GOES Infrared Sounders – the current applications and future needs

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Abstract

Since 1994 Geostationary Operational Environmental Satellite (GOES) Sounders (from GOES-8 to GOES-13) has been measuring broad band radiances in 18 infrared (IR) spectral bands, ranging from approximately 3.7µm – 14.7 µm. These data have been used to provide atmospheric and cloud products for meteorological applications on an hourly basis over North America and adjacent oceanic regions. The products include clear-sky radiances, atmospheric temperature and moisture profiles, total precipitable water, cloud-top pressure, water-vapor tracked winds, etc. Products are generated operationally by NOAA/NESDIS in Washington, D.C. Some Sounder products, including total column ozone (TCO), are also produced at the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin-Madison (UW-Madison). Applications of those products include: nowcasting and forecasting of weather events, assimilation of cloud products into regional numerical forecast models, and monitoring of temperature and moisture changes in the pre-convective periods. One unique application of the current GOES Sounder products is the severe weather forecast, hourly GOES Sounder data of a hail storm happened in Madison, Wisconsin on 13 – 14 April 2006, were used to illustrate the unique value of the GOES Sounder measurements in short range severe weather forecast.

However, due to the lower spectral resolution and slow coverage rate of the current GOES Sounder, the information such as lower level temperature inversion,

surface emissivity, and vertical resolution, etc. is limited. There is requirement for the operational advanced IR sounding system on future geostationary satellite. The increased spectral, temporal and spatial resolutions of the hyperspectral geostationary sounder (GHS) will provide a substantial increase in the quantity and quality of the products. The GHS will provide high-spectral resolution Hemispheric Disk Soundings (DS) with spatial resolution better than 10 km spatial resolution. The GHS will be a flexible instrument that can provide hourly coverage of the near full disk, or provide more frequent coverage of smaller areas. The latter will be used when there is the potential for explosive development of severe thunderstorms, hurricanes, or severe winter storms. It can also be used over areas where the numerical forecast models have low confidence (targeted observations). IR data from the GHS will be used for: 1) providing an accurate, hourly three-dimensional picture of atmospheric temperature and water vapor: 2) tracking atmospheric motions by discriminating more levels of motion and assigning heights more accurately; 3) possibly distinguishing between ice and water cloud and identifying cloud microphysical properties; 4) providing a 5 km field of view (FOV) for better viewing between clouds and cloud edges; 5) providing accurate land and sea surface temperatures and IR surface emissivities; 6) distinguishing atmospheric constituents with improved certainty, including dust, volcanic ash and ozone; and 7) detecting clear-sky low-level atmospheric inversions. The GHS will be able to provide higher spectral resolution observations (on the order of 1 cm^{-1}, compared to 20 cm^{-1} on today's broadband GOES sounder).

Aspects of improvement of GHS over the current GOES Sounder includes: spatial coverage, vertical moisture information, nowcasting, numerical weather prediction, clouds, winds, dust/aerosols, trace gases, climate, ocean/land. With the improved spectral resolution, an improved surface emissivity can also be estimated. Current and future applications of GOES Sounder and GHS are demonstrated and compared in this paper by using the current satellite and aircraft measurements as well as simulated data.

1. Current GOES Sounder operational products and applications

There is variety of GOES Sounder products produced operationally; those products are used in the numerical forecasting and nowcasting. Table 1 lists the operational GOES Sounder products and their applications. For example, one of the primary applications of GOES IR sounding product is to determine the atmospheric vertical structure such as Lifted Index (LI) or CAPE (Convective Available Potential Energy) inversions in the region of pre–convective events.

Table 1. Operational GOES Sounder products and their applications.

