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Agenda Item: III.2

1999/00 Report on NOAA/NESDIS GOES Soundings and Winds

Summary and Purpose of Document

An overview of the NOAA/NESDIS operational wind product suite that includes the high density visible cloud-drift winds from the GOES imager and water vapor motion winds derived from the GOES sounder.

Action Requested: None

1999/00 Report on NOAA/NESDIS GOES Soundings and Winds

W. Paul Menzel [1], Timothy J. Schmit [1], Chris Velden [2], Jaime Daniels [1],
James P. Nelson III [2], and Mark Ruminski [1],

[1] - NOAA/NESDIS/ORA

[2] - Cooperative Institute for Meteorological Satellite Studies
Madison, Wisconsin

I. Introduction

The NOAA/NESDIS operational GOES-8/10 soundings and winds production has continued to evolve. Soundings are being produced every hour at 50 km resolution in clear skies (research retrievals are being run at 30 km resolution); three layers of moisture definition are being used operationally by the regional forecast models (Menzel et al., 1998); the effects of surface emissivity in profile retrievals from infrared multispectral radiances are being studied. Winds are being produced every three hours from IR window water vapor, and visible (when available) images with high spatial density; the quality of the wind product is being reported monthly in accordance with CGMS reporting procedures (Schmetz et al., 1999). Improvements in both product areas are planned.

II. NESDIS Operational Winds and Research Areas

NOAA/NESDIS, together with CIMSS, is continuing to improve the operational wind product suite. New wind products now operationally supported include the high density visible cloud-drift winds from the GOES imager and water vapor motion winds derived from the GOES sounder 7.0um and 7.4um moisture channels. All of the NOAA/NESDIS wind products are now being encoded into the unified BUFR template. NOAA/NESDIS has enhanced its processing strategies to utilize available 15-minute and 7.5-minute images loops for the derivation of visible cloud-drift winds. The quality of the wind products continues to look good.

IIa. Operational Imaging Schedules

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

Table 1: NOAA/NESDIS Operational Wind Products

Wind Product	Frequency (hrs)	Image Sector(s)	Image Interval (min)
IR Cloud Drift	3	Extended NH; SH	30
Water Vapor	3	Extended NH; SH	30
Vis Cloud Drift	3	RISOP	7.5
	3	PACUS/CONUS	15
	3	Extended NH; SH	30
Sounder 7.0 WV	3,6	CONUS/Tropical	60
Sounder 7.4 WV	3,6	CONUS/Tropical	60

The newest operational wind products include the visible cloud drift and GOES sounder water vapor motion winds. The visible cloud-drift wind products are generated routinely for GOES-8 and GOES-10 every three hours during daylight hours over the Northern and Southern Hemisphere. The GOES sounder water vapor winds are generated every three hours over the Continental United States (CONUS) and every six hours over the adjacent oceanic regions.

IIb. Use of Higher Frequency Interval Imagery

New processing strategies have been developed for operational wind processing to take advantage of the higher frequency interval imagery offered by the current GOES scanning schedules. The capability to routinely use higher frequency interval imagery in the operational derivation of visible and infrared cloud-drift (CD) satellite wind vectors has recently been added to the wind production suite at NOAA/NESDIS in June 2000. 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. Use of this higher frequency interval imagery has resulted in significant increases in vector coverage and more uniform winds. The Northern Hemispheric image sectors, which are scanned every 30 minutes, are used to generate wind products outside the CONUS, PACUS, and RISOP domains in order to achieve full Northern Hemispheric coverage. The Southern Hemispheric image sectors, which are scanned every 30 minutes, are used to achieve coverage in the Southern Hemisphere. These image sectors are illustrated in Figure 1.

