS simulated GOES-12 and GOES-R ABI fire detection in the 3.9 μm band and fire characterization in terms of FRP. Non-saturated MODIS simulated data were used to calculate instantaneous fire temperature and FRP for saturated GOES-12 and GOES-R ABI data. These estimates are denoted as negative values in the graphs to give an indication of the information

**Comparison of MODIS Simulated
GOES-12 and GOES-R ABI Data and
Fire Characterization in Southern California**

Mean Fire Pixel FRP:
GOES-R ABI: 46 W/m2
GOES-12: 24 W/m2

Note: Non-saturated MODIS simulated data were used to calculate
instantaneous FRP for saturated GOES-12 and GOES-R ABI data.
These estimates are denoted as negative values in the graphs to
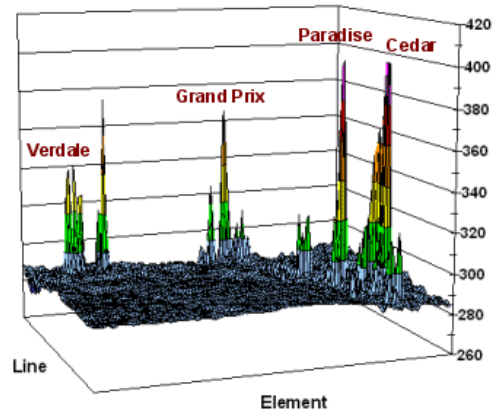indicate information lost
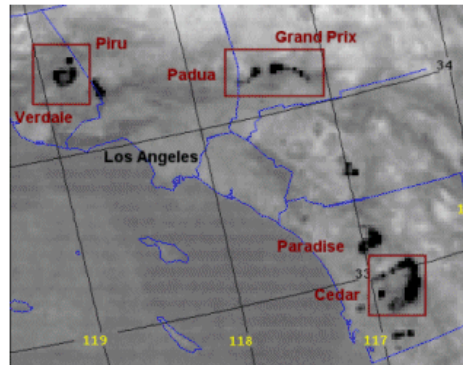
Southern California Fires
Simulated GOES-R ABI 3.9 micron image
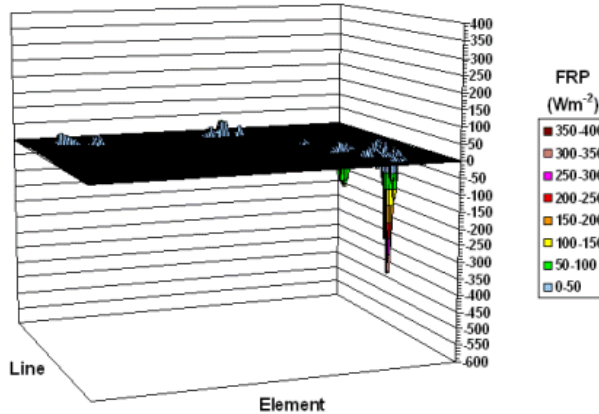Date: 27-October-2003   Time: 09:50 UTC

Simulated GOES-12 3.9 micron Data
Date: 27-October-2003   Time: 09:50 UTC
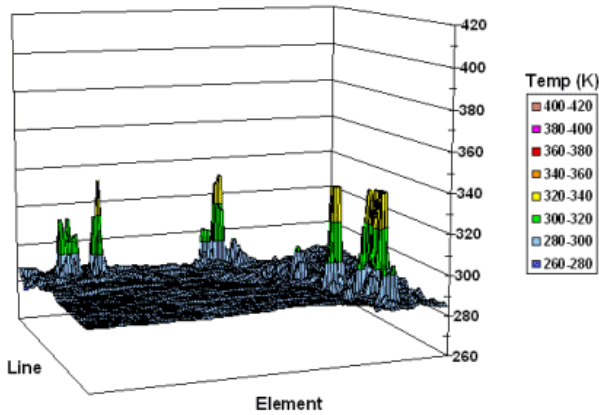
Simulated GOES ABI 3.9 micron Data
Date: 27-October-2003   Time: 09:50 UTC

Simulated GOES-12 FRP
Date: 27-October-2003   Time: 09:50 UTC

Simulated GOES ABI FRP
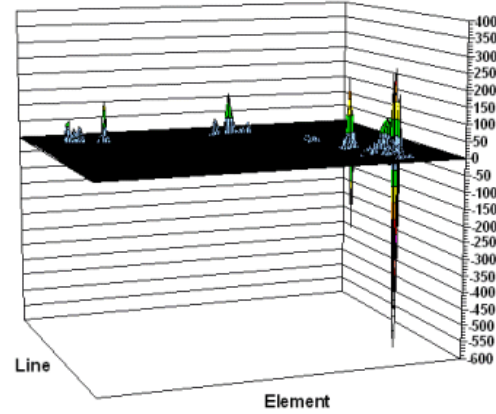Date: 27-October-2003   Time: 09:50 UTC

Figure 1.1: GOES-R ABI and GOES-I/M spatial response and sampling differences.

lost. Saturation in the 3.9 µm band on GOES-12 inhibited determination of FRP for 20% of the fire pixels. Only 4% of the ABI fire pixels were saturated. ABI was also able to characterize more of the variability in fire intensity due to the increased spatial resolution. The mean fire pixel FRP was 46 Wm-2 for GOES-R ABI and 24 Wm-2 for GOES-12. This is primarily due to the fact that several of the hotter fires were included in the average for GOES-R ABI, but were not included in the GOES-12 Imager calculation due to saturation. This difference shows the substantial improvement in fire characterization with GOES-R ABI allowing for more realistic estimates of emissions.
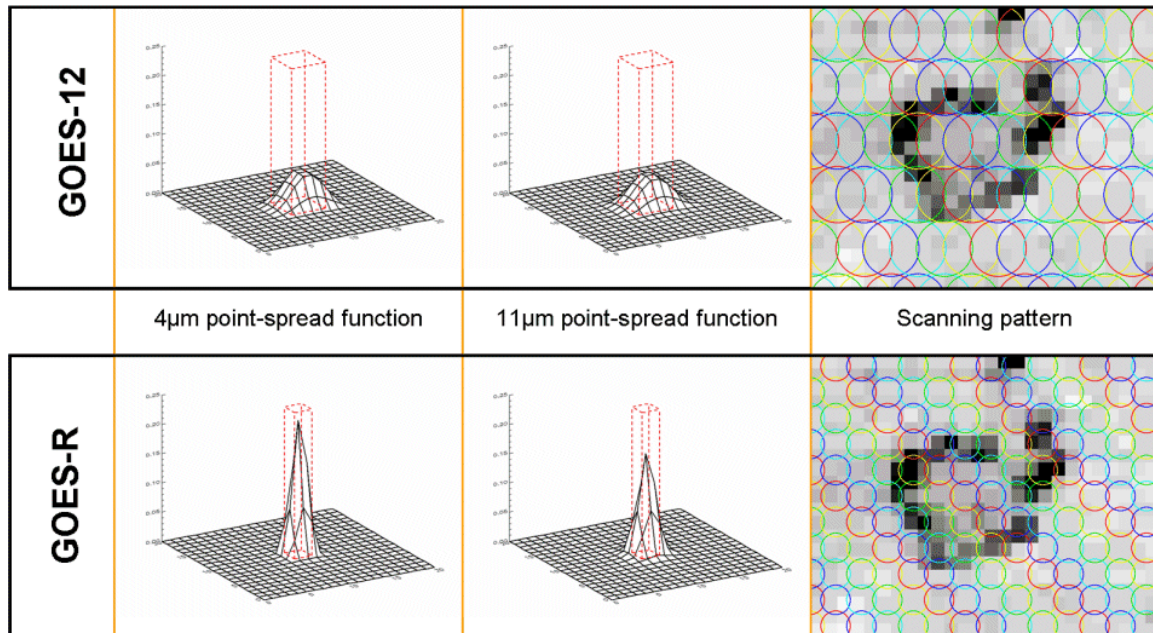

Figure 1.2: Comparison of MODIS Simulated GOES-12 and GOES-R ABI Data and Fire Characterization in Southern California.

