**Advanced high-spectral resolution infrared geostationary observations**

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Description:

There are many potential uses for advanced high-spectral resolution infrared geostationary measurements: radiances, vertical moisture, atmospheric instability, improved atmospheric motion vectors, surface emissivity, cloud properties aerosols and trace gases. The geostationary perspective allows for a rapid refresh. There is a gap over the U.S.

Body:

A challenge is to better observe the vertical distribution of moisture on fine space and time scales, a key measurement for understanding dynamical and physical weather processes, especially for convection. These observations are needed to better monitor and predict rapidly changing conditions, often associated with convective-scale weather events.

Improved global observations of the vertical distribution of both temperature and moisture on large scales has been achieved using advanced infrared high spectral resolution sensors in low earth orbit (e.g., AIRS, IASI, and CrIS). These measurements allow for a better understanding of many atmospheric processes (Wulfmeyer et al, 2015). The largest impact of a given sensor in global Numerical Weather Prediction (NWP) is the polar-orbiting advanced infrared sounder. It is these advances, in both the data and techniques to use the data that highlight the path forward to the geostationary orbit. While the polar-orbiting measurements offer global coverage, the refresh rate is fairly slow over a given location. Adding a finer time dimension associated with a geostationary orbit will bring similar improvements to the meso and regional scales. The sensor technology has matured and can now be applied to the geostationary perspective. Having similar observations from the geostationary perspective allows monitoring moisture on the same time scales that it changes on.

Several critical science questions remain, including: “How do convective-scale and large-scale

circulations interact? What determines the mesoscale organization, internal structure and dynamics, and life cycle of convective systems? What modulates the rate at which convective storms (of all types) intensify to produce severe weather, tornadic storms, lightning, and other hazards?” (NASA Weather Workshop Report, 2015). There are many potential uses for advanced high-spectral infrared geostationary measurements to help answer these and other questions. A high spectral (and hence vertical) resolution IR sounder with faster scanning is able to monitor important low-level information about the atmosphere and thus substantially improve the capability to forecast severe weather. The time sampling from the geostationary perspective and the high spectral resolution leads to many uses including: radiances for NWP, vertical moisture (near-casting), atmospheric instability for pre-convection situational awareness, improved atmospheric motion vectors, surface characterization, skin temperature, cloud properties, air quality and trace gases (ozone, SO2, etc.).

A high-spectral-resolution infrared (IR) sounder, originally called the Advanced Baseline Sounder (ABS) and then the Hyperspectral Environmental Suite (HES), was slated to be on GOES-R as a companion to the ABI. In 2006, predominately because of budgetary pressure, the HES was removed from the GOES-R series. The scientific objectives for the instrument were justified. The many HES-related validation requirements remain unmet. In fact, when an ‘analysis of alternatives’ was investigated after the cancellation of the HES, it was determined that there was nothing else that could fill the observational hole, with respect to the measurements and derived products.

The World Meteorological Organization (WMO) has stated the need for advanced geostationary sounders (WMO 2004; WMO 2009). This is consistent with the recommendations from a National Research Council (NRC) decadal study report to ‘‘develop a strategy to restore the previously planned capability to make high temporal- and vertical-resolution measurements of temperature and water vapor from geo orbit’’ and to achieve ‘‘essential sounding capabilities to be flown in the GOES-R time frame’’ (NRC 2007). EUMETSAT has documented, vetted and accepted the need for these advanced geostationary high time, high spectral measurements (EUMETSAT). Their first planned operational sensor (IRS: Infrared Sounder) is 2021. China’s plans call for an experimental advanced geostationary sensor (2016), followed quickly by two operational sensors. There is a great void over the Americas. No existing, nor planned, U.S. or international programs will provide high spectral resolution infrared observations over the Americans on the scales of an hour (or finer) and 10 km (or finer) spatial resolutions. High-spectral resolution infrared sensors operated in the geostationary orbit by the US would constitute the US contribution to this international effort.

The NWS (NWS Operational Requirements Document for the Evolution of Future NOAA Operational Geostationary Satellites, 1999) reiterated that the requirement for at least one temperature and humidity sounding every 10 km (single FOV pixel soundings to enhance mesoscale sounding capabilities) in clear areas at least every hour. The goal for the moisture profile accuracy was +/- 5%, implying high-spectral resolution. As technology advances, it is anticipated that there will be additional future requirements for sounding capability for measurements within areas of extensive cloud cover. This has the benefit of allowing the monitoring of rapidly changing precondition situations, particularly threshold values, for forecasting severe weather conditions. According to a National Weather Service (NWS) memo from September 15, 2010, the need for an advanced geostationary infrared geostationary sensor was the top request in the geostationary orbit, including the “advantage of the increase in temporal refresh”.

