**Advanced geostationary sounders are needed   
to significantly enhance capabilities for issuing crucial pre-storm warnings**

*Principal Author: Henry E. Revercomb*

*Co-authors: William L. Smith, W. Paul Menzel, Timothy J. Schmit, Mitch Goldberg, Ralph Petersen, Jun Li, David C. Tobin, Robert O. Knuteson, Joe K. Taylor, Steven A. Ackerman, Jeffrey R. Key, Dave Santek, Jordan Gerth, Grant W. Petty, Gregory J. Tripoli, Tristan L'Ecuyer, Robert Rabin, William D. Collins, Martin G. Mlynczak, Henry Buijs*

*1. What are the key challenges or questions for Earth System Science across the spectrum of basic research, applied research, applications, and/or operations in the coming decade?*

A key challenge for operational weather forecasting is ***making timely, credible, location-specific, severe weather warnings.*** While warning on forecast lead times for mid-continental severe weather have been roughly doubled recently by making better use of existing data (see Section 1.b.), frequent measurements containing more information about pre-storm atmospheric stability and moisture gradients, both horizontal and vertical, are needed to move from warning times of order tens of minutes to warnings of greater than an hour. The high value of earlier warnings for protecting people and property is made shockingly apparent during every tornado season in the mid-section of the United States. Collecting the required rapid sampling information (order of minutes) with high spatial resolution and continental scale coverage is a job for satellite-based observations from geosynchronous orbit, clearly making this a challenge for joint action by NASA and NOAA (The NASA Authorization Act of 2015 states that “[NASA] shall continue to develop first-of-a-kind instruments that, once proved, can be transitioned to other agencies for operations”).

A space-borne system to answer this challenge was highly recommended in the 2007 Decadal Survey, but unfortunately it became “the forgotten recommendation”. The Survey strongly supported implementing an advanced imaging sounder that would provide high resolution spectra of Earth emitted radiances from which high vertical resolution temperature and water vapor profiles could be obtained on an imaging grid with 4-5 km pixels covering about 500 km squares in 12 seconds.

Specifically, the Executive Summary on pages 5-6 stated that “*NOAA should restore several key climate, environmental, and weather observation capabilities to its planned NPOESS and GOES-R missions; namely*:” followed by 4 bullets. The 4th was **“***Develop a strategy to restore the previously planned capability to make high-temporal- and high-vertical-resolution measurements of temperature and water vapor from geosynchronous orbit*,” followed by:  
**“***the committee recommends consideration of the following approaches:*

* *Working with NASA, complete the GIFTS instrument, deliver it to orbit via a cost-effective launch and spacecraft opportunity, and evaluate its potential to be a prototype for the HES instrument, and/or [the Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) is a NASA sponsored prototype built with New Millennium Program support]*
* *Extend the HES study contracts focusing on cost-effective approaches to achieving essential sounding capabilities to be flown in the GOES-R time frame.”*

While these specific approaches may no longer be applicable, these statements show how seriously the implementation of these “essential sounding capabilities” was taken. The operational need is still unmet, and a joint commitment by NASA and NOAA should be made to fill the void. Also, the detailed industry studies of the Hyper-spectral Environmental Suite (HES) instrument design are available for providing cost and risk information for the new Decadal Survey (See section 1.a.).

Regarding the efficacy of the high vertical resolution information from high spectral resolution IR data, the case has been made even more strongly than was known when the earlier survey was written, a time when the NASA EOS AIRS was relatively young. Since then two new types of advanced polar-orbiting, operational sounders have been successfully vetted (IASI on MetOP A and B starting in 2006 and 2012, and CrIS on Suomi NPP starting in 2012). ECMWF has ranked the forecast impact of each individual hyper-spectral IR sounder to be higher than that of any other single instrument, highlighting the value of increased vertical resolution. This performance from polar orbit clearly demonstrates the capability of this type of measurement for determining atmospheric stability from GEO.

*a. Whether existing and planned U.S. and international programs will provide the capabilities necessary to make substantial progress on the identified challenge and associated questions. If not, what additional investments are needed?*

There are no credible plans to fly a GIFTS- or HES-like instrument with coverage over the United States. While two commercial ventures have received licenses from the Department of Commerce permitting them to provide this capability worldwide (GeoMetWatch, and Tempus), these endeavors have become bogged down in legal issues, have not demonstrated the availability of necessary financial resources, and cannot now be relied on for timely and predictable implementation.