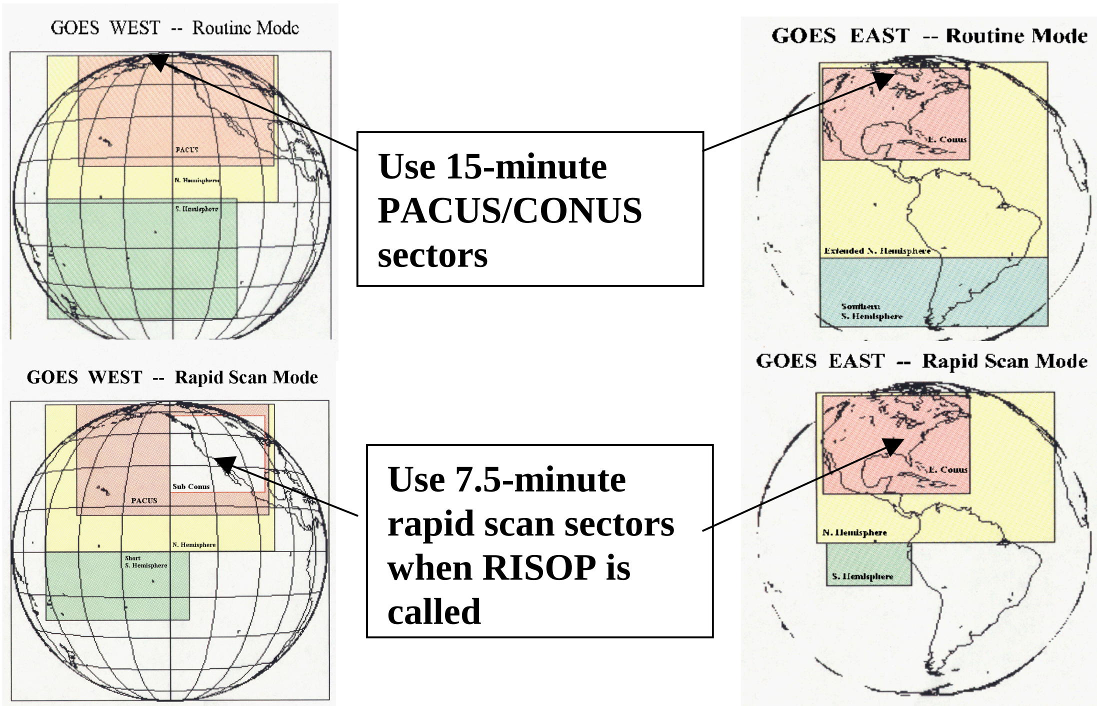

Figure 1: GOES East and GOES West Image Sectors. Use of CONUS, PACUS, and RISOP sectors offer benefits to wind processing.

IIc. Low Level Cloud Tracer Height Assignments

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

IId. Product Distribution

All of the operational NESDIS wind products shown in Table 1 are now encoded into the unified BUFR format and available on a NESDIS server. All of the operational NESDIS wind products shown encoded into the unified BUFR format and available on a NESDIS server. Distribution of the these BUFR files over the Global Telecommunication System (GTS) is expected to begin in September 2000.

IIe. Quality of Operational Winds Product

The NESDIS operational winds continue to perform well. The quality of the wind products is being tracked according to CGMS guidelines. Figure 2 presents the summary from the last twelve months.