These advanced space-based observations would not be used alone, but fused with other measurements. For example, numerical weather prediction output, surface and aircraft observations and other satellite measurements have been fused and analyzed with today's low spectral resolution geostationary sounders. The increasingly fine space and time resolution of regional models need improved data to initialize the fields and the rapid refresh from the geostationary is needed for improving regional models. Much larger positive impact is expected due to increased vertical resolution, surface emissivity, cloud characterizations and better definition of low level moisture. A former director of NOAA’s NCEP has stated “…the more you repeat the information inflow into the numerical prediction system (the 4th “D” in 4DVAR) the more the model should hold onto that info and sustain the more accurate model results from run to run. Given the proposed temporal resolution of the GOES HES, this observing system should be a natural for any 4 D assimilation system.” A number of Quick OSSEs have demonstrated the utility of high spectral resolution infrared measurements (Li and Lui, 2009; Lui and Li, 2010; Wang et al, 2015; Jing et al, 2014).

The anticipated scientific and societal benefits are large, estimated to be in the billions of dollars. Recent results show that the potential additional [over the current GOES] socioeconomic benefits for an advanced (high spectral resolution) sounder are estimated to be $4.2 billion (U.S. dollars net present value; Bard et al. 2008). The $4.2 billion estimate may be conservative because only five economic sectors were included. These values change if less conservative assumptions are used for the discount rate and/or inflation rate. In addition, the benefits to a host of users or application areas were not included in the studies, such as the Department of Defense or international users, nor were applications related to human health or other agricultural sectors. (Schmit et al, 2009).

The science communities that would be involved cover many phenomena. This include, but are not limited to: pre-convection profiles and warnings (Huang et al, 1992; Wang et al, 2007; Li et al. 2012), hazards (volcanic plumes (Ackerman et al, 2008); dust (Sokolik et al, 2002) and aerosols), land (surface emissivity (Li et al, 2012) and skin temperature), and the atmosphere (moisture (Smith and co-authors, 1990), clouds (Smith et al, 1993; Holz et al, 2006)), atmospheric motion vectors, air quality (Fishman et al, 2008), aviation safety, trace gases (Barnet et al, 2004), and infrared calibration (Tobin et al, 2006), etc). These communities would be international in scope, building on the experiences of EUMETSAT and others.

A path forward is clear that leverages earlier work, both in terms of the instrumentation and the data uses. As was stated by Hayden and Schmit, 1991 “...there seems little question that high spectral resolution, geostationary sounding will come eventually”. The need for these measurements is evident, and the instrument approach is known, the time is now to fill in this large observational void.

References:

Ackerman et al, 2008: doi:10.1029/2007JD009622.

Bard, S. K., T. A. Doehring, and S. T. Sonka, 2008: http://ams.confex.com/ams/pdfpapers/135746.pdf.

Barnet et al, 2004: SPIE Proceedings, Vol. 5548

EUMETSAT: <http://www.eumetsat.int/website/home/Satellites/FutureSatellites/MeteosatThirdGeneration/MTGDesign/index.html>

Fishman et al, 2008: http://dx.doi.org/10.1175/2008BAMS2526.1

Hayden and Schmit, 1991: http://dx.doi.org/10.1175/1520-0477(1991)072%3C1835:TASCOG%3E2.0.CO;2

Holz et al, 2006: http://dx.doi.org/10.1175/JTECH1877.1

Huang et al, 1992: http://dx.doi.org/10.1175/1520-0450(1992)031%3C0265:VRAAOA%3E2.0.CO;2

Jing, Z. et al, 2014: 10.1007/s00376-014-3162-z

Li, J. et al, 2012: doi:10.1029/2012JD018279

Li and Liu, 2009: doi:10.1029/2009GL038285

Liu and Li, 2010: http://dx.doi.org/10.1175/2009JAMC2374.1

NASA Weather Workshop Report, 2015: http://science.nasa.gov/media/medialibrary/2015/08/03/Weather\_Focus\_Area\_Workshop\_Report\_2015.pdf

NOAA/NESDIS, 2004:GOES GOES-R sounder and imager cost/benefit analysis (CBA). NOAA/NESDIS phase 3 Rep.

NRC, 2007: http://www.nap.edu/catalog/11820/earth-science-and-applications-from-space-national-imperatives-for-the

NRC, 2008: http://www.nap.edu/catalog/12254/ensuring-the-climate-record-from-the-npoess-and-goes-r-spacecraft

Schmit et al, 2009**:** http://dx.doi.org/10.1175/2009JTECHA1248.1

Sokolik et al, 2002: doi:10.1029/2002GL015910.

Wang et al, 2007: http://dx.doi.org/10.1364/AO.46.000200

Wang, et al, 2015: DOI: 10.1002/2014JD022976

WMO 2004: https://www.wmo.int/pages/prog/www/OSY/Publications/TD1267\_Impl-Plan\_Evol-GOS.pdf

WMO 2009: <http://www.wmo.int/pages/prog/www/OSY/Publications/Vision-2025/Vision-for-GOS-in-2025_en.pdf>

Wulfmeyer et al, 2015: http://onlinelibrary.wiley.com/doi/10.1002/2014RG000476/full