GOES Sounder Product	*Operational Use within the NWS*
Clear-sky Radiances	**Assimilation into** NCEP operational regional & global NWP models over water
Layer & Total Precipitable Water	**Assimilation into** NCEP operational regional & global NWP models; **display and animation within** NWS AWIPS for use by forecasters at NWS WFOs & National Centers in forecasting precipitation and severe weather
Cloud-top retrievals (pressure, temperature, cloud amount)	**Assimilation into** NCEP operational regional NWP models; **display and animation within** NWS AWIPS for use by forecasters at NWS WFOs; **supplement to** NWS/ASOS cloud measurements for generation of total cloud cover product at NWS/ASOS sites
Surface skin temperature	**Image display and animation within** NWS AWIPS for use by forecasters at NWS WFOs
Profiles of temp & moisture	**Display (SKEW-Ts) within** NWS AWIPS for use by forecasters at NWS WFOs in forecasting precipitation and severe weather
Atmospheric stability indices	**Image display and animation within** NWS AWIPS for use by forecasters at NWS WFOs in forecasting precipitation and severe weather
Water Vapor Winds	**Image display and animation within** NWS AWIPS for use by forecasters at NWS WFOs

A hail storm case is studied to demonstrate the utilization of GOES Sounder data in severe storm forecasting and now casting. The hail storm of April 13 – 14, 2006 caused damage to many houses in Madison area in Wisconsin. The storm produced large hails. The GOES Sounder 11 μm image at 22 UTC on 13 April shows that a super cell is likely to be developed. The multispectral band classification (Li et al. 2003) shows that there are typical four classes (4, 5, 6, 10) of clear air mass surrounding the super cell (see Figure 1), two hours later (00 UTC on 14 April) the class 10 moves toward east while class 6 move towards north. The clear sky atmosphere is very unstable from 22 UTC to 00 UTC, and the super cell starts to develop. From 00 UTC on 13 April to 02 UTC on 14 April, the air mass continue to move (classes 6 and 10), and the super cell develops fast and becomes convective system. The soundings observed by GOES Sounder before and during the convective storm are very useful for short range storm forecasts.