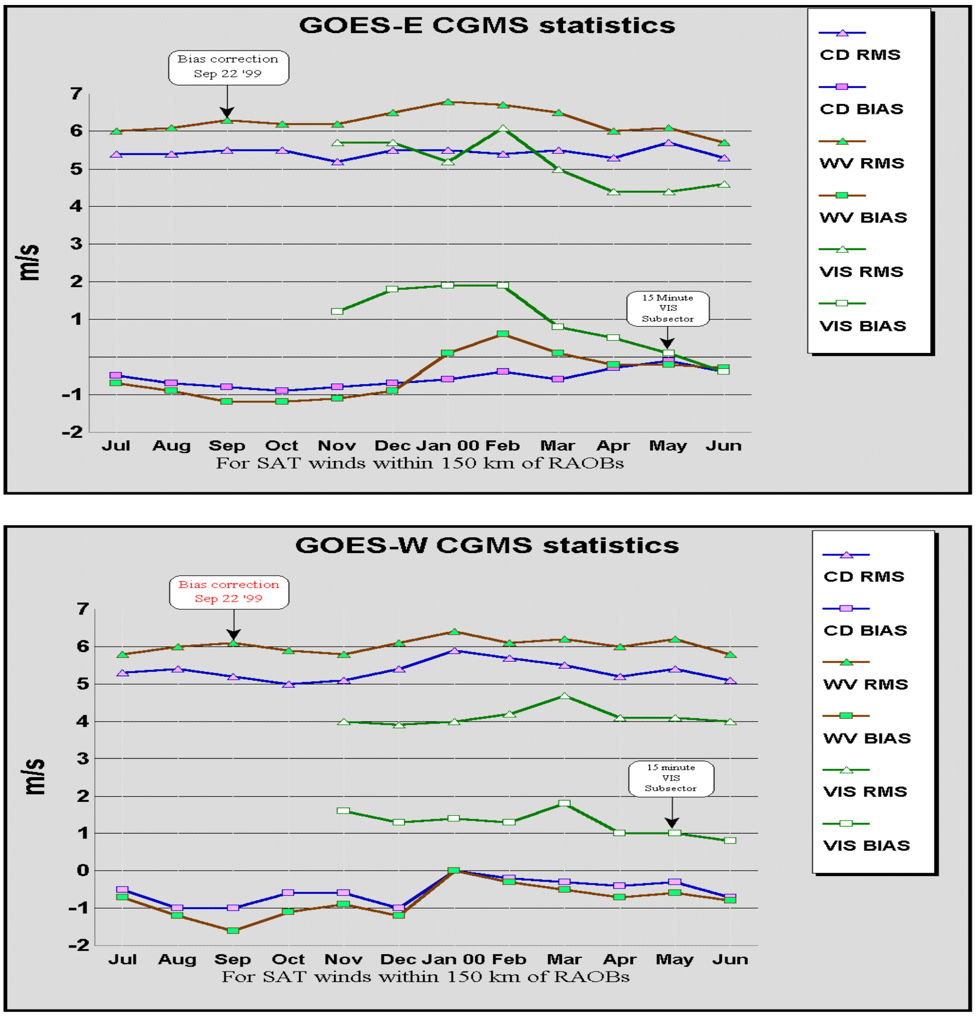

Figure 2. CGMS statistics (bias and root mean square) for GOES-E/W cloud drift (CD) and water vapor motion (WV) winds for July 1999 through June 2000.

The wind statistics have been affected by a couple of changes made to the speed bias correction procedure. Beginning in September 1999, the speed bias correction procedure was turned off for all winds (IR and WV) in the tropics (25N - 25S) and increased to 10% for (a) all cloud drift winds with speeds greater than or equal to 10 m/s and pressures less than or equal to 300mb and (b) cloud (not clear air) WV winds with speeds greater than or equal to 10 m/s and pressures less than or equal to 300mb.

Beginning in February 2000, NESDIS began operationally producing CD and WV winds from GMS-5 measurements using NESDIS high density wind algorithms. These products are encoded into BUFR and are available from the operational NESDIS product server.

IIf. Wind Research Areas

One active research area involves around improving the clear-air water vapor winds. Specifically, WV feature tracking can be significantly improved by increasing the time interval between WV imagery from 30 minutes to 60 minutes. Increased vector coverage at middle levels (400-700mb) of the atmosphere are observed when using 60 minute interval imagery. When these winds are compared to radiosondes, improvements of 2-3 m/s in the mean vector difference are observed. Another area of research involves assessing the impact of using the middle image in an image triplet to perform target selection and height assignment for all wind product types. Wind vectors are computed forward and backward in time and averaged in this approach. This approach opens up additional opportunities for quality control involving vector consistency checks.

Other planned operational implementations include production of the EUMETSAT Quality Indicator (QI) in November 2000. CIMSS has transferred code to NESDIS FPDT for operational implementation. This code includes the Quality Indicator (QI) module (Holmlund et al. 2000), and the capability to process winds from other geostationary satellites (GMS, Meteosat).

