NASA Science Community Workshop on Polar Orbiting IR and MW Sounders

November 1st and 2nd, 2010,

Greenbelt, MD

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Workshop Objectives

Hyperspectral infrared and microwave sounders, e.g., Atmospheric Infrared Sounder (AIRS), Advanced Microwave Sounding Unit (AMSU) and Infrared Atmospheric Sounding Interferometer (IASI), have become invaluable tools for modern operational numerical weather prediction. The rich information content in their data, along with other IR sounders such as Tropospheric Emission Spectrometer (TES) and Measurement of Pollution in the Troposphere (MOPITT), are becoming increasingly integral to a diverse suite of science investigations including the hydrological cycle, climate variability and feedbacks, atmospheric composition, air quality, and global greenhouse gas distributions. With the eventual loss of the A-train in conjunction with the increasing need to construct long-term climate-quality data sets, it is vital that continuation of some part of these measurements and their derived products be made by current and planned operational sounders (e.g. the European IASI instrument and the Cross-track Infrared Sounder (CrIS) and the Advanced Technology Microwave Sounder (ATMS),). However, identification of those products critical to the community and an assessment of the expected accuracy and precision for currently planned sounders has not yet been fully explored.

Among the many measurements expected to cease in the next few years, the NRC decadal survey committee identified temperature and water vapor profiles as two of the measurements providing critical information today. These measurements need to be sustained into the next decade. Other measurements made by the current generation of sounders including cloud properties, greenhouse gases, and trace constituents impacting air quality gases, have become critical to the scientific community. In order to identify paths for continuity in sounder observations and needs for further improvement, NASA sponsored a 2-day Science Community Workshop on Polar Orbiting IR and MW Sounders.

The four following questions were the focus of the discussions and consequently the organization of this report within each breakout group:

1. What is the range of scientific research currently being carried out with atmospheric sounding instruments including AIRS, IASI-A, AMSU, TES, and MOPITT?

2. How can the planned CrIS, ATMS, IASI-B, IASI-C continue to support the scientific research enabled by the Earth Observing System (EOS) sounders?

3. What requirements must be satisfied by future sounders (e.g. post-EUMETSAT Polar System (EPS), post-Joint Polar Satellite System (JPSS)) to address the critical challenges in weather, climate, air quality and carbon cycle research.

4. How can planned and future sounders complement, or act as a bridge to NASA Decadal Survey missions?

The workshop was held on November 1st and 2nd 2010 at the Greenbelt Marriott in Greenbelt, Maryland immediately preceding the NASA Sounder Science Team Meeting (November 3rd through 5th at the same venue). The scientific community was invited to participate and share their research and future needs through oral and poster presentations.

NASA Science Community Workshop on Polar Orbiting IR and MW Sounders
November 1st and 2nd, 2010, Greenbelt, MD

Executive Summary and Recommendations

Over 140 people attended the workshop, held at the Greenbelt Marriott on November 1st and 2nd, 2010. NASA, NOAA and other government agencies as well as the several universities and international partners were represented. Breakout sessions for weather, climate and composition captured the value of the sounders and made recommendations for current and future needs of the scientific community. Three recommendations common to all three breakout sessions are given here, with additional recommendations given in the body of this report.

The workshop identified a significant need for a clear definition of scientific requirements, in addition to operational requirements, to ensure scientific progress enabled by these sounders and to best manage resources and coordination amongst the various participants including NASA, NOAA, the JPSS, and our European colleagues.

Recommendation I: The formation of a US based Sounding Science Team is required to identify the current and future needs of the weather, climate and atmospheric composition communities using data from the IR and MW sounders

With the eventual loss of the EOS in conjunction with the increasing need to construct long-term climate-quality data sets, it is vital that continuation of some part of these measurements and their derived products be made by planned CrIS and ATMS on JPSS. The scientific potential of these sounders are maximized when the full spectral resolution and coverage are made available. Moreover, these data are critical for intercalibration and climate data record construction. Providing these data will enable the community to make best use of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) & JPSS instruments, and EPS assets. Studies assisting requirements formulation have identified a second recommendation:

Recommendation II: The JPSS enable the full spectral resolution possible with the Flight Model 1 (FM1) CrIS on NPP as soon as possible.

The current sounders have made tremendous scientific breakthroughs that have led to significant improvements in forecasts of weather, climate, and atmospheric composition. This knowledge is being infused in a new generation of general circulation and Earth System models that operate at higher vertical and horizontal spatial resolution and encompass a broad range of interacting processes. Future sounding observations of temperature, water vapor, and cloud properties must provide improved horizontal and vertical resolution to initialize and validate the new generation of atmospheric models and enable studies such as sub-gridscale moist thermodynamic processes controlling cloud formation in the boundary layer, which are critical for understanding cloud radiative feedback processes. Moreover, measurements such as water vapor isotopes, carbon monoxide, carbon dioxide, ammonia, and ozone, will be key to understanding the carbon, nitrogen, hydrological, and atmospheric chemical cycles and the coupling between them. Based on studies by community workshops, EUMETSAT is considering a two-fold improvement in spectral resolution and radiometric accuracy in the IASI Next Generation (IASI-NG) as a part of the EPS mission with Phase A starting in 2011. The current NASA sounder workshop expressed the need for higher spatial resolution to complement IASI-NG (on the order of 1 km in the IR) with improved spectral resolution compared to AIRS. Concepts studies should be initiated to assess the scientific and operational impact of the sounders with the aid of tools such as observing system simulation experiments (OSSE).

Recommendation III: NASA should begin development of an advanced IR sounder with higher spatial resolution and improved spectral resolution compared to AIRS to be ready to follow the current planned sounders expected to retire in the 2020 timeframe.

Overall, it was recognized in this workshop that the sounding community is not well represented within the Decadal Survey. The NRC Decadal Survey for Earth Science identified water vapor and temperature as critical measurements that need to be sustained in the next decade, but did not identify requirements for these measurements or paths to enhancements of current observations. There is also concern that the JPSS mission is not sufficient to meet the *evolving* needs of the sounding community. The NPOESS (now JPSS) Integrated Operational Requirements Document II (IORD-II) document was written before the launch of the EOS satellites Aqua, Aura, and METOP, and does not incorporate many of these new areas of research into the requirements. The atmospheric sounding community believes that the value of atmospheric sounding to the scientific and operational community warrants further investment by NASA and NOAA to continue to improve these observations and products they produce.

Plenary Session

Speakers

Pagano, Tom (JPL)

Chahine, Moustafa (JPL)

Kakar, Ramesh (NASA)

Uccellini, Louis (NOAA)

Goldberg, Mitch (NOAA)

Dessler, Andrew (TAMU)

Teixeira, Joao (JPL)

Clerbaux, Cathy (CNRS - LATMOS/IPSL)

Schluessel, Peter (EUMETSAT)

Introduction

In order to identify the current and future needs of the scientific community for sounder data, NASA sponsored a 2 day Science Community Workshop on Polar Orbiting IR and MW Sounders. Over 70 participants attended the workshop, which took place at the Greenbelt Marriott in Greenbelt, MD on November 1st and 2nd, 2010. NASA, NOAA and other government agencies as well as the several universities and international partners were represented. Following a half-day plenary session, three breakout sessions were held for the remainder of the first day and most of the second. The three breakout sessions represented the primary scientific disciplines of the user community: Weather, Climate, and Atmospheric Composition, captured the value of the sounders to science and operations, and made recommendations for current and future needs of the scientific community.