Conference Papers/Posters:
Schmidt, C. C. and E. M. Prins, 2006: Comparison of Current and Future GOES Fire Characterization, Fourth GOES-R Users Conference, May 1-3, 2006, Broomfield, CO.

Task 2: Nowcasting

Work is underway in four areas during 2006 and has continued to focus on the ability to detect the development of areas of convective instability 3-6 hours in advance of storm development using full-resolution satellite moisture profile data. Ongoing tests with existing GOES sounder DPI data provide a lower-spatial resolution surrogate for GOES-R ABI data, while tests being initiated with AIRS data will be used to assess the added impact of improved vertical resolution.

1) Development of visualization tools. - Much of this work during the last quarter was again focused on improved visualization tools and web presentation capabilities. An hourly updated nowcast web page has been developed and will be available to the public in the near future. It includes animations of mid- and high-level precipitable water parcel motion 6 hours into the future, along with DPI-like continuous images of the nowcasts and verification information for each nowcast period. Some of the imbalances
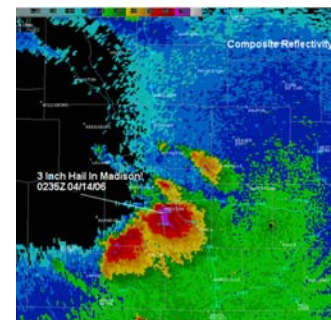

Figure 1 - WSR-88D Image of Hail-storm affecting MSN for 0235 UTC 14 April 2006.

noted the RUC wind data used as initial values for the parcel motions noted in the previous experiments were reduced by using layer averaged winds.

An example of web images is shown from a new case study performed on the 13 April 2006 hail storm, which tracked from south of Madison west o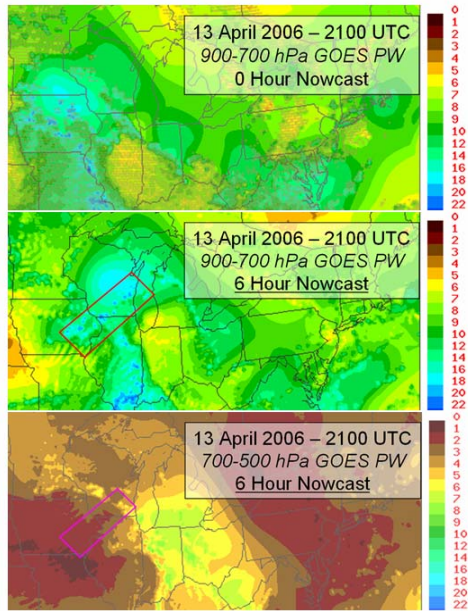f Milwaukee and caused millions of dollars of property damage (Fig. 1). The nowcast system was able to retain detailed horizontal and vertical moisture variations present in the initial DPI data (Fig. 2a) 6 hours before the storm, when the entire area was convectively stable. The nowcast trajectories then transported the low-level moisture maximum from east-central Iowa into an isolated band extending across south-central Wisconsin (Fig. 2b), while simultaneously overlaying it with a narrow area of mid-level dryness that originated over central Minnesota (Fig. 2c). By overlaying the two moisture nowcast images (Fig. 3), the local areas where convective stability was expected to develop are easily identified over extreme southern Wisconsin (bluest regions). The results clearly show both the importance of the information available for GOES and the ability of the nowcast system to retain and project isolated moisture extremes in anticipation of major convective events, especiall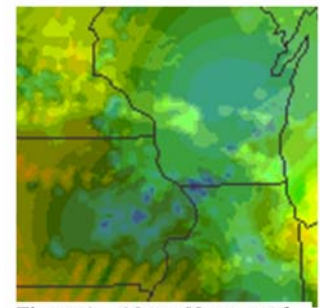y hard-to-forecast isolated events. The higher spatial resolution from the GOES-R ABI will further enhance the nowcast details and can be available immediately after launch.

Figure 2 – *Top:* Initial 900-700 hPa GOES DPI moisture observations (initial nowcast parcel locations - dots) and DPI-like image from 2100 UTC 13 April 2006. *Center:* 6-hour Nowcast of 900700 hPa moisture valid 0300 UTC 14 April 2006. (Moisture maximum outlined). *Bottom:* 6-hour Nowcast of 700-500 hPa moisture (Important dryness maximum outlined).

Figure 3 – 6-hour Nowcast of Convective Instability (*darkest blue areas*) valid at 0300 UTC 14 April 2006.

Future work in this area will incorporate 'cycling' into the image production, in which the previous nowcast image valid at each hour will be used as the 'guess' for subsequent images, thereby increasing resolution by retaining past data in subsequent nowcasts.

2) Incorporate AIRS sounder products into the NCEP-based WRF/GSI system. - This work, being done in collaboration with ERSL, is scheduled to become more active later in the year. Efforts underway with AIRS retrievals (task 3) will be used to provide 'projected radiances', which can then be used in the ESRL assimilation activities.

Assessments of the temporal and spatial representativeness of 6-minute Wind Profiler observations for use in the nowcasts have also been conducted to determine if parcels initiated using observed data at Wind Profiler sites (in addition to smoother, analyzed RUC wind fields) can add value to the nowcasts. These data could be especially useful in projecting the higher vertical-resolution AIRS data. Results of the Profiler evaluation were presented at the Atmospheric Profiling meeting in Boulder in June.

3) Use of POES satellites in nowcasting. – AIRS retrievals were provided by Jun Li for comparing existing GOES moisture data with AIRS sounding products over land. Initial study of

these data showed a clear advantage of GOES versus POES systems, in that the important moisture features that had been observed in GOES DPI products fell between the orbital paths of AIRS and were completely absent from the POES data sets. A second case has been identified and tests using these higher-vertical resolution data are planned for the near future. Preliminary results of the GOES-AIRS intercomparisons are expected to be presented the August SPIE meeting in San Diego.

4) Develop relationships with several National Weather Service Forecast Offices (WFOs), the National Severe Storms Laboratory and NCEP/SPC to evaluate new objective nowcasting products. - Initial discussions have begun with the SOO and forecasters at NWS/GRB. An overview seminar will be presented based on the fully functional web page, including discussions on means of quantifying the usefulness of the products and presentation methods for next years severe storm season. Additional seminars and evaluations are being planned with WFOs in Sullivan and LaCrosse. Discussions have begun with NCEP/SPC for the inclusion of the GOES nowcasts as part of their 2007 spring research program.