Other research areas include 1) The further exploration of winds from five minute interval GOES images (Velden, 2000), which will include an exploitation of a special GOES-10 scanning mode during the PACJET field experiment in early 2001. Testing is underway with the recently-launched GOES-11 satellite, which includes a science checkout period with 5-minute imaging; 2) An examination of nighttime 3.9 micron winds; 3) Another analysis of water vapor wind height assignments (Rao et al. 2000); 4) use of the middle image for targeting, and exploration of image sequences of 5 (3 used now); 5) model impact studies (Soden et al. 2000); and 6) Application of the wind fields to hurricane analyses (Dunion et al. 2000).

III. NESDIS Operational Soundings and Research Areas

Operational production of GOES-8/10 soundings continues every hour over North America and the nearby oceans. Atmospheric temperature and moisture profiles are generated using a simultaneous physical retrieval algorithm. During the past year:

- Sounder derived product images became operational
- NWS forecasters gave a positive assessment of the operational utility of sounder products
- Parallel tests in regional models quantified the impact of sounder moisture data
- Comparisons at the DOE ARM CART site showed the quality of sounder data
- GOES-11 was launched and is in the process of being checked-out
- Single FOV soundings are being investigated
- Effects of surface emissivity in profile retrievals are being studied with MAS infrared multispectral radiances

IIIa. Operational Sounding Peformance

A comparison of layer moisture data between GOES-8 and 10, the current NCEP forecast first guess (from the Eta model), and nearby radiosondes is shown in Table 2. The total column water vapor RMS difference with respect to radiosondes for this twelve month period in 1999-00 has been reduced from 3.4 mm for the forecast first guess to 3.1 mm for the GOES-8 retrievals.

Table 2. Comparison of moisture (mm) from the period April 1999 to March 2000 of the Eta model first guess and the GOES-8/10 retrievals with respect to radiosondes. Collocation is within 0.25 degrees. Bias and root mean square (RMS) scatter about bias are indicated. Sample size is 2828 and 563 for GOES-8 and 10, respectively. Sigma levels are defined as the pressure divided by surface pressure.

GOES-8:

	Eta Guess		Retrieval	
	Bias	RMS	Bias	RMS
Total Water Vapor	-.3	3.3	-.4	3.1
WV1 (Surface to .9 sigma)	-.5	1.5	-.5	1.4
WV2 (0.9 to 0.7 sigma)	-.1	1.9	-.1	1.8
WV3 (0.7 to 0.3 sigma)	.3	1.1	.3	1.0

GOES-10:

	Eta Guess		Retrieval	
	Bias	RMS	Bias	RMS
Total Water Vapor	-.7	2.5	-.5	2.4
WV1 (Surface to .9 sigma)	-1.0	1.3	-.9	1.3
WV2 (0.9 to 0.7 sigma)	.1	1.4	.1	1.4
WV3 (0.7 to 0.3 sigma)	.3	0.9	.3	0.8

Hourly retrievals of three layers of moisture as well as the total column are being assimilated in the Eta model for the regional forecasts. Thus, differences from the first guess would probably be larger if the GOES-8 and –10 data were not operationally assimilated every three hours into the Eta Data Assimilation System (EDAS) during this time period. To support this hypothesis, the statistics were calculated for a period prior to the assimilation of GOES sounder data into the Eta system. For the year April 1996 through March 1997, the first guess TPW RMSE indeed improved by a larger amount (3.4 to 2.7 mm) (Ma et al. 1999).

IIIb. Validation of Moisture Soundings

To confirm the GOES sounder depiction of time changes of moisture estimates, Dostalek and Schmit (2000) reported a correlation coefficient of 0.71 (and a bias of 0.02 mm) for 12 hourly changes between TPW retrievals and those of co-located radiosondes. The first guess has a correlation coefficient of 0.59 (and a bias of 0.28 mm). A one-year period consisting of 2384 samples was examined in that study.