Presentations

The workshop began with a plenary session including speakers from NASA and NOAA management and representatives from the international atmospheric sounding scientific community. Presentations by the plenary speakers are available on the sounder workshop website at http://nasa-sounder-workshop.jpl.nasa.gov/

Thomas Pagano (AIRS Project Manager, NASA JPL), the workshop moderator called for introductions from the participants, and presented the workshop agenda (also available on the sounder workshop website). Tom then introduced the chairs of the breakout sessions: Chris Barnet (NOAA) for Weather, Joel Susskind (GSFC) for Climate, and Kevin Bowman (JPL) for Atmospheric Composition. He then identified the four primary questions drafted by the organizing committee to capture the needs of the community:

1. What is the range of scientific research currently carried out with atmospheric sounding instruments including AIRS, IASI-A, AMSU, TES, and MOPITT?
2. How can the planned CrIS, ATMS, IASI-B, IASI-C continue to support the scientific research enabled by the EOS sounders?
3. What requirements are needed from future sounders (e.g. post-EPS, post-NPOESS) to address the critical challenges in weather, climate, air quality and carbon cycle research?
4. How can planned and future sounders complement, or act as a bridge to NASA Decadal Survey missions?

These four questions were the focus of the discussions and consequently the organization of this report within each breakout group.

Mous Chahine (AIRS Science Team Leader, NASA JPL) expressed his appreciation for the large turnout at the meeting and recalled a similar meeting that took place 20 years ago when AIRS was conceived. Back then, the requirement for AIRS was to meet temperature profile accuracy to 1K/km. Looking forward, Mous expressed his vision for AIRS at 1km horizontal spatial resolution.

Ramesh Kakar (Aqua Program Scientist, NASA HQ), as the workshop sponsor and member of the organizing committee, Dr. Kakar addressed NASA's interest in the four questions raised. He said the workshop will help NASA in formulating a future course of action to meet the community needs. He showed several examples of recent scientific discoveries made with the sounders including the highest impact to operational forecasts at the European Centre for Medium-Range Weather Forecasts (ECMWF) (comparable to IASI), quantifying water vapor feedback strength, and measuring the global carbon monoxide burden. He expressed concern that the NRC Decadal Survey assumed the CrIS and ATMS would provide whatever continuity is needed to support sounding science, yet these instruments were not designed with requirements for climate quality data. He said this report will serve as input to future NRC Decadal Survey reviews.

Louis Uccellini (Director, NOAA National Center for Environmental Prediction) reviewed the historical roles of Geostationary Earth Orbit (GEO) and Low Earth Orbit (LEO) satellites to support weather forecasters and modelers, respectively, noting how that distinction is becoming blurred. Through the Joint Center for Satellite Data Assimilation (JCSDA), NASA, NOAA, and the DOD are positioned to accelerate the use of research and operational satellite data in operational numerical weather prediction models. Furthermore, they are using an "operations to research" paradigm to focus their collaborative development efforts by ensuring that operational satellite data access, data assimilation, and numerical models can be used by the larger community in their satellite assessment activities. He showed the numerous satellite data products currently being assimilated and their respective forecast impacts, with AMSU, IASI, and AIRS among the most significant contributors to forecast skill. The current JCSDA priority for IR sounding is to extend the success with AIRS and IASI to CrIS. Future sounders of high potential value include the Constellation Observing System for Meteorology, Ionosphere and Climate II (COSMIC II) GPS, the Geosynchronous IR Sounder Hyperspectral Environmental Suite (HES), and the NRC Decadal Survey Precipitation and All-weather Temperature and Humidity (PATH) missions. Operational requirements for future sounders include reduced data latency, improved calibration processes, and capability to blend products from different platforms. Continued success depends not only on high quality observations, but also on having the computational capacity and science development (for data assimilation and modeling) to take advantage of the existing and new LEO and GEO satellite systems.

Mitch Goldberg (Chief of the Satellite Meteorology Division, NOAA) said NOAA uses IR and MW sounders for improved understanding and prediction of weather and climate. IR sounders have demonstrated their value for understanding the role of the Saharan Air Layer and the prediction of tropical cyclone track and intensity. IR sounders also play an important role in understanding global distributions of CO_2, particularly in the mid-troposphere. He said an AIRS type sounder at 1km horizontal spatial resolution would be extremely valuable in the development, initialization and validation of advanced cloud resolving models. He said that operational missions traditionally commit to 20 or more years with the same instruments, and that technology development programs must be supported so the next generation capabilities are ready when needed.

Andrew Dessler (Texas A&M University) said the sensitivity of climate change to anthropogenic forcing is difficult to measure. The change in all-sky top-of-atmosphere radiative flux is not well correlated with surface temperature, making measurements of the radiative damping rate subject to large uncertainties — which is one reason that the canonical climate sensitivity range has remained unchanged at 2-4.5°C for several decades. Breaking the all-sky top-of-atmosphere radiative flux into its components, we see that changes in the outgoing radiation due to water vapor (water vapor feedback), temperature (or lapse rate) feedback and surface albedo feedback are all well behaved. So the scatter in the radiative damping rate is due mainly to the cloud feedback. And because of this scatter, a few more years of data will not help. We must understand what processes (e.g., Madden–Julian oscillation (MJO)) besides surface temperature are driving the cloud variations, and future sounding missions might want to focus on this question.

Joao Teixeira (NASA, JPL) also identified the large uncertainty in climate prediction due to the cloud feedback uncertainty. He said a better understanding of the processes involved in the cloudy boundary layer is needed, but measurements in this part of the atmosphere are extremely challenging. The strong vertical gradients, turbulent mixing, and large fields of low cloud cover (stratocumulus) make measurements with IR sounders problematic. However, IR sounders do very well in deeper boundary layers with lower cloud cover. He showed the first maps of the Boundary Layer Height made with the AIRS instrument. He stressed the importance of higher horizontal and vertical resolution for future instruments to improve the understanding of cloud variability in the boundary layer.

Cathy Clerbaux (LATMOS/CNRS**)** showed recent results of atmospheric composition data products from IASI. She showed several examples including carbon monoxide, methanol, ammonia and volcanic sulfur dioxide and ash. The measurement of these and other trace gases, in conjunction with models, aid in quantifying emissions, atmospheric chemistry and transport. These products are used both operationally (e.g. aviation safety) and for atmospheric composition research.

Peter Schlüssel (EUMETSAT) showed the process used by the Europeans to identify the requirements for the next-generation "post-EPS" IASI. Two workshops have been held to date, with the first in 2006, and the second in 2009. Currently the program has completed MDR and is starting Phase A studies. User requirements were identified by specific application expert groups. The groups identified the numerous applications of IASI, from weather prediction, climate monitoring, hydrology, oceanography, atmospheric composition and air quality. A 2x improvement in spectral and radiometric resolution is planned for the post-EPS IASI. Additional channels are also planned for the next generation microwave sounder. Launch of the first satellite with the new instruments is planned for 2020.