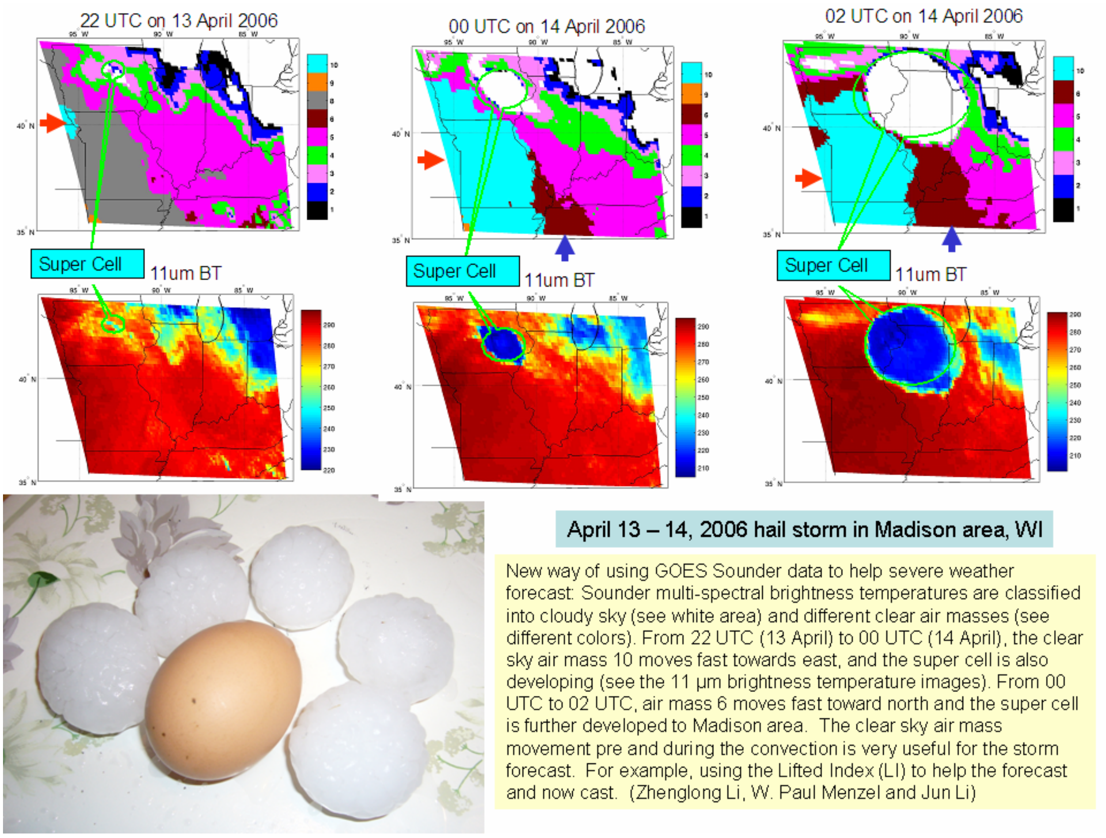

Figure 1. Clear air mass classes from clustering (upper panels) and 11 µm brightness temperature images at 22 UTC on 13 April, 00 UTC and 02 UTC on 14 April 2006.

In addition to the operational products, there are lots of research products being developed. For example, total column ozone (TCO) product is now produced hourly in near real time at the Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin (Li et al. 2007). Figure 2 shows a case study of OMI ozone (upper right), GOES-12 Sounder TCO (lower right), and the scatterplot between OMI ozone measurements and GOES-12 SFOV TCO retrievals on 12 February 2006. Good agreement was found in both the distributions and the magnitudes between OMI ozone measurements and GOES-12 Sounder TCO retrievals, revealing the good quality of the GOES Sounder new SFOV TCO product.

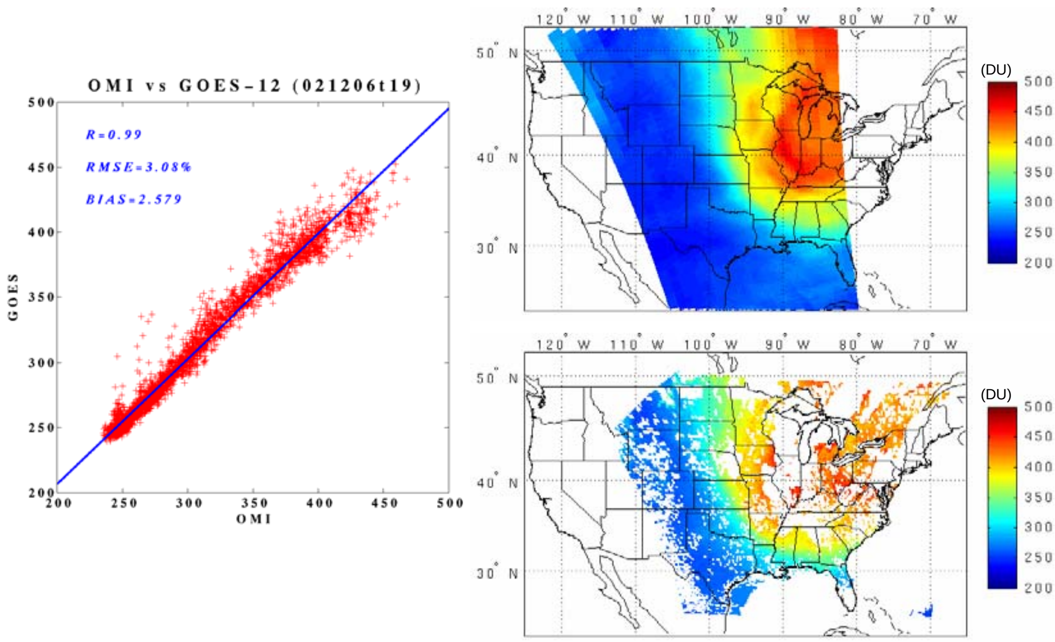

Figure 2. OMI ozone (upper right), GOES-12 Sounder TCO (lower right) at 19 UTC on 12 February 2006 and scatterplot between OMI ozone measurements and GOES-12 Sounder TCO retrievals (left).