Additionally, the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site offers TPW data for more precise validation of GOES retrievals than is possible with radiosondes. An operational Microwave Radiometer (MWR), located at the central CART facility near Lamont, Oklahoma provides accurate measurements of TPW. The MWR measures total precipitable water vapor every five minutes measurements with a microwave radiometer at the Department of Energy – Atmospheric Radiation Program (DOE ARM) Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site (Stokes and Schwartz 1994) allowed more accurate assessment of moisture data at high temporal resolution. Figure 3 shows a one-day comparison of TPW on 12 April 1998 between the MWR and GOES-8. The diamond symbols represent the first guess from Eta model forecasts. GOES retrievals are the plus symbols. Notice that while the Eta first guess is relatively flat throughout the period, the GOES retrieval algorithm produces nearly the same water vapor tendency patterns as measured by the MWR. Recall that the satellite retrieval, using a 3 x 3 FOV matrix (equating to a 36 km x 45 km box), represents a volumetric profile over a larger horizontal area than the MWR. Smooth temporal changes are maintained by the GOES physical retrieval algorithm, even when the first guess experiences a discontinuity (e.g. at 18 UTC). GOES follows the water vapor fluctuations between a local minimum of approximately 13 mm at 1130 UTC and a maximum of approximately 24 mm at 14 UTC; the temporally and spatially coarse radiosonde network did not capture those changes. Overall, GOES demonstrates skill in resolving the mesoscale water vapor fluctuations on this day.

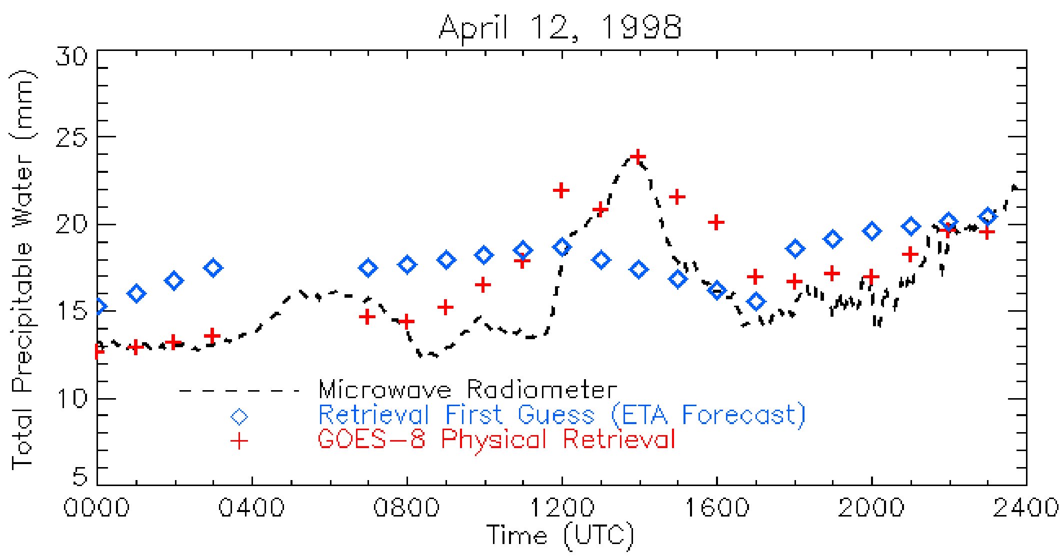

Figure 3: Microwave radiometer (dashed line), GOES-8 first guess (“diamond” symbols), and GOES-8 physical retrieval (“plus” symbols) total precipitable water vapor comparisons near Lamont, Oklahoma on 12 April 1998**.**