Breakout Session 1: Climate

Chair: Joel Susskind

Co-Chair: Eric Fetzer

Participants

Chahine, Moustafa (JPL)

Kakar, Ramesh (NASA)

Uccellini, Louis (NOAA)

Goldberg, Mitch (NOAA)

Dessler, Andrew (TAMU)

Teixeira, Joao (JPL)

Clerbaux, Cathy (CNRS - LATMOS/IPSL)

Schlüssel, Peter (EUMETSAT)

Aumann, George (JPL)

Botti, Jim (Inst. for Global Envir. Strategies)

Butler, Jim (NASA)

Elliott, Denis A. (JPL)

Fetzer, Eric (JPL)

Gambacorta, Antonia (NOAA)

Hearty, Thomas (NASA)

Heyman, Roger (NOAA)

Hulley, Glynn (JPL)

Jucks, Ken (NASA)

Kalnay, Eugenia (UMD)

Lacis, Andrew (NOAA)

Mango, Stephen (NOAA)

Minnett, Peter (University of Miami)

Molnar, Gyula (NASA)

O'Callaghan, Fred (JPL)

Platnick, Steve (NASA)

Qian, Haifeng (NOAA)

Ruzmaikin, Alexander (JPL)

Savtchenko, Andrey (NASA)

Gu, Degui (NGC)

Gunn, Lara (Berkeley)

Halem, Milt (UMBC)

Shi, Lei (NOAA)

Stephens, Graeme (JPL)

Susskind, Joel (NASA GSFC)

Introductory Presentations

The first talk, by Stan Kidder of Colorado State University, was titled "New Applications for Water Vapor Sounding for Weather & Climate." He stressed the importance of having a suitable system in space to ensure observational continuity, and cited the example of the NASA Water Vapor Climatology (NVAP) data set for the 1988-1999. He noted that the NVAP record includes four time discontinuities, due to a combination of hardware and algorithm changes. The challenge with NVAP is to extend to 1987-2010. He also noted the value of blended total precipitable water (TPW) vapor observations from several MW instruments, and that histogram matching became operational in 2009. However, there are no satellites at noon or midnight. One application has been orographic rain index, very useful on the West Coast. Stan's proposal is a sounding constellation in 7 orbital planes, 2 satellites per plane. When queried by a member of the audience, he noted the value of 1 km spatial resolution.

In the second talk George Aumann described "Future Hyperspectral Sounder Requirements for Climate." He noted the value of combined AIRS and IASI radiance data. However, there are some subtle pitfalls. Although AIRS and IASI observations show excellent agreement where a one-on-one comparison is possible, global means can be different due to systematically missing data. Global maps of the locations of Deep Convective Clouds (DCC) from AIRS and IASI look almost identical. However, although globally only 1% of the IASI data is flagged as low quality, the lat/lon positions of the bad data look like the DCC map identifying the Intertropical Convergence Zone (ITCZ). The likely cause for this effect is the IASI image motion compensation, which has difficulties in the presence of DCC. This effect is detected in the raw IASI interferograms by the IASI ground calibration software and flagged as "bad data". The systematic elimination of a small number of (very cold) DCC leads to a global warm bias of about 0.1K in the IASI global mean in the 11 micron window. It should be noted that 0.1K is equivalent to one decade of global warming, i.e. the warm bias could be misinterpreted as a climate signal.

The third talk, by Brian Kahn, was titled "Monitoring Decadal Changes of Clouds – One View from A Satellite Perspective." He asked what observations were needed to monitor the spatial and temporal structure of various cloud processes. A partial list of desirable cloud properties and related quantities includes cloud microphysics (phase, number density, optical thickness and effective radius), moist thermodynamics (temperature and water vapor, and derived moist conserved thermodynamic variables such as equivalent potential temperature and liquid water potential temperature), vertical velocity, and aerosol quantities. He closed the talk with a number of literature citations that argue the need for improved observations. He showed plots of CloudSat/CALIPSO, and noted a lack of knowledge about low clouds in pre-CloudSat/CALIPSO cloud feedback studies by Bony and Dufresne (2005) and Stephens (2005). He also illustrated aerosol effects with examples from Stevens and Feingold (2009), and showed correlations between carbon monoxide and cloud effective diameter in Jiang et al. (2009). He noted the challenges of characterizing cloud ice from MLS and CloudSat in Li *et al.* (2007). He showed the value of fine-scale temperature and water vapor observations noted by Tompkins (2002), the effects of precipitation on radiation in Li *et al.* (2011), and showed high cloud feedbacks in Zelinka and Hartmann (2010).

The final talk, by Joel Susskind was "Sample Use of AIRS for Climate Research", with a focus on AIRS outgoing longwave radiation (OLR) and clear sky OLR. He compared 7.5 years of monthly mean OLR computed from AIRS products with OLR obtained by CERES. The anomaly time series of AIRS and CERES

OLR were virtually indistinguishable at 1-degree spatial resolution. The AIRS product confirmed CERES observations that global mean OLR decreased at about 0.1 W / m^2 per year between September 2002 and February 2010. He showed further that this decrease is primarily a result of El Nino- and La Nina-induced changes in the distribution of tropical water vapor and clouds.

Discussion

The organizing questions were posed by the chair and discussed by the audience during the remainder of the afternoon session. The discussion continued the morning of the following day.

Questions 1: What is the range of scientific research currently carried out with atmospheric sounding instruments including AIRS, IASI-A, AMSU, TES, and MOPITT?

This discussion focused on future sounder needs and challenges. The participants acknowledged a move toward earth system modeling. This requirement places special consideration to coupling near the surface, with significant value from surface observations to estimate surface fluxes. This requires high vertical resolution. Experience with carbon dioxide assimilation shows that satellite observations can effectively constrain fluxes, although information about vegetation over land is also needed.

The discussion moved to trends and long-term variability. One participant noted that trends need to be attributed to physical processes, and another stressed that phase shifts are also important. The value of GPS to complement IR sounding was noted.

The complexity of climate, and the need for varied observations and analyses, was noted. While trends in climate variables are important, monitoring of natural variability and extreme events is also necessary. Interannual variability was noted as the most important signal next to long-term trends.

Recommendation 1.1.1: The value of monitoring long-term variability and extreme climate events should be emphasized in all sounding systems.

The discussion shifted to what quantities need to be monitored. Besides those covered by weather observing systems (temperature and water vapor, and some clouds), constituents like carbon dioxide, and cloud microphysics are also important. The value of long-term observations of water isotopes –in addition to those of water vapor—was also noted; AIRS has sensitivity to heavy water (HDO), but information about HDO has not been extracted (Susskind et al., 2011)

The question was raised about whether good temporal coverage from LEO was also desirable. It was argued that very high spatial resolution, attainable only in LEO, was of potentially greater value since high temporal resolution observations are available from geosynchronous instruments. The importance of very large samples was emphasized, as noted in early general session talk by Joao Teixeira. The need for improved techniques lead to the following recommendation:

> *Recommendation 1.1.2: Further research to generate new and improved products from AIRS and IASI is needed, especially with regard to cloud and dust microphysical and radiative properties. Improved theoretical techniques are needed for multiple scattering at finer spatial resolution.*

The value of trace gases, as from TES and MOPITT was discussed, but left for the parallel session.

The topic turned to spatial coverage of retrievals from IASI and CrIS, and the need for more accurate retrievals under cloudier conditions. Compared to AIRS, IASI is limited by higher noise in the shortwave channels, and only four (versus nine AIRS) fields of view within an AMSU field of view. A participant cited Cathy Clerbaux's earlier talk showing retrieval success with up to 25% cloud cover. The IASI yield of ~30% was noted; this is about half the yield from AIRS. The need for documentation on this change in capability was stressed. An attendee noted that IASI retrievals are based on PCA reconstruction, which is most valuable for data compression. Another participant reiterated that IASI is a weather instrument, though climate needs could help guide requirements. Considerations about cloud effects on current sounders lead to the following recommendation:

> *Recommendation 1.1.3: Fully characterize IASI performance with increasing cloud cover, using AIRS as baseline. Evaluate 3+ years of IASI products generated by NOAA using an AIRS science team-like algorithm. Compare interannual differences and trends obtained from AIRS and IASI products. Repeat this experiment using a NOAA IASI retrieval algorithm when it becomes available.*

Questions 2: How can the planned CrIS, ATMS, IASI-B, IASI-C sounding instruments continue to support the scientific research enabled by the EOS sounders?