2. ABI continuation of current GOES Sounder products

Since the Advanced Baseline Imager (ABI) will fly before GHS, it is very important to study the continuation of the current GOES Sounder operational products. The needed ‘continuity’ products (radiances, TPW, LI, skin temperature, clouds, winds) from today's sounder can be provided by the ABI, although, the ABI is still not a sounder! It is demonstrated that when average ABI to 10 km field-of-regard (FOR), the moisture sounding performance is close to the current GOES single field-of-view (FOV, 10 km) moisture sounding performance. However, the temperature soundings from ABI are much worse than that from the current GOES Sounder due to limited CO_2 absorption bands in ABI.

The alternative of sounding product using combined ABI and forecast is also investigated. The retrieval simulation is performed with radiosonde observations (RAOBs) over the Continental United States (CONUS) with lifted index less than zero. The TPW retrieval simulation from approximately 300 unstable atmospheric profiles shows that

(1) ABI (within 10 km FOR) alone is slightly worse than the forecast, while the current GOES Sounder alone is better than the forecast. HES (Hyperspectral Environmental Suite) alone is much better than both forecast and the current GOES Sounder alone. See Figure 3a for details.

(2) ABI + forecast is similar to GOES Sounder + forecast, both are better than forecast. HES + forecast is much better than either ABI + forecast, or GOES Sounder + forecast. See Figure 3b for details.

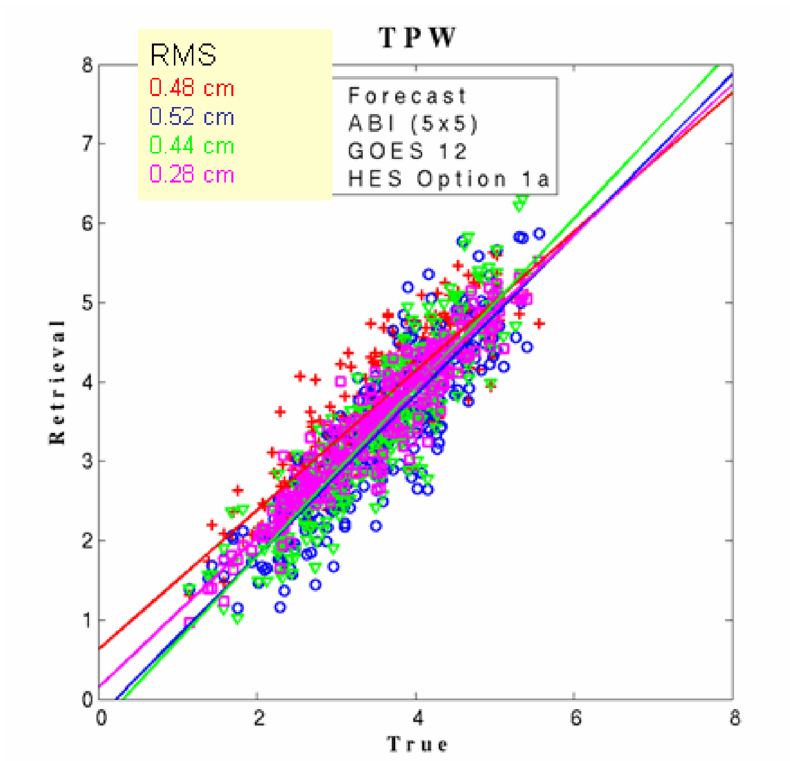

Figure 3a. Scatterplot between true TPW and retrieved TWP with ABI, GOES-12 Sounder and HES.