IIIc. NWP Assimilation of Moisture Information

From October 1998 through July 1999, assimilation of 3-layers of moisture retrieved from GOES sounder measurements improved Eta model precipitation forecasts, even out to 48 hours. The data were assimilated, in a fully cycled mode, every 3 hours during the 12-hour period prior to the final analysis time, after which the forecast model was executed. Fully cycled implies that the 12-hour forecast from the previous model run was used as the background for the current model run. A larger Equitable Threat Score (ETS) indicates the forecasts compared more favorably to verifying 24 hour rain gauge precipitation totals (Rogers et al. 1996) derived from the River Forecast Center network. The ETS ranges from 0 to 1 and increases for grid points with a correct forecast of precipitation and decreases for either a missed or a false alarm precipitation forecast. The ETS was tabulated for nine ranges of precipitation (bins). The seven bins with the greatest number of matches showed an improvement due to the inclusion of the retrieved GOES sounder layer moisture data. The two bins with high rain amounts (where the number of samples was relatively small) were degraded. Most of the rain cases are improved. Overall, precipitation forecasts (when weighted by the total number of cases) were improved approximately 2.3% by inclusion of the GOES sounder moisture information. These improvements are significant. Kalnay et al. (1998) illustrated the average 10-year (1987-1997) improvement of the threat score (TS) as 0.06 for 24-h forecasts at the 12.7 mm (0.5 in) precipitation threshold. This translates to an average increase of 0.006 per year. The TS improvement is 0.007 when GOES sounder moisture data are included. Therefore, the impact of including the GOES sounder moisture data is of the same order-of-magnitude as the yearly historical average improvement. When only the four summer months (May – August 1999) are considered, the improvement in ETS increases to 4.5%. The positive impact of the GOES sounder 3-layer PW on the precipitation forecasts (compared to 12 UTC rain gauge readings) is sustained out to 48 hours (Schmit et al., 2000).

IIId. Use of the Soundings at Weather Forecast Offices

Soundings and Derived Product Images (DPI) continue to be made available to NWS Forecast Offices in realtime, assisting the forecasters with their short-term forecast responsibilities. Forecasters have found that the sounder profiles and DPIs are making significant positive impacts to their forecasts of location and timing of severe weather (such as thunderstorms). From 19 July through 30 August 1999, the NWS Office of Meteorology conducted daily assessments of the operational value of the GOES-8 and GOES-10 sounder products. Thirty-seven NWS forecast offices, four national centers, and the NESDIS Satellite Analysis Branch participated in the evaluation, providing a total of 638 responses. Forecasters used the sounder products to heighten their awareness of the potential of a wide variety of weather events, including severe thunderstorms, monsoon precipitation, and flash floods. Their responses showed that in over 79% of all active weather situations, the use of GOES sounder products led to the issuance of improved forecasts. In the words of a forecaster in Minneapolis, MN on 9 and 10 August 1999 who stated:

> “The Sounder Derived Product Imagery (DPI) helped a lot anticipating convective development over southern MN this evening. I looked through the DPI's over a few hours and saw a definite decreasing trend in the CINH (Convective Inhibition) from 19-21Z. It was only a matter of time before the convection fired into southern MN. Impressive CAPE values (3500-4500J/KG)

> and LI's -10 to -12 pointed to the possible severity of the convection. We received many reports of funnels/brief tornado touchdowns across south central MN as the convection went through. We were about ready to give up on any serious development...it was quite late (after 8pm CDT) before it developed. These products overlayed on surface maps/satellite/radar displays on AWIPS would be invaluable to the mesoscale forecaster."

Figure 4 shows the GOES-8 Sounder Convective Available Potential Energy (CAPE) values at 00 UTC on 10 August 1999. The axis of CAPE values greater than 2500 J/kg was depicted and extended from eastern Nebraska into southern Minnesota. CAPE values calculated from the 00 UTC radiosondes were too sparse to capture this feature. Just after 02 UTC an F-2 scale tornado (winds between 182 and 253 km h^{-1}) was reported in northern Iowa (Storm Damage Report 1999).

Real-time examples of both retrieved moisture and stability information as well as cloud top pressures can be seen on the CIMSS web page at http://cimss.ssec.wisc.edu. Another site with real-time GOES sounder products supported by the NOAA/NESDIS Forecast Products Development Team is http://orbit-net.nesdis.noaa.gov/goes/.