Much of the discussion of Question 2 was included in the previous discussion. It included two recommendations:

> *Recommendation 1.2.1: Repeat the last recommendation, using CrIS and IASI-B retrievals when these data sets become available.*

> *Recommendation 1.2.2: Develop retrieval algorithms for water isotopes (in addition to water vapor) because isotope observations are needed to constrain faster hydrologic processes. Future sounders*

should be designed with spectral resolution and coverage to obtain lower tropospheric HDO, as with TES.

Question 3: What requirements are needed from future sounders (e.g. post-EPS, post-NPOESS) to address the critical challenges in weather, climate, air quality and carbon cycle research?

Discussions here addressed the merits and feasibility of improved spectral resolution and spatial resolution compared to AIRS and IASI. As in earlier conversations, the need for high vertical resolution near the surface to estimate fluxes was emphasized. A future instrument with better spectral/spatial resolution than AIRS or IASI is expected to provide higher vertical resolution, though pressure broadening –not instrument resolution—ultimately constrains vertical resolution. A four- to eight-thousand channel sounder at 1 km resolution is within current technology, though we would be able to telemeter only a fraction of the data today. However, bandwidth shouldn't be an issue 10-20 years out since this concern is widely recognized in the satellite community. The real challenge was noted to be interpretation, not technology. Techniques to deal with multiple scattering will remain a major challenge. Some recommendations were:

Recommendation 1.3.1: High vertical resolution, especially in the boundary layer, is needed to constrain fluxes in next-generation climate models. CO_2 (and other gases) for assimilation, along with temperature and humidity, are needed. Higher spectral resolution (as on post-EPS IASI) will improve vertical resolution of sounding of trace gases.

Cloud property retrievals were discussed next. Higher spatial resolution is a real advantage for sampling discontinuous clouds, and the need for careful radiometry was noted. We need to retrieve cloud top temperature, optical properties, etc., though 5 km horizontal resolution currently used for MODIS averaging may suffice for some cloud properties. This must be addressed through further analysis. It was noted that the greatest challenge in cloud remote sensing is profiling microphysics. Proper cloud retrievals will require collocated visible observation to complement the IR. The following recommendations were made concerning cloud observations:

Recommendation 1.3.2: Increased horizontal resolution results in greater cloud contrast within the field of regard, and allows for successful soundings under more cloud conditions than achievable with AIRS. This increases spatial resolution and yield for all retrieved products.

Recommendation 1.3.3: Good radiometry is needed to retrieve cloud properties. Other important cloud properties that are needed include cloud top temperature, phase, and optical properties.

Recommendation 1.3.4: Collocated visible and IR observations are complementary for cloud characterization.

Recommendation 1.3.5: Collocated microwave observations are needed to characterize state variables in the presence of clouds.

Recommendation 1.3.6: While the Climate Absolute Radiance and Refractivity Observatory (CLARREO) addresses these requirements explicitly, they must be taken into consideration in any future sounder planned for use in climate monitoring.

The discussion turned to higher spatial resolution in observing surface temperature, emissivity and the atmospheric boundary layer. Current carbon dioxide sampling is only sufficient for monthly analyses, suggesting a need for finer resolution to increase sampling rates. An additional challenge arises in correcting for the intervening atmospheric state, where deviations from climatologies can lead to biases. Near-surface temperature and humidity are critical in problem areas, for example, dry polar regions or very moist regions. There is a need to simultaneously retrieve profiles and surface skin temperature. The focus should be on accurate determination of the vertical distribution of humidity, and its temperature difference with respect to the surface temperature, on spatial scales comparable to the surface skin temperature retrieval (i.e. ~1 km). The ability to characterize the first guess at higher spatial scales over land was also noted, though current spectral resolution is sufficient for land surface emissivity. The following recommendation for improved boundary layer information were made:

Recommendation 1.3.7: High spatial resolution improves soundings over land, especially in the boundary layer, because small-scale variability in surface emissivity and topography are better characterized.

Recommendation 1.3.8: High vertical resolution, especially in the boundary layer is needed to constrain fluxes in next-generation climate models. A higher spatial resolution (1 km) AIRS-like instrument should lead to improved land and ocean surface skin temperature, spectral emissivities, surface-leaving radiance fluxes, and cloud radiative properties. Improved surface properties will lead to improved profile retrievals in the boundary layer, especially over land.

The subject then turned to diurnal variability and long-term trending. Resolving the diurnal cycles requires at least two satellites in well-spaced orbits. For long-term trending, sounder calibration accuracy and stability must be specified. Stability is also required under all conditions. For example, IASI compensates for Doppler shift such that the four IASI fields of view (FOVs) have biases of ~100 mK. The following recommendations were made:

Recommendation 1.3.9: Monitoring climate trends or small interannual changes require high stability. High stability means day and night separately, and stability at all scan angles.

Recommendation 1.3.10: Multiple satellites mitigate concerns about the diurnal cycle.

Recommendation 1.3.11: The value of annual mean, interannual, and other natural modes of variability should be considered when designing future sounder systems.

Recommendation 1.3.12: GPS is needed to complement infrared sounding.

Question 4: How can planned and future sounders complement, or act as a bridge to NASA Decadal Survey (DS) missions?

The discussion began with CLARREO, which is designed for detecting trends in long-term fluxes, especially zonal means. It was noted that the IRIS data record from 1970 shows that almost all 15 km resolution scenes contain some clouds, though often these are subvisible cirrus. Also, future climate models will have much finer resolution, and we will need the longest possible record for climate model assessment. This suggests a need for calibration requirements on microwave instruments (besides the strength of sidelobes), and the necessity for a locked orbit for microwave observations. The following recommendations were made concerning Decadal Survey missions and future sounders:

Recommendation 1.4.1: An AIRS-class instrument, preferably at higher spatial resolution than AIRS, is highly complementary to CLARREO in resolving and explaining fine-scale structure in regional climate processes and variability.

Recommendation 1.4.2: Two or more orbits at fixed local time are needed to describe the regional diurnal cycle.

Recommendation 1.4.3: Improved boundary layer water vapor will lead to improved CO2 retrievals from OCO and ASCENDS.

Recommendation 1.4.4: Multiple instruments per platform allow multi-sensor cross calibration.

Breakout Session 2: Atmospheric Composition

Chair: Kevin Bowman

Rapporteur: Richard Baron

Participants

Al-Saadi, Jay (NASA)

Arellano, Ave (Arizona State)

Blaisdell, John (NASA)

Bowman, Kevin (JPL)

Chahine, Moustafa (JPL)

Clerbaux, Cathy (CNRS - LATMOS/IPSL)

DeCola, Phil (Sigma Space)

Hannon, Scott (UMBC)

Kopacz, Monika (NOAA)

Maddy, Eric (NOAA)

Olsen, Edward T. (JPL)

Ott, Lesley (GEST, MBC)

Pierce, Brad (NOAA)

Pougatchev, Nikita (JPL)

Stajner, Ivanka (NOAA)

Tangobrn, Andy (UMBC)

Xun, Jiang (University of Houston)

Yurganov, Leonid (UMBC)

Introductory Presentations

The atmospheric composition session was characterized by an impressively diverse array of applications including global atmospheric chemistry, air quality, greenhouse gases, natural hazards, and coupling and tracers of atmospheric dynamics. As a consequence, the discussion demonstrated how IR hyperspectral sounders such as AIRS, IASI, TES, and MOPITT interrogate key aspects of the Earth System including the carbon cycle, nitrogen cycle, hydrological cycle, atmospheric chemistry and dynamics.