Task 3. Preparation for Data Assimilation

Significant Inputs in the last three months
The work completed in this three-month period involves two major areas:
- 1D-Var Experiments: Data assimilation of high temporal and high spectral resolution radiances in combination with GPS radio occultation (RO) data.
- Adjoint sensitivity experiments: Explain inconsistency between the maximum WF heights and the maximum relative sensitivity heights, which causes inconsistency between the maximum WF heights and the maximum analysis increments.

See separate report file: FSU-QR2-2006.doc for details.

Plans for Next Three Months
Prof. Zou of FSU, under subcontract agreement, will continue to perform the following activities during the next few quarters:

1. Continue to conduct 1-D-Var experiments using selected AIRS channels which have weighting function peaked between 200 and 800 mb layer.

2. Confirm the new finding of "the vertical levels at which analysis increments are largest are determined by the maximum relative sensitivity, which could be different from the maximum WF heights.

Task 4: GOES-R Ground System Design and Studies

A brief status is provided for each of the proposed tasks:

• *Evaluate and refine the ATBD for the algorithms used to produce calibrated radiances from raw FTS data using Thermal Vacuum test data from the NASA GIFTS sensor*
Working to verify spectral and radiometric calibration algorithms using thermal vacuum data, also to add a nonlinearity correction algorithm to the ATBD.

• *Continue research into the use of internal calibration reference sources in the optimization of absolute calibration accuracy for the GOES-R program.*
Thermal vacuum characterization of the UW/SSEC built internal GIFTS blackbodies is in progress but preliminary results show excellent engineering performance.

• *Process GIFTS "option 2" thermal vacuum test data through the data processing system*
This task will be starting in the next quarter.

• *Create a 24 hour simulation of GIFTS on-orbit performance measurements using the GIFTS Information Processing System (GIPS) with special focus on characterizing the radiance calibration (and corresponding errors) over a range of instrument temperatures as it would experience them on orbit.*
A preliminary simulation has been created and GIPS processing has begun.

• *Create a searchable database of hyperspectral metadata products from the GIFTS simulated on-orbit data and the GIFTS thermal vacuum test data and demonstrate the data items unique to these large hyperspectral datasets.*
This task was begun by creating simulated GOES channels to use as metadata values for the hyperspectral dataset.

• *Design a Level 2 data processing architecture using the algorithms developed elsewhere in this proposal as a baseline for GOES-R.*
This task has not yet been started.

• *Identify or create prototype algorithm code that can be used in the Level 2 baseline processing system and begin the software development process that will lead to the generation of production software suitable for a software development system consistent with the GOES-R program requirements.*
Preliminary discussions are underway with algorithm providers on candidate code.

Task 5: Demonstration

Once an algorithm is developed and then implemented with the Data Processing and Archive System, demonstration efforts are conducted to assess: 1) the computational efficiency of the algorithm with respect to production requirements, and 2) the accuracy of the products with respect to product requirements. As described in the Algorithm Development section of the proposal, a variety of algorithm and product assessment activities take place under the Algorithm Development efforts. It is only those algorithms that have been passed on and implemented within the Data Processing system, however, which are evaluated within the Demonstration efforts. The relation of the Demonstration activities to the Algorithm Development and ground Data Processing efforts is shown in Figure 5.1. With the maturing of the GIFTS Information Processing System (GIPS), Demonstration efforts have begun.
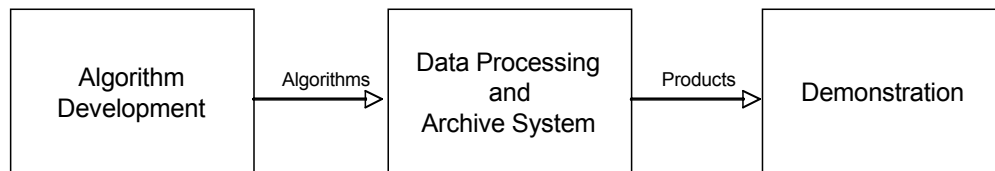

Figure 5.1. Block diagram showing the Demonstration activities process.

The following Demonstration activities were proposed:

1. Write the first draft of the Product Verification Plan, to document how we will demonstrate the production and assess the accuracy of the HES-like products.
2. Demonstrate and assess the accuracy of the GIFTS L0-L1 algorithms and L1 products using both simulated and real GIFTS data hosted by the GIPS.
3. Initial demonstration and accuracy assessment of a baseline T/q retrieval algorithm hosted by the GIPS. This will be demonstrated by implementing the baseline algorithm for aircraft (S-HIS or NAST-I), AIRS, and/or IASI and assessing the accuracy of the products by comparisons to independent validation data.

Progress and plans for next year
Thermal vacuum testing of the GIFTS Engineering Development Unit (EDU) was performed at the Space Dynamics Laboratory in Logan, Utah and completed in May 2006. As part of this effort, uplooking sky view data was collected. As part of this Demonstration effort, we have performed comparisons of measured and calculated upwelling sky view radiance spectra. A sample of the results are shown in Figure 5.2, which compares observed and calculated spectra looking at clear sky and at the moon. These comparisons demonstrate the calibration concepts which are now being implemented within GIPS, as well as the performance of GIFTS. A more extensive sky view Demonstration effort is also being planned for GIFTS under NASA support. This is scheduled to take place in September 2006. As part of the GOES-RRR efforts, the GIFTS data cubes will be processed through GIPS to produce calibrated radiance spectra and evaluated as part of the Demonstration efforts.
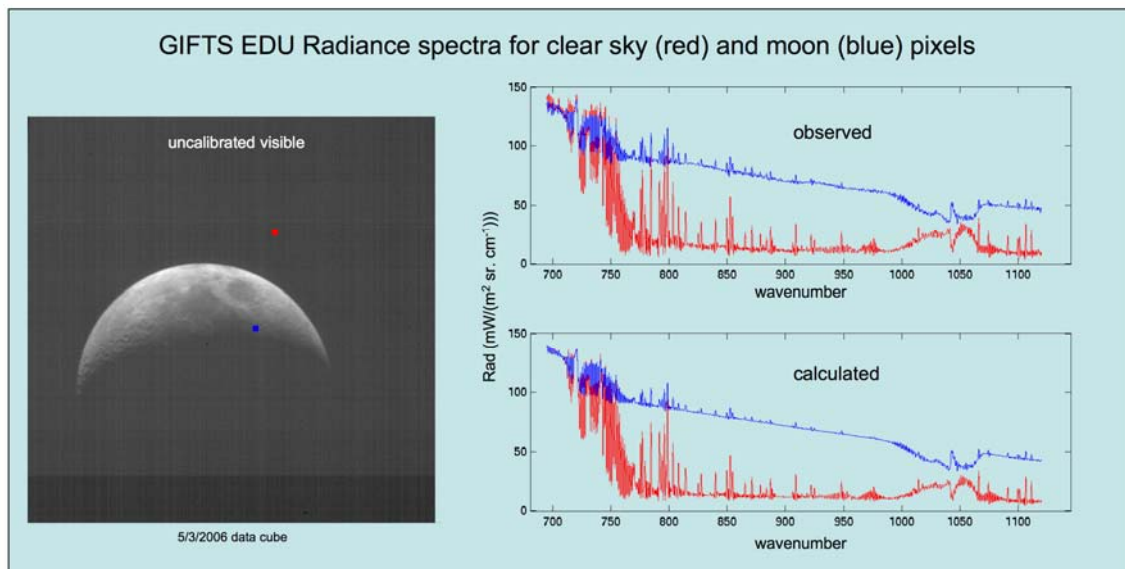

Figure 5.2. GIFTS EDU observed and calculated radiance spectra for clear sky and moon pixels. Data collected on 5/3/2006.