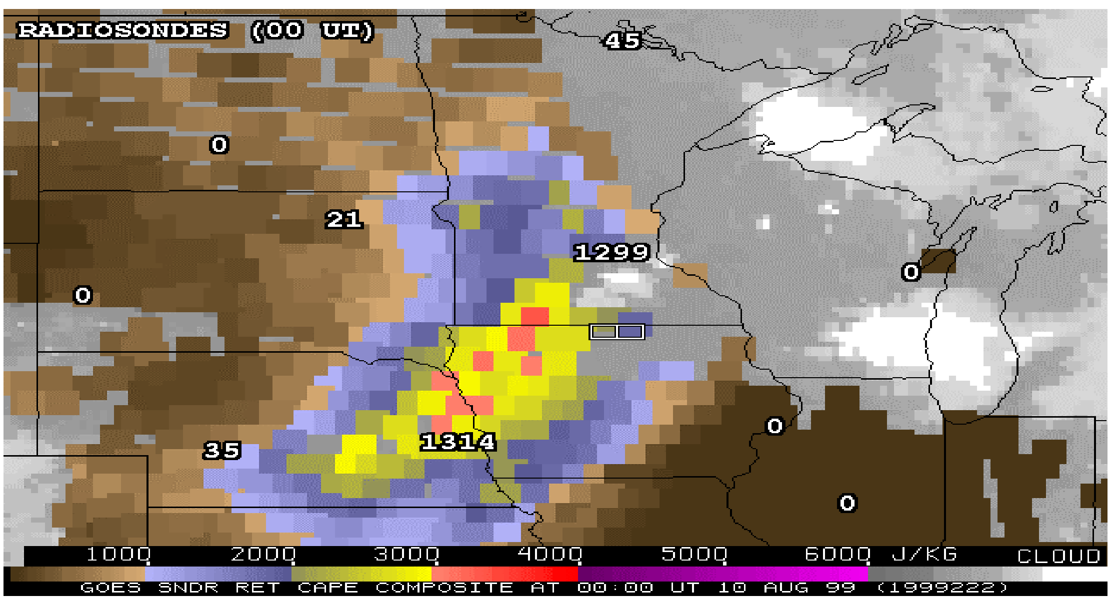

Figure 4. GOES-8 Sounder Convective Available Potential Energy (CAPE) values at 00 UTC on 10 August 1999.

IIIe. Soundings Research Areas

During the winter of 1999/2000, the improved cloud detection subroutine was tested. Several short-wave channels have been incorporated to help distinguish snow from cloud. The algorithm is based on the decreasing reflectivity of the shortwave channels with increasing wavelength. Positive results have lead to plans for operational implementation in the coming year.
At the current time, the recently launched GOES-11 sounder is being evaluated. Early indications are that the GOES-11 sounder is less noisy and has less striping than the operational GOES-8 sounder.

In order to study the effects of surface emissivity in profile retrievals from infrared multispectral radiances winter and summer cases studies have been conducted. To improve the accuracy of vertical profiles of temperature and moisture retrieved from infrared spectral measurements, the surface emissivity must be accounted for in the solution of the inverse problem (based upon the radiative transfer equation). The mathematical basis for the algorithm for retrieving temperature and moisture profiles, while accounting for the surface emissivity, are described in Plokhenko and Menzel (2000). That algorithm has been applied to spectral measurements from the MODIS Airborne Simulator (MAS) over winter and summer land surfaces. The surface emissivity and temperature are estimated directly from the infrared multispectral radiances. Vertical temperature-humidity profiles generated with and without surface emissivity consideration were compared; accounting for the surface emissivity in the solution of the inverse problem substantially and positively changes the meteorological profiles.

In the summer case study of a moist warm inhomogeneous atmosphere over a vegetated surface, estimation of single field of view variations in the surface emissivity produces a smoother more physical solution for the atmospheric moisture fields (see Figure 5) The retrieved surface temperature was negatively correlated within 0.8 to a vegetation index (more vegetated yields colder temperature). In this winter case study of a cold dry homogeneous atmosphere over a frozen surface, multispectral variations in surface emissivity are resolved along with a relatively constant surface temperature. The retrieved surface emissivity is positively correlated within 0.7 to a snow index. These MAS case studies reveal that (a) the surface emissivity is one of the strongest varying parameters in the RTE for infrared remote sensing; (b) an assumption of fixed emissivity is not effective for retrieving temperature and moisture profiles because the surface emissivity is a function of the angle of incidence and the composite cover of the surface; and (c) emissivity errors distort the atmospheric parameters primarily in the lower troposphere.