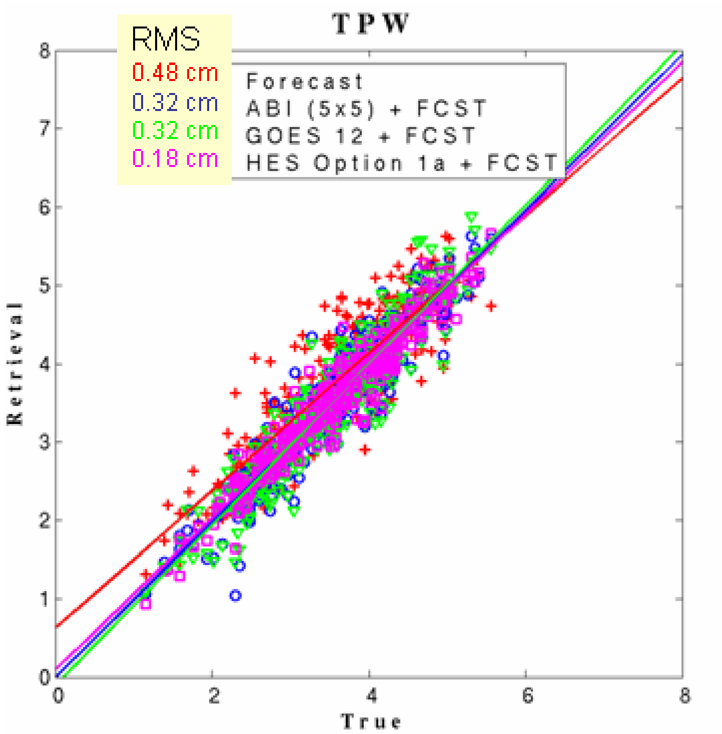

Figure 3b. Scatterplot between true TPW and retrieved TWP with ABI + forecast, GOES-12 Sounder + forecast and HES + forecast.

3. Future needs

Due to the current sounders' lower spectral resolution, the accuracy for sounding products from the current GOES Sounder is limited (~2 K for temperature and 20% for water vapor relative humidity). Since there is sounding requirements (1 K for temperature and 10% for water vapor relative humidity) for the future GOES sounding system, GHS is needed to obtain high spatial and temporal resolution 3-D atmospheric temperature and moisture soundings with high accuracy. Improved products include temperature and moisture soundings, surface skin temperature. The new products include surface emissivity spectra, tropospheric ozone vertical distribution, and trace gases. The hyperspectral sounding capability is also verified by Atmospheric InfraRed Sounder (AIRS). Figure 4 shows the AIRS brightness temperature spectrum (upper), AIRS sounding retrieval (light blue line, CIMSS version) and best estimated profile (blue, truth) at the ARM Cart Site. The retrieval starts with a smoothed first guess (red), and the vertical structures of temperature and moisture are captured by AIRS measurements. Those vertical structures are very important for short range and regional forecast.