An initial Level 2 AIRS temperature and water vapor profile retrieval algorithm has been delivered by the Algorithm Developers for implementation in the Data Processing system. Work in underway within the Data Processing group to implement this algorithm. Demonstration efforts will be conducted in the next quarter to evaluate the accuracy of the resulting products, primarily via comparison with ARM site matchup validation data.

No notable progress has been made towards the creation of a Product Verification Plan this quarter. Under NASA support, a GIFTS Measurement Concept Validation Plan was produced in

2001 (*Tobin, D. C., C. Velden, N. Pougatchev, S. Ackerman, GIFTS Measurement Concept Validation Plan, GIFTS Project Document GIFTS-MCVP-02-002, 12 February 2001*). We plan to build upon this document and the existing GIFTS Product Evaluation Plan to create a draft Product Verification Plan for GOES-RRR algorithms and processing in this pre-launch time frame.

CIMSS Finances Summary: GOES-R Funding and Spending Plan

GOES R Risk Reduction <u>Funding</u>		**GOES R Risk Reduction <u>Spending</u>**	
Through 2/2004	$1,270K	Through 2/2004	$1,299K
Through 2/2005	$ 750K	3/2004 - 2/2005	$ 880K
Through 2/2006	$ 910K	3/2005 – 12/2005	$ 645K
Total funding to date	$2,930K	Total spending thru 12/31/05	$2,824K

Updated funding and spending information will be provided when FY2006 funding arrives.

Appendices
WIND VECTOR CALCULATIONS USING SIMULATED HYPERSPECTRAL SATELLITE RETRIEVALS

Steve Wanzong, Christopher S. Velden, David A. Santek, Jason A. Otkin

University of Wisconsin – Madison
Space Science and Engineering Center
Cooperative Institute for Meteorological Satellite Studies
1225 W. Dayton St., Madison, WI 53706

Abstract

Derived image triplets of constant pressure level moisture analyses calculated from simulated hyperspectral satellite retrievals are examined for possible wind vector tracking. This method adapts the existing automated wind tracking code developed at the Cooperative Institute for Meteorological Satellite Studies (CIMSS). The modified code eliminates the necessity of the computationally expensive height assignment algorithms, as the altitude of the moisture surfaces being tracked is provided by the retrieval output. The moisture retrievals can simulate the Geostationary Imaging Fourier Transform Spectrometer (GIFTS), the Hyperspectral Environmental Suite (HES), and the Atmospheric Infrared Sounder (AIRS) processing, and are analyzed at 101 pressure levels. From a selection of these levels, winds can be derived in clear sky by tracking the advecting moisture features in the image triplet. As a result, vertical profiles of winds can be produced.

This work is a follow-on to the concept that was presented at the Seventh International Winds Workshop in Helsinki, Finland. At that time, in addition to showing first results of simulated data, one case of real hyperspectral data from airborne observations provided by the National Polar Orbiting Operational Environmental Satellite System Aircraft Sounding Testbed Interferometer (NAST-I) instrument was also discussed. Future research will explore the use of this methodology on real time AIRS retrieved moisture fields in the polar regions.

1.   INTRODUCTION

In preparation for the launch of the next generation GOES operational geostationary satellites, CIMSS is involved in risk reduction through demonstration studies in algorithm development, data processing, archiving, data assimilation, nowcasting and outreach activities. The risk reduction program is designed to investigate optimal processing methods to insure products can be applied to the future hyperspectral imagers and sounders to be launched in the next decade. Atmospheric Motion Vectors (AMV), a subset of the algorithm development element, are one such product. This study focuses on a novel method to derive winds in cloud-free regions from moisture fields provided at

selected constant pressure surfaces by retrieved profiles from simulated hyperspectral radiance data.

2. METHODOLOGY

Several steps are involved in producing the clear sky profiles of winds. Mesoscale models are used to generate simulated atmospheric profiles with detailed horizontal and vertical resolution. Top of atmosphere (TOA) radiances are determined using these profiles along with the GIFTS forward radiative transfer model. Single field of view vertical temperature and water vapor retrievals are calculated from the TOA radiances. Moisture profiles from the retrievals are analyzed on constant pressure surfaces, and converted to images. Three successive analyses (images) are used to generate targets and clear sky AMV using existing tracking techniques.

In 2004, the modelling group at CIMSS began using the Weather Research and Forecasting (WRF) model. The results presented at the Seventh International Winds Workshop used the fifth generation Pennsylvania State University – National Center for Atmospheric Research Mesoscale Model (MM5). The WRF model contains less numerical diffusion and explicit filtering; therefore, it is characterized by a higher effective resolution than the MM5 model. This is important as the simulated atmosphere is used to calculate the TOA radiances of the GIFTS or HES instrument that may have a 4-km horizontal resolution footprint. At this point, the WRF output is broken up into a horizontal grid of 128 by 128 data cubes. This represents the GIFTS detector arrays.

The GIFTS forward radiative transfer model developed at CIMSS calculates the TOA radiances in the infrared spectrum that will be observed by the GIFTS or HES instrument. The GIFTS clear sky forward model is a LBLRTM based Pressure Layer Optical Depth (PLOD) fast model. A cloudy sky contribution is now included using a two layer cloudy sky GIFTS forward model. The TOA radiances are used as the starting point for instrument modelling. The instrument model is broken into two parts. The first models how the optics of the instrument will contribute to the TOA radiances. The second simulates the effects of the detectors. All subsequent examples will refer to this process as introduced instrument noise effects.

Atmospheric temperature and water vapor profiles will be one of the primary products to be retrieved from the next generation GOES sounder. Therefore, the water vapor profiles that are used as data input into the AMV calculations can be derived from two possible sounder instruments being proposed: GIFTS and HES. Much like AMV processing, CIMSS has a long history in developing satellite retrieval software for high spectral resolution instruments. The current retrieval algorithms for GIFTS and HES were developed from and tested on aircraft instruments such as the High resolution Interferometer Sounder (HIS), NPOESS Airborne Sounder Testbed Interferometer (NASTI) and from the existing space based Atmospheric Infrared Sounder (AIRS). The full method utilizes a statistical retrieval followed by a nonlinear iterative solution. It is too computationally expensive to perform both methods in our simulations. Therefore, only the statistical regression algorithm output is used as input into the AMV software.

The AMV algorithm takes the retrieved clear-sky moisture analyses, at constant pressure levels, and converts them into images using McIDAS. Clouds are masked, and the pixels are not used in the targeting/tracking process. The water vapor amount is stretched over a range of 0 to 255 brightness counts in these images to enhance gradients for targeting. A sequence of three images (30 minutes to an hour apart) is then employed in an attempt to successfully track the targeted features. The height of the AMV is pre-determined by the pressure surface being tracked. Hence, height assignment errors that afflict current AMV production should be mitigated. The hyperspectral information (retrievals at 101 pressure levels) allows AMV production at multiple vertical levels. In comparison, current GOES imager clear sky water vapor winds are constrained mainly to the upper troposphere.