Preceding the composition session were several presentations by plenary speakers that provided important context for hyperspectral sounding of atmospheric composition. Peter Schlüssel from EUMETSAT articulated the requirements formulation and development of the post-EPS satellites. Of particular note was the recognition that operational centers were evolving from Numerical Weather Prediction (NWP) models for atmospheric data assimilation towards Earth system analyses and modeling that encompassed a broader scope of applications including oceans, climate, chemistry, hydrology, land surfaces, and cryosphere. Cathy Clerbaux from the University of Paris VI showed the impressive suite of atmospheric trace gases that can be measured from IASI, which can support research and operations for the Earth System in general and atmospheric composition in particular. Focusing more on the carbon cycle and anthropogenic emissions, Mitch Goldberg at NOAA/NESDIS is investigating whether greenhouse gas monitoring can or should be incorporated into the next suite of operational sounders.

Kevin Bowman gave the opening presentation on Earth System and application drivers for current and future research and operational uses of IR hyperspectral sounders. This presentation was followed by four presentations focusing on carbon monoxide and carbon dioxide.

Monika Kopacz of Princeton University (and in transition to the NOAA Climate Program Office) presented "Estimating CO Emissions From Space: Current Capabilities, Future Needs". Dr. Kopacz used the adjoint of the GEOS-Chem chemistry and transport model in the context of CO flux estimation to assess the CO consistency between different sounders including MOPITT, AIRS, TES, and the SCanning Imaging Absorption spectroMeter for Atmospheric CartograpHY (SCIAMACHY). Her findings show that the global annual CO emissions are found to be 1350 Tg and that CO emissions in N. America, Europe and China exhibit strong seasonality, consistent with surface and aircraft observations. She further finds that tropical (mostly biomass burning) sources in S. America and Africa are estimated to be 183 and 343 Tg, a figure mostly driven by AIRS data which is larger than MOPITT or SCIAMACHY in the southern hemisphere. She recommended for future sounding of CO long overlapping records, boundary level sensitivity as demonstrated by MOPITT, and the importance of intercomparison between satellites for assessment of biases.

Xun Jiang of the Univ. of Houston spoke on the "Variability of Tropospheric CO_2 Observed by the Atmospheric Infrared Sounder", which is co-authored with Yuk Yung at the California Institute of Technology. In this presentation, Dr. Jiang showed the importance of atmospheric dynamics such as El Niño/La Niña and the Madden Julian Oscillation (MJO) on explaining atmospheric CO_2 variability, e.g., [Li et al., 2010] along with convective vertical transport [Jiang et al., 2010]. Based on these studies, she emphasized the need for continuity and global coverage of CO_2 observations.

Ed Olsen from the Jet Propulsion Laboratory discussed "Stratospheric CO_2 retrievals from AIRS". He compared these preliminary retrievals against stratospheric CO_2 distributions from GEOS-Chem, MOZART, MATCH, and CarbonTracker. He showed significant discrepancies between the AIRS observations and these models, particularly over Canada indicating a need for more in-situ observations.

Ave Arellano, Jr. from the University of Arizona gave a presentation entitled "Exploiting satellite CO data for NWP". He assimilated MOPITT CO along with NCEP *in-situ* meteorological data into an Ensemble Kalman Filter assimilation scheme with the NCAR CAM model. He first showed, through a sensitivity analysis, that variations in horizontal winds at 350 hPa are correlated with variations in CO. He subsequently showed that when he included MOPITT data he obtained a better agreement with independent radiosonde data than with only meteorological input data. He furthermore pointed out that IASI CO data could potentially provide a better constraint on winds than MOPITT and that the new multispectral MOPITT CO retrievals could have an impact on winds closer to the surface. However, he emphasized these analysis are still preliminary and merit further investigation.

Discussion

The subsequent discussion revolved around the four workshop questions. The summary of that discussion to each of these questions is discussed in the following.

Questions 1: What is the range of scientific research currently carried out with atmospheric sounding instruments including AIRS, IASI-A, AMSU, TES, and MOPITT?

There is a broad suite of research areas enabled by atmospheric sounders covering the carbon, nitrogen, and hydrological cycles, their coupling through atmospheric dynamics, atmospheric chemistry and application areas including surface fluxes of CO, CO_2, and natural hazards. In global atmospheric chemistry/air quality, these sounders have been used for:

- Chemical data assimilation, e.g. [Parrington et al., 2008, Arellano et al., 2007, Pierce et al., 2009]
- Long range transport of pollution (ozone and CO), e.g., [Parrington et al., 2009, L. Zhang et al., 2008].
- Estimation of CO sources and sinks e.g., [Arellano et al., 2003, 2006, Jones et al., 2003, 2009, Bowman et al., 2009, Kopacz et al., 2010].

In the context of aerosol precursors and the nitrogen cycle, both ammonia and SO_2 have been measured [Beer et al., 2008, Clarisse et al., 2009, Clarisse et al., 2009]. Key biogenic tracers such as methanol [Beer et al., 2008] and formic acid [Razavi et al., 2009] have been retrieved with TES and IASI satellites. Elevated concentrations of SO_2, volcanic aerosols, and dust can also be detected from IR sounders [DeSouza-Machado et al., 2006] including the volcanic eruption at Eylafjallajökull, as shown in the earlier talk by C. Clerbaux.

The measurements of trace gases, particularly those with a longer lifetime, can be used both as tracers and constraints on transport. The impact of CO on numerical weather prediction results was shown by Dr. Arellano during the opening session. Nocturnal measurements of ozone from IASI have been used by ECMWF to constrain high latitude dynamics [Han and McNally, 2010]. Trace gases have also been used to understand convective mass flux [Ott *et al.*, 2009], the Asian Monsoon [Xiong *et al.*, 2008, Worden *et al.*, 2009], and the Madden Julian Oscillation (MJO) [Jiang *et al.*, 2010, Li *et al.*, 2010].

"Heavy" water—HDO—is a unique tracer of the condensation history of water vapor. Groundbreaking measurements of this tracer have been made by TES [Worden *et al.*, 2007] and IASI [Herbin *et al.*, 2009]. These measurements were recognized in both the weather and composition session as critical new measurements to consider for future sounders.

It was also recognized that trace gases are an important interferent for temperature and water vapor sounding and therefore important to quantify strictly for NWP applications.

Thermal, spectrally resolved sounders are natural sensors for measuring greenhouse gases such as carbon dioxide, methane, and ozone, the three most important radiative forcing agents from anthropogenically-induced climate change [Soloman *et al.*, 2007]. IR sounders have been used extensively to assess the distribution of free tropospheric CO_2 [Chahine et al., 2006, Crevoisier et al., 2009, Kulawik et al., 2010] and to infer carbon emissions [Chevallier *et al.*, 2007, Nassar *et al.*, 2011]. Similarly, methane concentrations have been also measured [Xiong *et al.*, 2008, Razavi *et al.*, 2009, Crevoisier *et al.*, 2009] and inferences from these observations are currently in progress [Wecht *et al.*, in preparation].

Tropospheric ozone is distinguished from carbon dioxide and methane by its heterogeneous spatial and temporal distribution. The radiative effect of this distribution has been quantified using TES [Worden *et al.*, 2009] and through novel instantaneous radiative forcing kernels [Aghedo *et al.*, 2011].

Questions 2: How can the planned CrIS, ATMS, IASI-B, IASI-C sounding instruments continue to support the scientific research enabled by the EOS sounders?