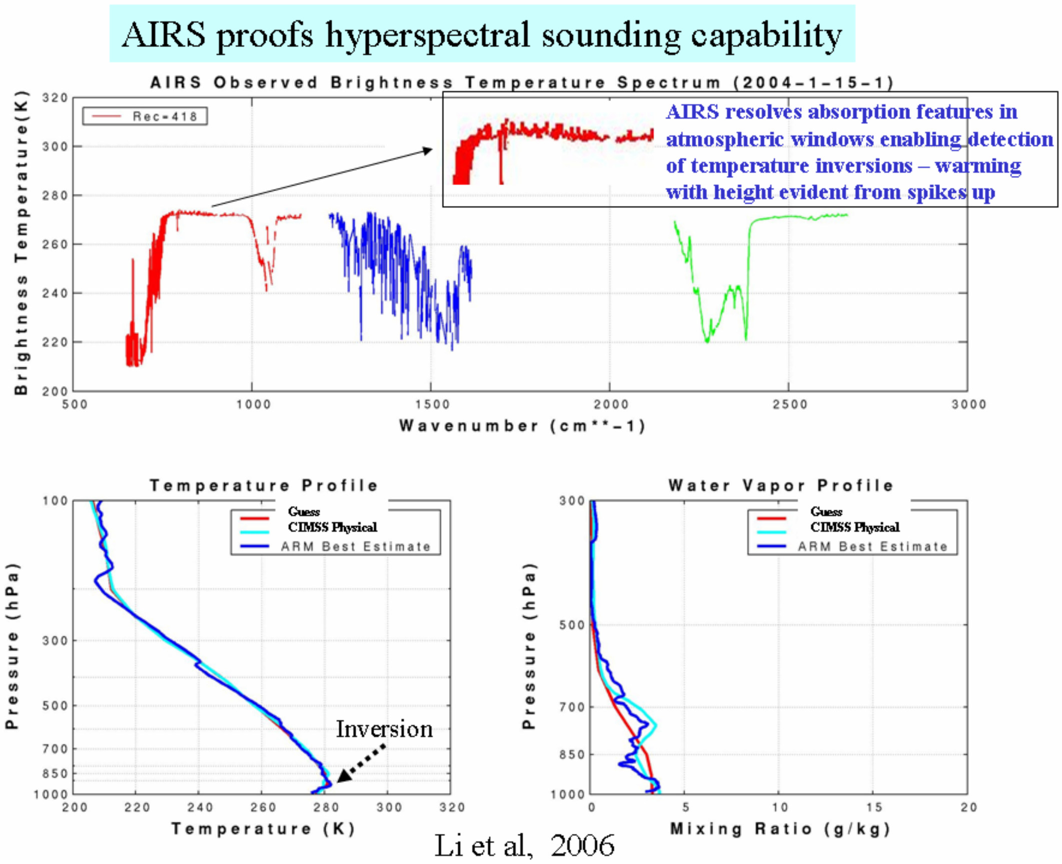

Figure 4. The AIRS brightness temperature spectrum (upper), AIRS sounding retrieval (light blue line, CIMSS version) and best estimated profile (blue, truth) at ARM Cart Site.

With GHS, the cloud-top property and above-cloud sounding can be retrieved simultaneously with a cloudy radiative transfer model. Results are promising when compare the above-cloud sounding retrievals with ECMWF analysis (not shown here). Specifically, the cloud-top pressure (CTP) retrievals from AIRS single footprint agree very well with the operational MODIS (Moderate Resolution Imaging Spectroradiometer) CTP product. Note that MODIS CTP product uses sounding profiles from global forecast, while AIRS above-cloud sounding approach retrieves CTP and above-cloud sounding simultaneously. Figure 5 shows the AIRS CTPs (13.5 km spatial resolution at nadir) from above-cloud sounding approach (left panel) and the operational MODIS CTP product (5 km spatial resolution at nadir) (right panel).