3. RESULTS

In this section two case studies will be discussed. The WRF model was used to simulate a strong extratropical cyclone that developed along the east coast of the United States during the Atlantic THORpex Regional Experiment (ATReC). The WRF model was initialized at 0000 UTC on 5 December 2003 with the 1-degree Global Forecasting System (GFS) analyses. It was run for 24 hours on a single 1070 X 1070 grid point domain with 2 km horizontal resolution and 50 vertical levels. The output dataset was averaged to 8 km resolution. This simulation contained a large cloud shield through all of the layers that we explored. Three times steps at hourly intervals were used to track the water vapor gradients at ~34mb increments from 931-343mb. A representative level is shown in Figure 1.
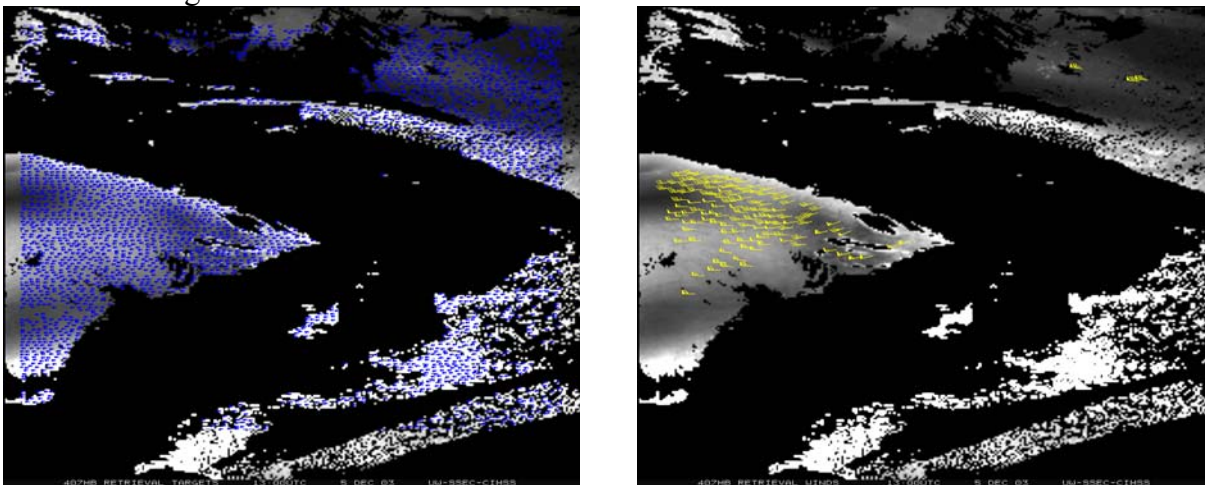

Figure 1. Plot of targets and AMV at 407mb, derived from tracking simulated retrievals of water vapor.

As can be seen in Figure 1, many targets were found in the retrieved water vapor image. Note that clouds are seen as black. Moisture is depicted as a grey scale, with higher Q values in white. Most targets cannot find a correlation in the tracking images as the broken cloud intrudes into the search box array. Currently the CIMSS AMV algorithm is tuned to dismiss a target with even one pixel of cloud in the search box. A future version of the code will alleviate this problem. A visual representation of the vertical profile of the wind field is shown in Figure 2.
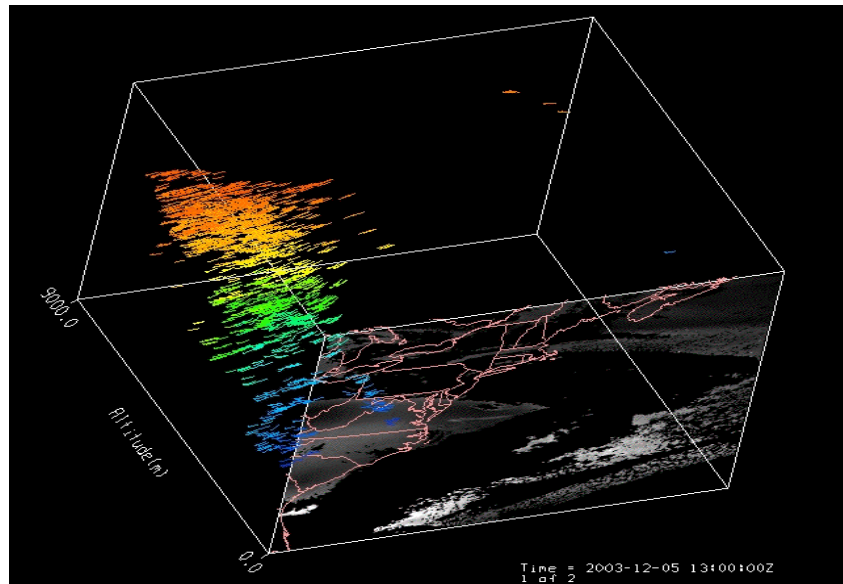
Figure 2. IDV display of winds from simulated retrievals illustrating the vertical distribution. Orange wind barbs are at the highest level of 343mb. Blue wind barbs are at the lowest level of 931mb.

The above wind field is plotted with a QI value of 50 and above. Other quality control algorithms used in normal CIMSS wind production (recursive filter) were not used and still need to be ported to the new scheme.

The final wind field was compared to the actual WRF model wind field, and to the winds generated using the WRF model mixing ratios as input to the CIMSS automated tracking routines. A comparison of all collocated vectors is shown in the table below.

100km Vector Match Distance	Winds with QI > 50
Simulated Retrieval Wind Count	1555
WRF Wind Count	983040
Match Count	1555
Speed Bias (m/s)	-3.3
Vector RMS (m/s)	5.7

100km Vector Match Distance	Winds with QI > 50
Simulated Retrieval Wind Count	1555
Model Q-tracked Winds Count	2105
Match Count	1496
Speed Bias (m/s)	-0.7
Vector RMS (m/s)	4.4

100km Vector Match Distance	Winds with QI > 50
Model Q-tracked Winds Count	2105

WRF Wind Count	983040
Match Count	2105
Speed Bias (m/s)	-2.1
Vector RMS (m/s)	4.9

The speed bias between the simulated retrieval winds and the WRF winds indicates the derived winds are slow on average. There is good agreement between the retrieval winds and the model Q-tracked winds. However, the slow speed bias is again observed between the model Q-tracked winds and the WRF winds. The RMS error values are fairly consistent, and closely represent values from operational AMV production.