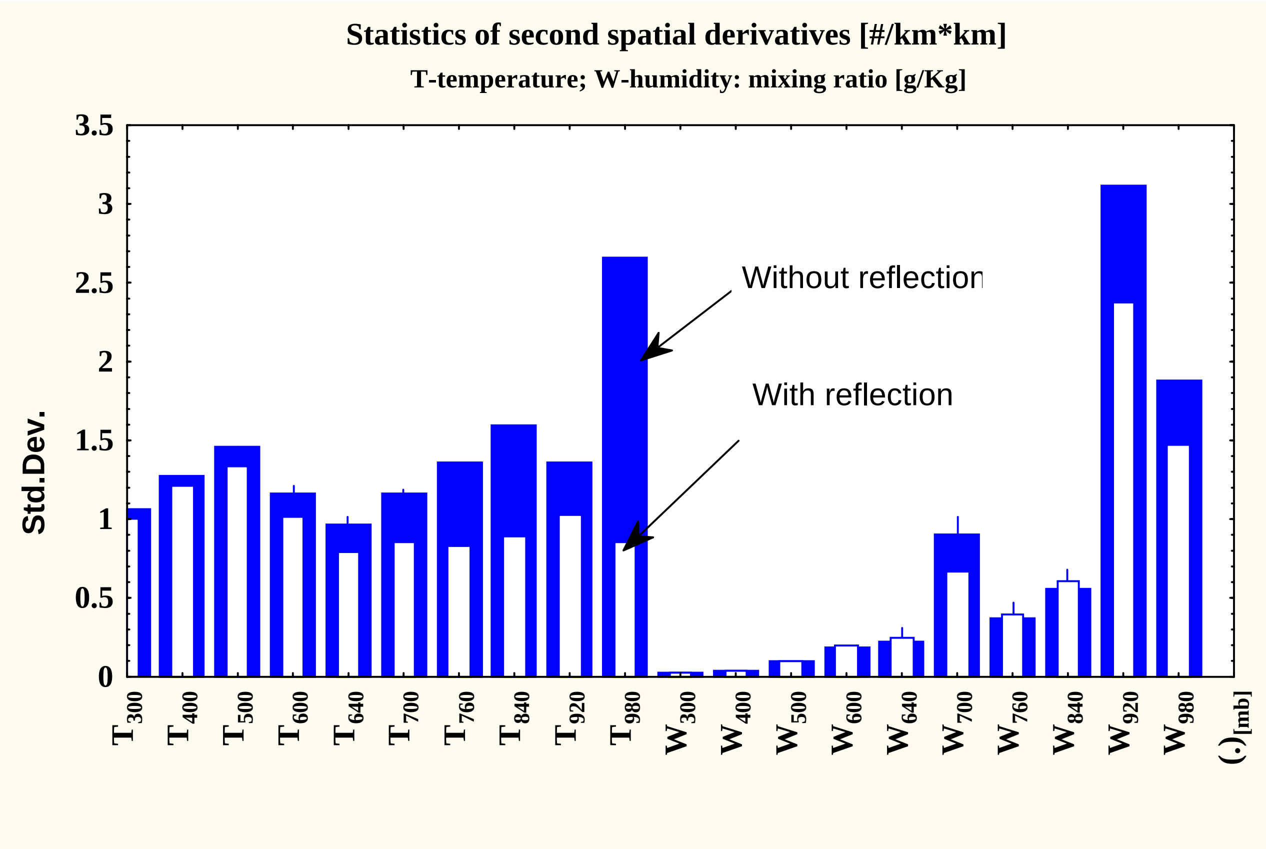

Figure 5. Stability of the solution for the two algorithms (with and without surface reflection) as measured by the standard deviation of the second derivative of the horizontal variation of temperature or mixing ratio at a given level of the atmosphere. Smaller values are more stable and hence better depicting the actual atmospheric state. Case study data are MAS flight over Kansas / Oklahoma on 12 April 1996.

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