A number of trace gas products are made from the IASI instrument, which will be continued with the IASI-B and IASI-C instruments. This trio of instruments promises to continue supplying at least a decade of composition products for the community. However, the morning orbit of IASI is not as ideal for composition as the afternoon orbit where the thermal contrast is greater, the planetary boundary layer is more stable, and photochemical production is higher.

There is concern as to the accuracy of several composition products, in particular Carbon Monoxide, generated from CrIS compared to AIRS, IASI, TES or MOPITT. The concern arises from the lower spectral resolution of CrIS compared to the other instruments. As a consequence, the community has made the following recommendations:

Recommendation 2.2.1: The full spectral resolution possible from CrIS be achieved for NPP and future flight units should be downlinked.

Recommendation 2.2.2: An assessment be made of the total composition products and retrieval accuracy of CrIS compared to the other IR sounders currently in orbit.

Even given these recommendations, there are capabilities provided by the current EOS instruments that cannot be made by the currently envisaged sounders. In particular, lower tropospheric ozone and HDO from TES as well as boundary layer CO from MOPITT will no longer be available to the community when these instruments cease operating.

Given that the composition community will increasingly look towards IR sounders, the optimal estimation retrieval approaches and their associated diagnostics, which has been implemented on all major composition sounders (including TES, Ozone Monitoring Instrument (OMI), The Microwave Limb Sounder (MLS), MOPITT, AIRS, IASI, Michelson Interferometer for Passive Atmospheric Sounding (MIPAS)), are needed to provide continuity and is now an expectation. Moreover, it was recognized that investments in integrated validation campaigns are key for insuring data quality. In summary: there is a need to focus on calibration issues since it will affect all products; with respect to CO, the product is expected to be better than the current product and with respect to CH_4 it may be comparable but more research is required.

Question 3: What requirements are needed from future sounders (e.g. post-EPS, post-NPOESS) to address the critical challenges in weather, climate, air quality and carbon cycle research?

For the composition and carbon cycle community, global coverage of trace gases with sensitivity within the boundary layer is important for quantifying emission sources and mixing processes. Lower tropospheric/boundary layer sensitivity leads to requirements of higher vertical resolution. However, it was also recognized that the spatial and temporal scales are higher near the surface relative to the free troposphere. Consequently, there is a concomitant need for higher spatial resolution, which also aids in point validation. Global coverage is still important particularly for greenhouse gases and for the same measurement to be made from multiple platforms, e.g., IASI and JPSS, to assess instrumental biases.

Innovative new remote sounding approaches exist that combine free tropospheric sensitivity from IR channels with solar reflective measurements from NIR, SWIR, UV, and VIS channels to dramatically increase boundary layer sensitivity. These techniques have been shown to work theoretically for ozone with IR+UV and IR+UV+Vis channels [Worden *et al.*, 2007, Landgraf and Hasekamp, 2007]. The practical implementation of these algorithms is currently being investigated with OMI and TES as well as IASI and

GOME-2. Based on these approaches, CrIS FM2 could be co-boresighted with Ozone Mapping and Profiler Suite (OMPS) to achieve similar near-surface sensitivity. A similar approach has been proposed to combine IR and NIR radiances for obtaining CO_2 profiles [Christi and Stephens, 2004]. However, multispectral techniques for estimating CO profiles with near surface sensitivity are the most mature and have been demonstrated with IR and SWIR channels on the MOPITT instrument [Worden *et al.*, 2010]. It was also recognized the having IR and NIR channels could help with the intercalibration of geo-stationary broadband sensors.

> *Recommendation 2.3.1: Multi-spectral approaches should be considered, either through co-boresighting different instruments or extending the spectral range of IR sounders, to obtain near- surface trace gas information.*

Question 4: How can planned and future sounders complement, or act as a bridge to NASA Decadal Survey (DS) missions?

The NASA Decadal Survey missions are predicated upon a strong polar observing system that includes the IASI and JPSS sounders [National Research Council, 2007]. These IR sounders will be the only means of continuing composition products initiated by TES, AIRS, and MOPITT. The primary composition platform, Aura, will not see a follow-on until the Global Atmospheric Chemistry Mission (GACM), which is slated to launch around 2030. As a consequence, these sounders will be the only bridge linking Aura trace gas observations to GACM observations. On the other hand, regional measurements of pollutants over North America will be provided by Geostationary Coastal and Air Pollution Events (GEO CAPE). However, these geo-stationary observations will need global trace gas observation from JPSS and IASI as boundary conditions. Aerosols and trace gas pollutants have in many cases the same sources. The future sounders of atmospheric composition could compliment the ACE aerosol measurements to provide additional constraints on aerosol precursors, e.g., ammonia, and sources. For greenhouse gases, sounder's broad spatial coverage and ancillary tracers, e.g., CO, can compliment the ASCENDS mission, which will provide high resolution, narrow swath measurements of CO_2.

Breakout Session 3: Weather

Chair: Chris Barnet

Participants

Atlas, Bob (NOAA/AOML)

Bajpai, Shyam (NESDIS/OSD)

Baker, David (CIRA - Colorado State Univ.)

Baker, Neal (Aerospace)

Barnet, Christopher (NOAA/NESDIS/STAR)

Baron, Richard (JPL)

Blackwell, Bill (MIT Lincoln Labs)

Boukabara, Sid (NOAA/NESDIS)

Collard, Andrew (NCEP/EMC)

Deron, Scott (SDL)

Divakarla, Murty (NOAA/STAR)

English, Steve (CPTEC)

Fishbein, Evan (JPL)

Guenther, Bruce (NOAA-JPSS)

Hagan, Denise (NGC)

Atlas, Bob (NOAA/AOML)

Han, Yong (JCSDA)

Iredell, Lena (SAIC/GSFC)

Jung, Jim (IMSS)

Kouvaris, Louis (SAIC/GSFC)

Lambrigtsen, Bjorn (JPL)

Lee, Sung-Yung (JPL)

Liu, Quanhua (JCSDA)

Machado, Sergio De-Souza (UMBC)

Pett, Todd (Ball Aerospace)

Reale, Oreste (NASA/GSFC, UMBC)

Rosenberg, Rob (SAIC/GSFC)

Ruf, Chris (Univ. Michigan)

Schlüssel, Peter (EUMETSAT)

Solbrig, Jeremy (NRL)

Zhou, Lihang (NOAA-JPSS)

Kahn, Brian (JPL)

Introductory Presentations

This session had three presentations followed by discussion of the four questions in the context of weather forecasting and regional weather applications. Here we present a brief summary of the three presentations:

Bjorn Lambrigtsen (NASA, JPL) presented a talk entitled "Deriving convective structure from microwave sounder observations" using observations from the High Altitude MMIC Sounding Radiometer (HAMSR) that flew aboard the ER-2 July 2005. Bjorn demonstrated that reflectivity measurements over hurricanes can be used to derive hurricane structure and also discussed the importance of averaging kernels to assess sounding information.

Chris Ruf (University of Michigan) presented a talk entitled "Synthetic thinned array radiometer instrument and capabilities overview". The Hurricane Imaging Radiometer (HIRAD) is a push-broom imaging radiometer and uses synthetic aperture technology, analogous to the synthetic aperture SMOS that is a LEO orbiting instrument with a range of 15 to 55 degrees incidence angle. During this presentation Chris also discussed that instruments using varying incidence angle have the same effect of improving vertical sampling as a higher spectral resolution microwave instrument (vertical weighting functions move with incidence angle).