A second WRF model simulation was initialized at 0000 UTC, 24 June 2003, and run for 30 hours. 30-minute data was available for this simulation. The ATReC simulation discussed above was chosen primarily for modeling purposes. This case study was chosen specifically for AMV calculations. It is also part of a much larger simulation designed to model the domain of a GIFTS or HES view of the earth (this will be part of a future demonstration). 101 pressure levels were available for each time period. However, AMV processing in the marine boundary layer was the goal. Therefore, winds were calculated only from 683mb down to 986mb at every available pressure level in between. A representative level is shown in Figure 3.
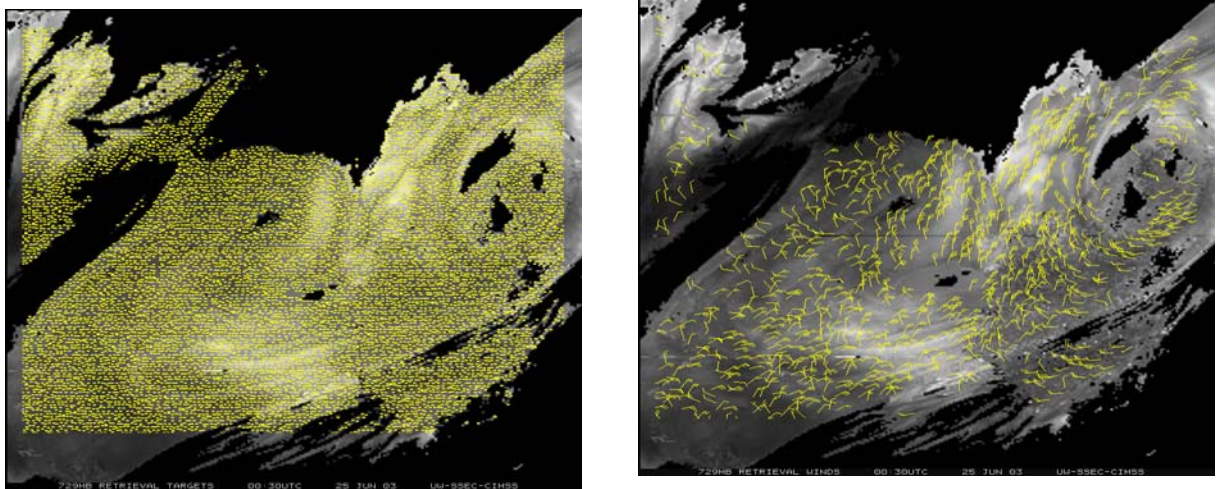

Figure 3. Plot of targets and AMV at 729mb, derived from tracking simulated retrievals of water vapor.

Figure 3 shows a prominently cloud-free environment, allowing good water vapor observations and AMV coverage. Note the low level circulation defined by the AMVs in the northeast section of the image. Figure 4 shows the vertical density of the AMV achieved in this simulation.
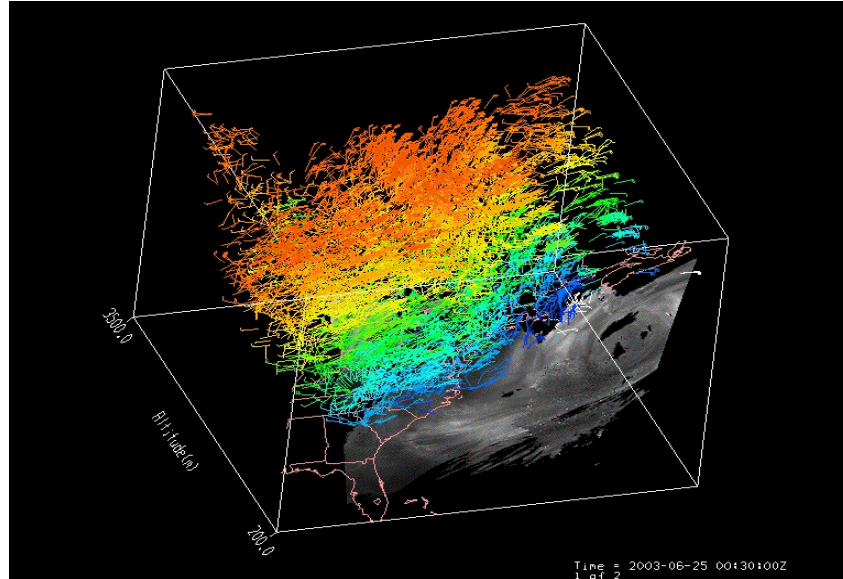
Figure 4. IDV display of winds from the simulated retrievals illustrating the vertical density. Orange wind barbs are at the highest level of 683mb. Blue wind barbs are at the lowest level of 986mb.

As in the first case, the only quality control routine applied to the wind set was the QI. The same comparisons between all wind fields were performed for this simulation (see table below).

100km Vector Match Distance	Winds with QI > 50
Simulated Retrieval Wind Count	13812
WRF Wind Count	851968
Match Count	13812
Speed Bias (m/s)	1.3
Vector RMS (m/s)	6.7

100km Vector Match Distance	Winds with QI > 50
Simulated Retrieval Wind Count	13812
Model Q-tracked Winds Count	32737
Match Count	13741
Speed Bias (m/s)	0.3
Vector RMS (m/s)	8.4

100km Vector Match Distance	Winds with QI > 50
Model Q-tracked Winds Count	32737
WRF Wind Count	851968
Match Count	32737
Speed Bias (m/s)	0.7
Vector RMS (m/s)	4.9

In this case, the retrieval winds are now slightly faster than the WRF model winds, but with lower biases. However, RMS errors are somewhat larger than in the first case. This product is in its infancy, and too early to draw any conclusions from the statistics on two case studies.

4. SUMMARY

CIMSS is developing a new approach to clear sky water vapor AMVs that will be viable on future hyperspectral sounders such as HES and GIFTS. The trials and results in this study were limited to simulated hyperspectral data sets. The results indicate that method/algorithm improvements are needed to exploit this new capability. However, the proof of concept has been demonstrated, and the method will be applied to real data using the AIRS moisture retrievals over the poles as a next step.

5. REFERENCES

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Satellite Wind Vectors from GOES Sounder Moisture Fields