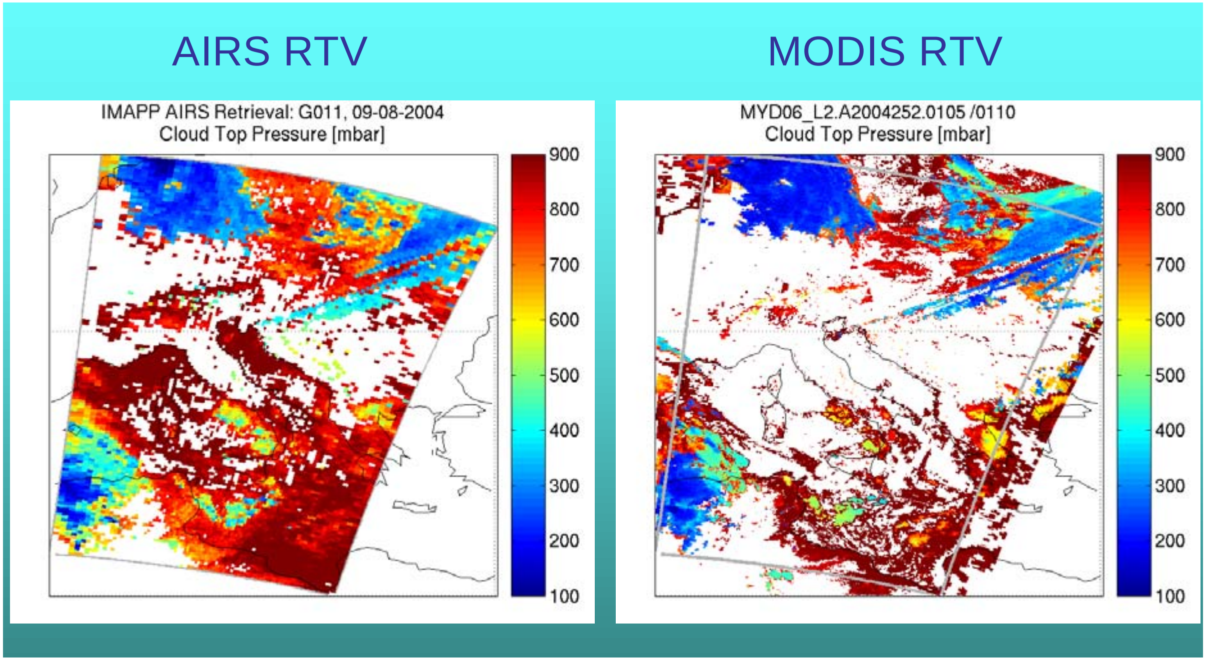

Figure 5. AIRS CTPs (13.5 km spatial resolution at nadir) from above-cloud sounding approach (left panel) and the operational MODIS CTP product (5 km spatial resolution at nadir) (right panel).

4. Summary

High-spectral-resolution infrared radiance measurements from the geostationary perspective remain a high priority in the evolution of the GOES observing capability. These advanced sounders will have hundreds of channels with spectral widths less than a wavenumber; the current GOES Sounders have 18 bands with spectral widths of tens of wavenumbers. It is expected that they will improve geostationary sounding capabilities by expanding the hourly spatial coverage, increasing the vertical temperature and moisture sounding resolution, capturing atmospheric motions at many more levels, and penetrating the boundary layer to depict small scale temperature and moisture changes. These improved capabilities will significantly impact nowcasting, short-range weather forecasting, and longer-range numerical weather prediction.

While tradeoffs between area coverage, spatial resolution, and frequency of observation continue to be discussed, there is a need for large scale (hemispheric) hourly sounding as well as small scale (1000 x 1000 km) every five minute sounding directed to regions where severe thunderstorms, hurricanes, or severe winter storms are pending or to areas targeted by numerical forecast models.

The next GOES Sounder will have goals that include (1) identifying small scale features of moisture vertically and horizontally; (2) detecting clear-sky low-level atmospheric inversions; (3) tracking atmospheric motions in more levels with accurate height assignments; (4) providing better viewing between clouds and near cloud edges; (5) enabling accurate land and sea surface temperature determinations in addition to IR surface emissivity estimates; (6) distinguishing atmospheric constituents with improved certainty, including dust, volcanic ash, and ozone.