Finally Bill Blackwell (MIT Lincoln Laboratory) presented a talk entitled "Future requirements for all-weather, high resolution sounding." He began with discussing the recent SBIR (released on Oct. 13, 2010) to explore building a prototype hyperspectral microwave sensor. He showed that the JPSS requirements for all-weather can be met by instrument concepts such as Geostationary Microwave Array Spectrometer (GEOMAS, 88 channel, 118/183 GHz) that can achieve temperature accuracies of 1.5 K/1-km and moisture accuracies of 15%/1-km. For more information see Blackwell (2010). He also discussed snowfall retrievals in cold regions during daytime where traditional microwave sounding channels see the surface. Utilizing 229 and 380 GHz bands could provide improved snowfall retrieval in the polar regions.

Discussion

The four questions in order and are summarized below followed by a summary of all the recommendations discussed within this session.

Question 1: What is the range of scientific research currently carried out with atmospheric sounding instrument including AIRS, IASI-A, AMSU, MHS, TES, and MOPITT?

Question 1 does not include the Special Sensor Microwave Imager / Sounder (SSMIS) which should be available through 2020. The following recommendation is made:

Recommendation 3.1.1: Add SSMIS to list of instruments covered in these questions.

There was a significant amount of discussion of improving the use of cloudy radiances in both global and regional models. Rejection of radiances below the clouds and in active regions is a big problem. The long-term plan is to utilize a full microphysical forward model; however, there is a significant need for more research and there is a question as to whether the current complement of instruments is capable of constraining the cloud physics in the model. UKMet is now using channels of AIRS and IASI that are sensitive down to the cloud tops. The plan is to steadily increase the sophistication of cloud models to increase the number of channels and scenes assimilated.

The GSFC Laboratory for Atmospheres has been experimenting with the use of AIRS retrieval products, derived from instrument-team cloud cleared radiances (CCRs), and found that there is a need for good quality control (QC). This QC will vary by application and should be optimized for each specific use. The temperature and retrieval products provide higher yield in active regions (see Reale et al. [2009] and Zhou [2010]). Finally, retrieval products have vertically correlated errors (retrievals are constrained to outgoing radiances) and therefore more difficult to assimilate than radiances. Models can be quite sensitive to lapse rate errors and the vertically correlated retrieval errors are important to quantify. The following recommendation was made:

Recommendation 3.1.2: Product developers should provide averaging kernels and error co-variance matrices in addition to quality control for all retrieval products

Infrared CCRs contain all the information of the derived retrieval products discussed above. CCRs are possibly easier to ingest into the data assimilation environment since they have a similar format to cloud radiances; however, they can have large spectrally correlated noise.

CCRs could increase the yield of information in partially cloudy regions. There is still a need to investigate the direct assimilation of CCRs; however, some participants felt that the level of sophistication in handling cloudy radiances has already arrived at the point where there is little to be gained from CCRs. Use of the model background in the cloud clearing algorithm should improve the yield and quality control of these radiances relative to the instrument-team derived CCR products and, therefore, have the best chance of showing large positive impacts. Presumably, this would be a near-term while NWP centers continue to improve the cloud models.

Recommendation 3.1.3: NWP centers should undertake an objective evaluation of the use of cloud cleared radiances, specifically, in regions where profiles have shown large impact.

We also discussed the use of trace gas climatologies to improve the utilization of infrared radiances with forecast models. Carbon dioxide ($CO2$) and nitrous oxide ($N2O$) has been increasing (~0.5%/year,

~0.25%/year, respectively) and can cause long-term seasonal, diurnal, and regional biases relative to a model that holds these gases fixed. Other trace gases that can affect temperature sounding are ozone, nitric acid, and volcanic sulfur dioxide to which the infrared radiances are highly sensitive.

The use of principal components (PCs) or radiances reconstructed from PCs ("reconstructed radiances") was also discussed. The advantage of PCs is that they can provide data compression and can be utilized to remove random noise in spectral regions with high redundancy. For PCs there was concern raised over the broad, oscillating Jacobians and the fact that geophysical information tends to be convolved within PCs, making it difficult to assess the impact of any individual PC (e.g., you cannot identify a "water PC" in the same way as you can identify a "water channel").

The current operational hyperspectral sounders (AIRS and IASI) have not had the expected impact in water vapor in the models. There are many possible reasons such as representation error, non-linearity of the Jacobian, and while there are many channels, poor knowledge of correlated errors makes it difficult to use more than a small number of these channels without creating problems. There was also a discussion of the use of the more opaque water channels to provide information on upper troposphere and lower stratospheric water and that including these channels improves the upper level temperature analysis at 5 to 50 hPa.

There was a discussion on improving scattering in the forward models. For the microwave this is targeting improvements in precipitation forecasting. For the infrared scattering from dust is contributes a large component that is not currently handled well in models or retrievals. UMBC has shown that high resolution measurements can provide information about the properties of dust.

Of special note was a desire for retrievals and models to improve in the boundary layer. To do this there was a consensus that retrieval and modeling of microwave and infrared observations needed to continue to improve. Analysis of boundary layer depth (Martins et al., 2010) and the ability to derive information on temperature inversions were highlighted as important areas of study.

Short time-scale process studies are important to improve model parameterization. These activities are important to continue using the suite of space-borne assets that we have today. While this was not discussed in detail, it was noted that the following studies are important:

- Variance scaling (Kahn and Teixeira, 2009)
- MJO (Tian et al., 2010)
- Gravity Waves (Alexander et al., 2009)
- Stratospheric/Tropospheric exchange indices.
- Convective indices.
- Moist convection.
- Non-linear adjoints or Jacobians – for microwave water vapor, infrared clouds.

The utility of high spatial resolution was also discussed. MODIS-like instruments have been shown to improve the quality of infrared cloud cleared radiances. They have the ability to characterize the variance of sub-pixel moisture, emissivity, as well as the impact of clouds on calibration (e.g., the instrument line strength (ILS) is a function of scene temperature in multi-FOV interferometers such as IASI and CRIS). The MODIS has shown value in moisture-tracked winds in models and should be continued (use of 1-km spatial in 1.6, 6.7, 7.3, and 11 μm). Improvements to MODIS-like instruments are needed to minimize striping and improve data latency as 3 orbits are required for wind computations.

In this session it was apparent that we have only begun understanding how hyperspectral sounders can be used in global and regional models. The utility of these sounders in applications such as air-quality forecasting is in its infancy. Improvements in the boundary layer, temperature inversions, improved water information, cloudy radiances, and improved products over land are desired. We have a lot to do before we have reached the existing instruments' capabilities.

Question 2: How can the planned CrIS, ATMS, IASI-B, IASI-C continue to support the scientific research enabled by the EOS sounders?

Recommendation 3.2.1: Add the Microwave Imager/Sounder MIS to list of instruments in this question.

In general, there is a need to have workshops such as these to guide the research community. This workshop report should be considered a "living document" and be periodically re-assessed within the community. It was recommended that the recommendations of this workshop be prioritized and that the community holds annual workshops to revise and add to these recommendations. This could be a primary role of a US based sounding science team to identify and promote current and future needs of the weather community for microwave and infrared sounding.

Recommendation 3.2.2: The sounding science community should hold annual meetings to strengthen, prioritize and revise the recommendations from this workshop.