Iliana Genkova*, Chris Velden**, Steve Wanzong**, Paul Menzel*

* NOAA-NESDIS, Madison, WI
** University of Wisconsin, CIMSS, Madison, WI

ABSTRACT

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

INTRODUCTION

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

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

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

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

DATA DESCRIPTION

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

GOES sounder vertical profiles can be easily converted to a set of images representing moisture on constant pressure levels by extracting the variable of interest (i.e., Td) from each profile at the desired available constant pressure level. The pressure levels are predetermined by the initial guess profile. These images then serve as input image sequences for the satellite wind retrieval algorithm. We used the Man-computer-Interactive-Data-Access-System (McIDAS) (Lazzara et al.,1999) environment to extract *constant pressure images* of *Td* at selected constant pressure levels.
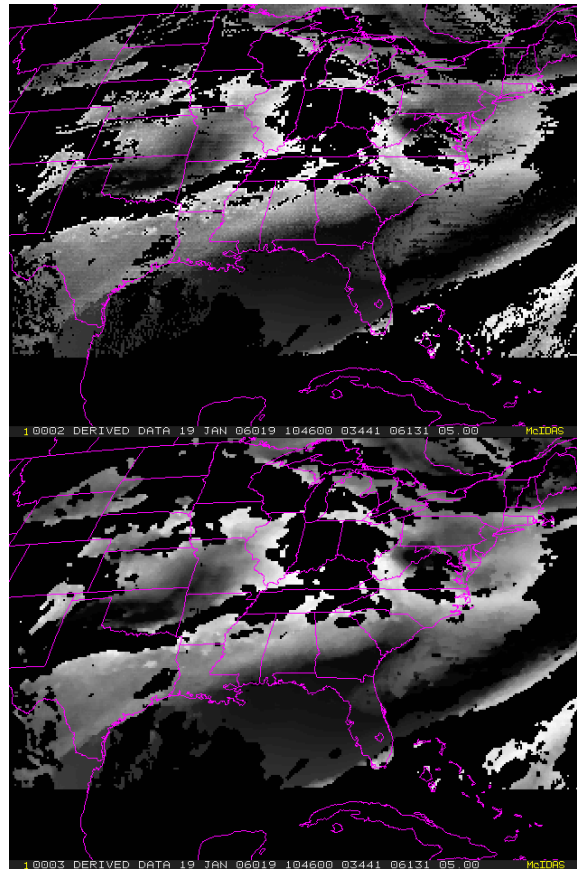
To assure tracking of features in the moisture fields, and not cloud edges and features, cloud pixels have been masked and a median 3x3 filter was then applied to remove remaining single cloudy pixels. Often under broken cloud conditions many initial moisture targets are not tracked, since the search box can not include cloudy pixels (a current limitation of the tracking code that will be addressed in a future version). Thus it is vital to set a proper search box size: small enough to not eliminate many targets under broken clouds, but also large enough to allow retrieval of the fastest winds at high altitudes. This will be discussed later in the paper. Also, as part of the image pre-processing step, an optimal histogram stretch was applied to every image triplet to achieve maximum brightness contrast and to increase the number of targets to be tracked. Figure 1 shows an example of an image generated from GOES-12 sounder derived dew point temperature profiles at 500mb. The different stages of image extraction, preprocessing and wind retrieval are illustrated. By their nature, the sounder generated moisture field images overcome the problem of assigning heights to the wind vectors. Atmospheric motion vectors were derived using a 5X5 pixel target box, a search box of size of 11x19 pixels, and a 10 m/s U and V component acceleration check quality control threshold.

EXAMPLES AND DISCUSSION

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

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

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

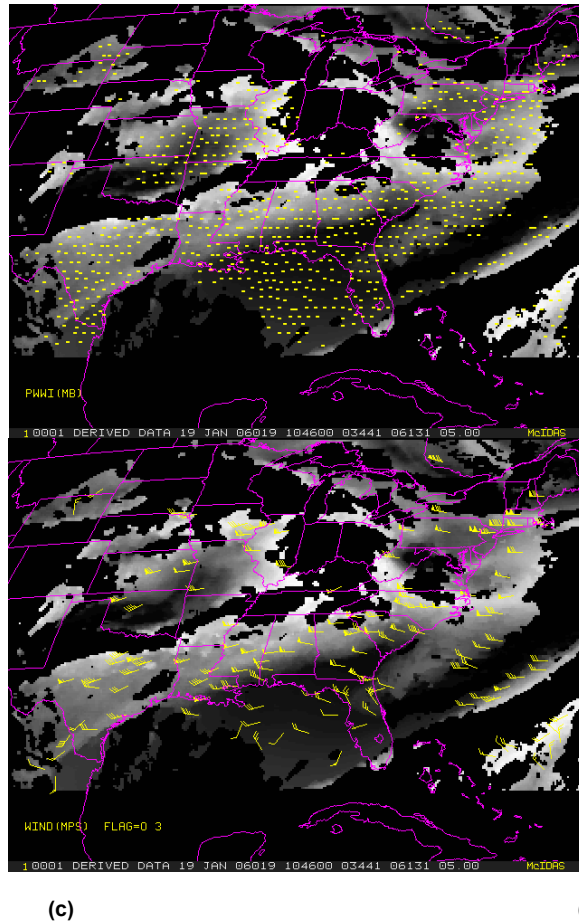(a)   (b)

PWWI(MB)

10001 DERIVED DATA 19 JAN 06019 104600 03441 06131 05.00   McIDAS

WIND(MPS) FLAG=0 3

10001 DERIVED DATA 19 JAN 06019 104600 03441 06131 05.00   McIDAS

(c)   **(d)**

Figure 1. GOES 12 sounder-derived constant pressure Dew Point Temperature (*Td)* images at 500mb, on 19 January 2006, 10:46 UTC. Blacked-out regions indicate where the retrieval cloud-mask was applied. (a) extracted image from the SFOV profiles after histogram stretch; (b) same as (a) but after a median 3x3 filter to smooth out single cloudy pixels; (c) distribution of targets identified from the moisture fields; (d) atmospheric motion vectors derived at 500mb from triplet images between 10:46 and 12:46 UTC.
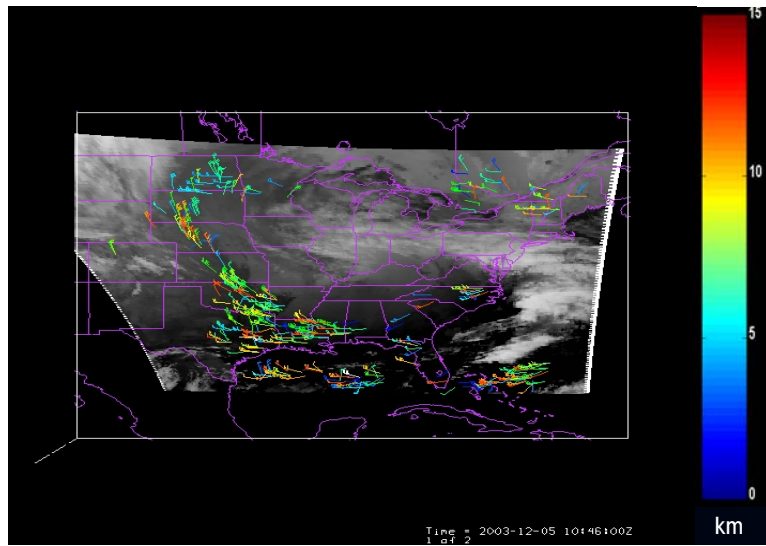
Figure 2. (on the following page) GOES sounder derived moisture (Td) winds from 5 December 2003, 12 UTC:
(a) Raw (unedited) winds - view from the top; (b) Vertical distribution of raw winds; (c) Quality controlled winds with QI≥50 – view from the top.
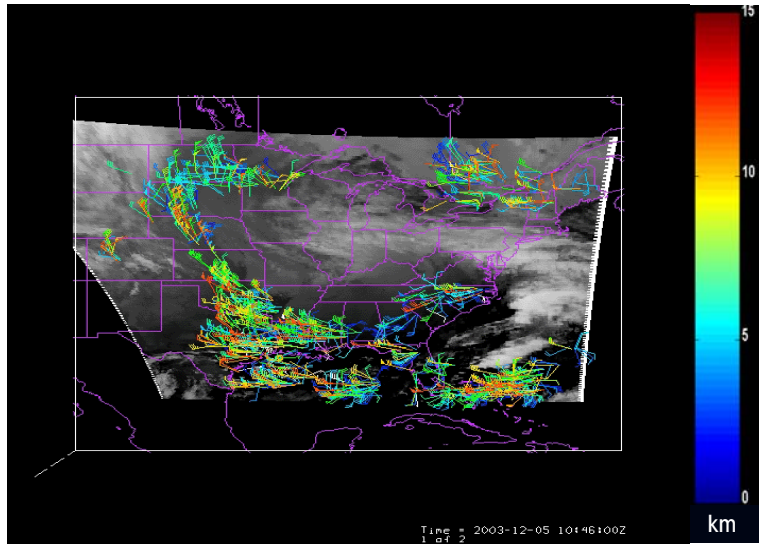
(a)
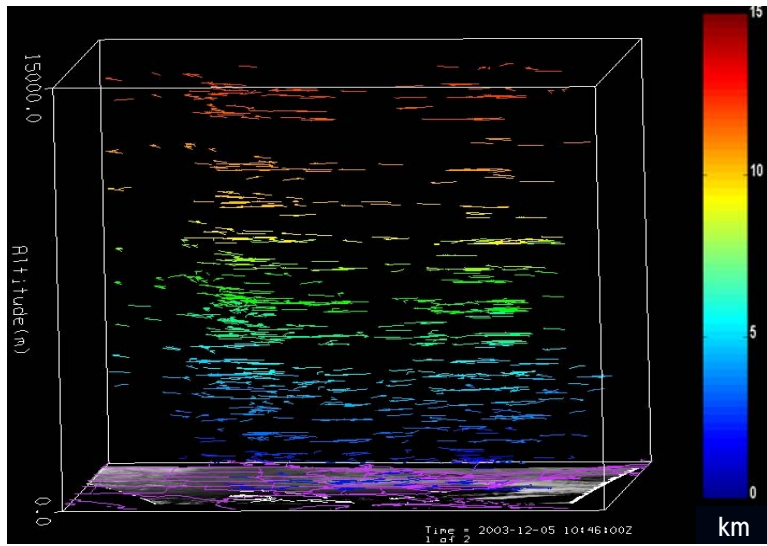
(b)