Acknowledgement

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References

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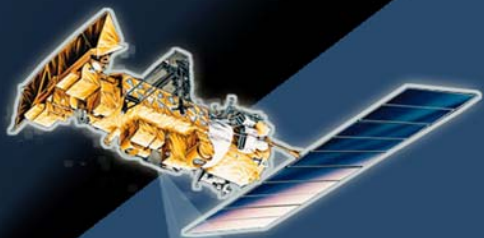

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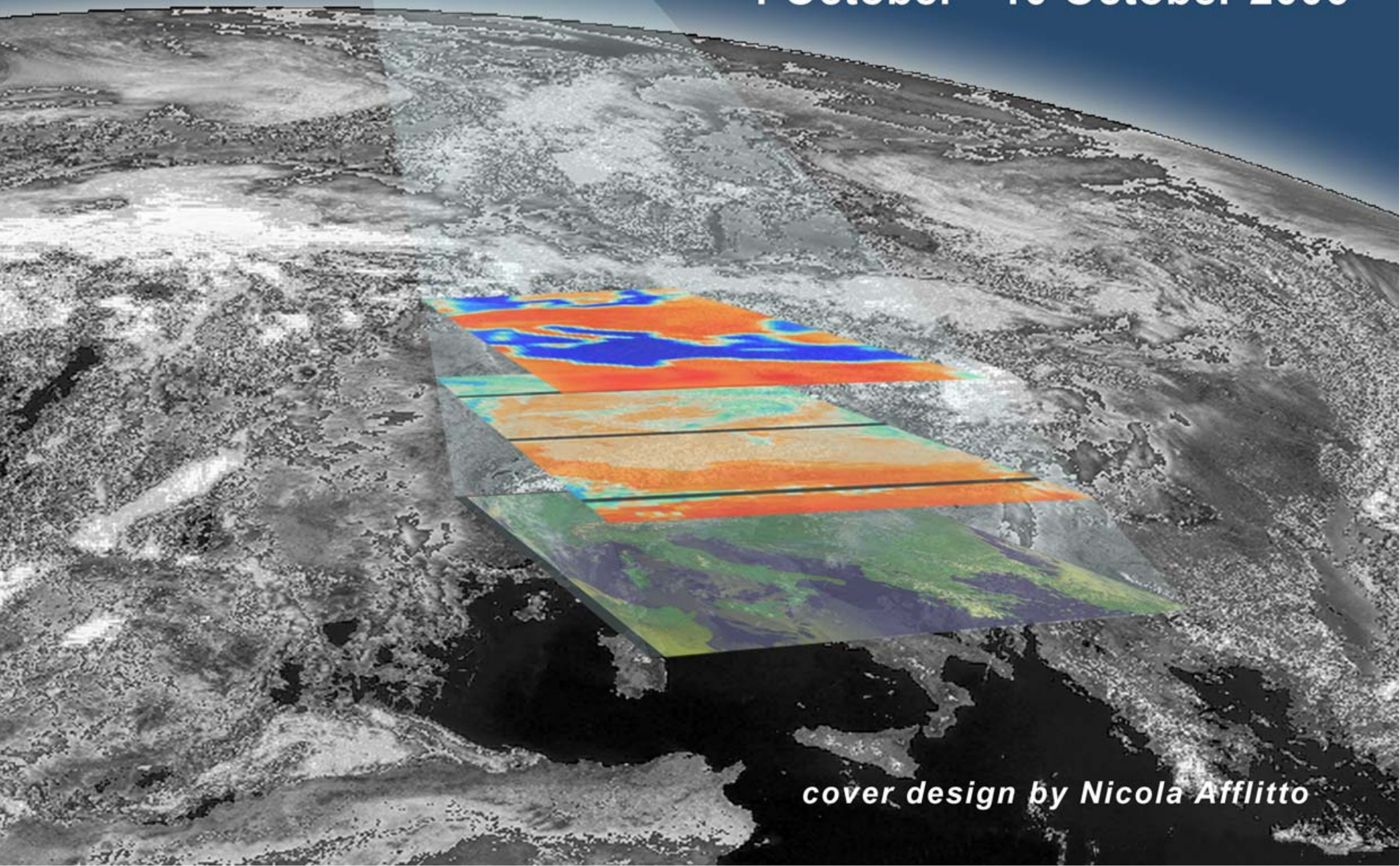

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