No other type of observation, existing or planned, can perform the rapid atmospheric stability observations on the fine spatial scale possible from geostationary orbit. The capabilities of this type of instrument are unique. Polar high spectral resolution sounders have inadequate temporal coverage. GPS-RO has inadequate spatial resolution (as well as temporal resolution currently). The present GOES sounder has inadequate vertical resolution and is not being continued on GOES-R. The GOES-R imager has inadequate vertical resolution, as would a future geosynchronous microwave sounder. Comparing GIFTS to the present GOES sounder, the vertical resolution is 3 times higher, the spatial footprint area is 6.3 times smaller (4 km compared to 10 km), and the temporal coverage is 5.5 times faster; yielding a factor of 100 more detail in space and time.

Other countries are pursuing this capability, but of course this will not provide coverage over the US. China is planning to fly a series of Geostationary Interferometer Infrared Sounder (GIIRS) instruments on FY-4 (A in 2016, B in 2018, C in 2020) with capability approaching that of GIFTS by FY-4C. Also, a European advanced IR sounder (IRS) similar to GIFTS will be a key part of Meteosat Third Generation with a planned sounder launch in about 2021. We expect these efforts to succeed, but clearly they will not fulfill the needs for severe weather warnings in the US and will not fulfill WMO recommendations for a global constellation of advanced Geostationary IR Sounders.

Regarding the additional investments needed, credible cost estimates were produced under the NOAA/NASA HES program. It is our understanding that the cost for 4 instruments was on the order of $ **½** B and that there were no high risks. Specifically, the 2007 NOAA *Analysis of Alternatives* after the GOES-R sounder was de-manifested categorized (1) Performance, (2) Space Development/Integration, (2) Schedule for 2014 free flyer, and (4) Ground System to all be low risk and the cost risk for demo mode to be moderate. The Decadal Survey should strongly recommend a NASA pathfinder to reduce cost risks for the ultimate NOAA operational system.

*b. How to link space-based observations with other observations to increase the value of data for addressing key scientific questions and societal needs*

A new approach developed as a NOAA/CIMSS research product called ProbSevere is a great example of increasing the value of data by combining space-based and other observations to address the key challenge of improving severe storm warning times. ProbSevere uses optimum estimation on historic weather records to extract the information needed to produce earlier warnings from a combination of radar, NWP, and GOES data. It has been demonstrated to roughly double warning times by adding an extra 10 minutes. While a hugely positive development, significantly longer warn on forecast times would clearly be extremely valuable, and adding advanced sounder data to ProbSevere may be a good approach when they becomes available.

*c. The anticipated scientific and societal benefits*

The anticipated societal benefits of the advanced sounder are tied to the protection offered to life and property by forecasts with more accurately located regions of severe weather, issued over an hour in advance of tornadic and other life threatening events. An OSSE based on WRF model simulations on a 2 km grid with realistic clouds for 12-13 June 2002 has demonstrated these extended warning times. Comparisons of advanced sounder performance were made with model truth, GOES-R imager performance, and radar; using lifted index less than -9 as the indicator of likely severe weather for the satellite data. The advanced sounder (1) significantly reduced false alarms from using GOES-R imager data, (2) provided substantially better location agreement with truth, (3) began seeing evidence for severe weather even eight hours before the radar started to detect rain, and (4) provided an accurate depiction of severe instability several hours in advance of severe weather.

It is expected that the implementation of improved forecasts will initially use a technique called nearcasting that makes use of model winds combined with measured stability, and will transition to using data assimilation techniques for regional models.

*d. The science communities that would be involved.*

The advanced sounder approach to addressing this key challenge would clearly involve the communities connected to NOAA weather research and satellite data product developments, along with NASA Earth System Science and instrument development, and university atmospheric sciences and remote sensing expertise.

*2. Why are these challenges/questions timely to address now especially with respect to readiness?*

This highly valuable capability is seriously overdue. Readiness was proven by the GIFTS prototype and supplemented by the HES industry studies and demonstrations. And we are falling behind the rest of the world in this arena that we pioneered.

*3. Why are space-based observations fundamental to addressing these challenges/questions?*

Space-based observations from geosynchronous orbit are especially well suited to providing the detailed and comprehensive spatial coverage and rapid sampling needed to meet this challenge.

While planning for GOES-R, NOAA sponsored cost/benefit studies that documented the large expected value of the system and about half of the benefits were attributed to the sounder, not present on the current system. The sounder will help reach the goal of a “Weather Ready Nation", which will not be met until storm warning lead times are extended into hours.