(c)

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

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

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

As mentioned earlier, the winds are derived using a 5x5 pixel target box, and a 11x19 pixel search box. The size of the search box was selected to allow measurement of the fastest jet-stream winds of 120 m/s. Given that the winds at lower altitudes are not reaching such high speeds, we will be able to reduce the size of the search box, thus improving the mean bias and the VRMS. The results (for raw winds) in Table 2 suggest that it may be beneficial to apply different size search boxes depending on the pressure level of the moisture fields being analyzed. The statistics are produced for the winds from 19 January 2006. The mean bias is not greatly improved, but it has relatively low values even with the 11x19 search box. The VRMS however has been reduced significantly by employing a smaller search box, as much as 50% for the high winds.

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

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

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

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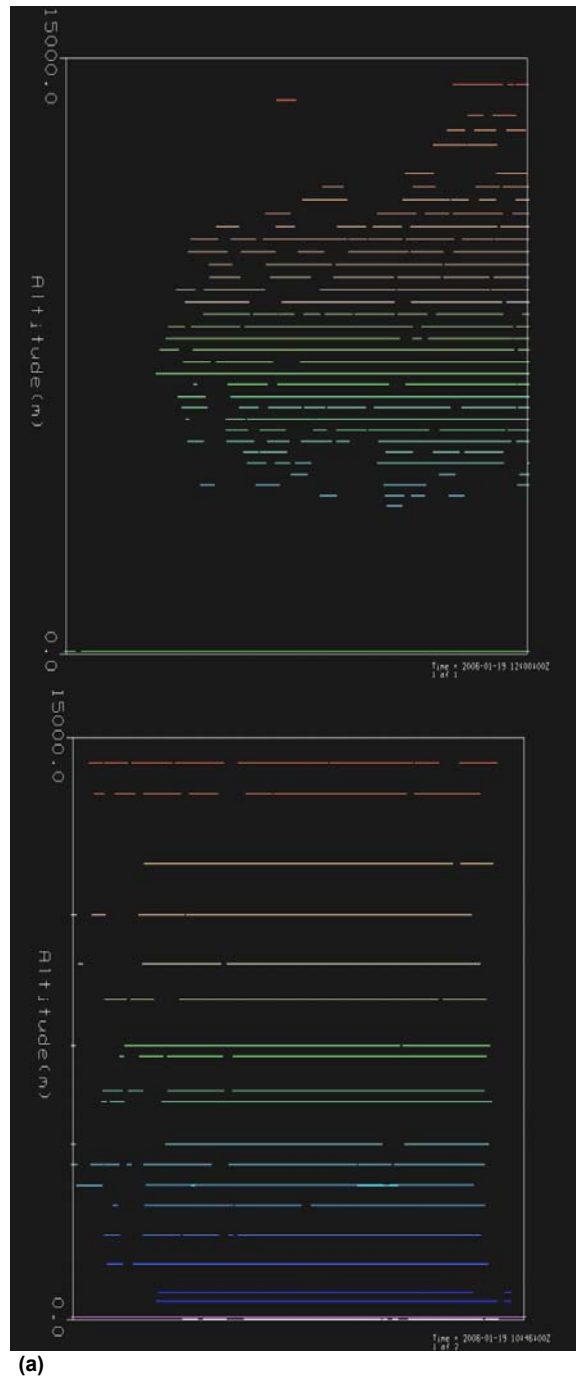
Figure 3. Vertical distribution of AMVs for 12 UTC on 19 January 2006: (a) operational GOES Water Vapor tracked winds; (b) from GOES sounder derived product moisture fields

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

that when the contrast is higher, more vectors are derived independently of the amount of moisture.
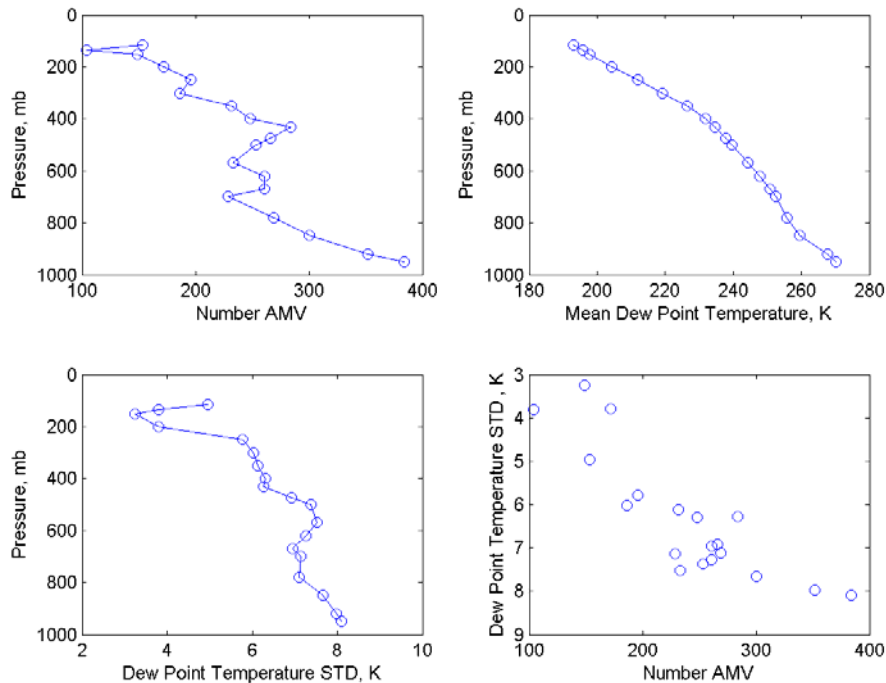

Figure 4. Correlation between dew point temperature variation with altitude and number of AMVs, 19 January 2006, 12 UTC.

CONCLUSIONS AND FUTURE WORK

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

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

Acknowledgements

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