Of particular importance in this context is that we recognize that missions cannot always support validation and calibration given the competition for funds. During a mission there are always subtle calibration issues that arise as instruments age. Also, as researchers learn how to utilize instruments the demands on calibration and validation become more complex with time. Unfortunately, most programs have decreasing funds as instruments age and as new instruments are prepared for launch. In addition, there are subtle (sometime not so subtle) differences between instruments. In the microwave, the ATMS sampling and channel polarization will be different from AMSU – and AMSU was different than MSU. IASI and CrIS have different issues than AIRS. While it is understood that each sounder will be slightly different in the way it obtains data, as much consistency as possible would be helpful in creating a set of products that forecasters and other end users can use without needing to be re-trained as to the strengths and weaknesses. Finally, even the same sensor in different orbits can behave differently (e.g., cloud statistics are different for MODIS-Terra and MODIS-Aqua) and we need to understand what are the relevant impacts on sounder design and sampling strategies. Therefore, the community needs to encourage multi-sensor characterization and inter-comparisons, such as Global Space-based Inter-calibration System (GSICS), so that we can fully exploit these space-borne assets and provide continuity of measurements within the data assimilation community.

Recommendation 3.2.3: The sounding community should encourage multi-sensor characterization and intercomparisons for long-term sensor validation.

This group discussed the need to ensure that the JPSS instruments meet the needs of the weather community. There is concern that the CrIS instrument will not be utilized to its full extent and that it may not be able to meet the expectations of the community. The CrIS instrument is capable of having 0.625 cm^{-1} unapodized resolution in all three bands (long-wave, mid-wave, and short-wave); however, the program decided to limit the resolution to 0.625, 1.25, and 2.5 cm^{-1} due to historical downlink constraints. Of highest priority is to increase the short-wave resolution to provide better spectral calibration and continuity for the AIRS and IASI carbon monoxide product. Of secondary importance, is increasing the resolution of the mid-wave band to allow upper tropospheric and lower stratospheric water retrieval and subsequent improvements seen in upper atmosphere temperature profiles.

Recommendation 3.2.4: The spectral resolution of the CrIS shortwave and midwave bands should be increased to the full optical capability of 0.625 cm^{-1}.

All of the items discussed in question 1 are relevant here and research needs to be continued, and that research considered in the design of new sounders. Continuation of the studies of how to best exploit the information context of these instruments in data assimilation is of utmost importance (e.g., PCs; models of correlated error in profiles). Instrument teams and the sounding community should continue to develop capabilities as a basis for future research-to-operations transitions for data assimilation. Some new areas of research discussed were:

- Develop an understanding of the analysis of the heavy water isotope (HDO) to improve knowledge of the hydrologic cycle. The infrared sounders (AIRS, IASI, TES, CrIS) are sensitive to this gas and the measurement of heavy water can be used to infer the hydrologic cycle, specifically the history of evaporation and precipitation. Lower SW spectral resolution and spectral coverage of instruments such as CrIS will negatively impact the ability of retrieval of HDO.

- An emphasis is needed on continued improvements of microwave and infrared spectroscopy – in particular, the improvements mentioned in question 1 about scattering forward models for microwave and the infrared.

- Microwave ILS have historically been treated as boxcar functions by the data assimilation community. Instrument teams need to provide the best measurements of ILS to the community for microwave instruments.

- Combination of datasets, such as AIRS/IASI, AIRS/MODIS, IASI/AVHRR are important to improve knowledge of the diurnal cycle as it applies to clouds.

- Studies of sub-pixel and frequency effects on the ILS are important for use of interferometers in weather applications. For interferometers (IASI, CrIS) sub-pixel inhomogeneous radiance (inhomogeneous surface, clouds, etc.) can induce a scene dependent ILS. For grating instruments (AIRS) the diurnal, seasonal, and long-term changes in frequency can induce a spectrally correlated noise. There is a need to continue the analysis and correction methodologies and, as discussed above, these kinds of corrections are usually understood towards the end of mission life when funding is diminishing.

- There was a concern raised over the nonlinearity corrections for the CrIS detectors. OSSEs should be performed to understand the impact on data assimilation of residual nonlinearity error and a recommendation be made to fix this issue for future units.

- For multi-FOV interferometers the FOVs can have cross-talk (electronic and/or optical) and for single-FOV instruments such as AIRS the along-track FOVs have correlated signals along track due to overlap in sampling during scanning. This can induce spatially correlated scenes and impact algorithms such as cloud clearing. Future instruments should ensure the FOVs can be used as independent measurements.

Improvements are needed in intercalibration of FOVs. Of particular concern is that forecast models do not perform bias correction on individual FOVs from the same instrument and, therefore, they require ≈0.01K agreement between FOVs. ECMWF is only using one of the four IASI FOVs due to ≈0.5K biases due to the knowledge of the position of the FOV within the focal plane (Collard 2009). Note that Collard (2009) did not assess the impact of inter-FOV calibration on forecast skill; however, they did demonstrate that NWP will resort to using subsets of FOVs when there is questionable calibration. NCEP is still using all four FOVs presumably due to differences in the front-end processing that makes it less sensitive to this issue. For CrIS there is an issue related to choice of calibration parameterization that has been shown to mitigate this problem (Larrabee Strow, personal communication); however, the JPSS Sensor Data Record (SDR) team is reluctant to implement this solution as the current parameterization "meets specifications."

Recommendation 3.2.5: The CrIS SDR team should adopt the calibration approach that ensures the "best" performance even if the current approach meets specification. Specifically, this applies to inter-calibration of FOVs and non-linearity corrections.

Retrievals may also have value for atmospheric research, especially processes on hour to monthly time-scales (Reale et al., 2009). AIRS had a positive impact on the analysis and forecast track of tropical cyclone Nargis in a global assimilation and forecast system. Examples of areas of study that should be encouraged are the atmospheric component of the hydrologic cycle, moist thermodynamics, cloud processes (i.e., formation and dissipation) and precipitation. One study that has already been published shows a remarkable improvement in precipitation analyses and forecasts consequent to the assimilation of AIRS temperature retrievals under cloudy conditions, with respect to clear sky radiances (Zhou, 2010).

The question was raised as to the appropriate balance between improvements in instruments and improved utilization of the data we already have. What is really needed is the ability to capture more information from sounders measurements to improve the models. This is application dependent and the needs of a global model are not necessarily the same as a regional model or a hurricane prediction center. While we recognize the need for better instruments, we also need to improve exploitation of information from the space-borne assets we already have. Continued research into the items discussed during questions 1 and 2 needs to be supported by the sounding community. For example, many researchers have explored the use of single-FOV retrievals from AIRS and IASI. The operational CrIS/ATMS retrieval algorithm is capable of retrieving higher spatial resolution for scenes that will allow it (9 FOV, 4 FOV, and single FOV depending on scene classification). Research into these approaches should be encouraged and the sounding community should objectively evaluate these approaches.

Question 3: What requirements are needed from future sounders (e.g. post-EPS, post-NPOESS) to address the critical challenges in weather climate, air quality and carbon cycle research?

It is recognized that better latency (less than 30 minutes), higher spatial resolution (a few hundred meters for regional, 1 km for global), higher temporal resolution (30 minute for much of the globe), and low, spectrally and spatially uncorrelated noise are all design tradeoffs of a space-borne sensor system. No specific recommendations were made, but there were a number of comments made that can be used as guidance for system planning. These were not discussed in great detail, so for completeness they are simply listed:

- Hurricane forecasting requires very high spatial and temporal sampling at specific times and places (e.g., following hurricane formation and tracking). Again, an appropriate sampling strategy to meet both global forecasting and regional forecasting needs should be considered.
- Low latency is important for global and mesoscale forecasting. A requirement of 20 to 30 minutes from time of observation to distribution is desired. Active regions (developing unstable regions, storm fronts, etc.) require higher spatial and temporal resolution with low latency. This is a high priority area for data assimilation because more data can be utilized and it reduces representation error in models. While this is not an instrument issue, it is important that sounding missions reduce the latency of their products.

- Future hyperspectral instruments should be spatially and spectrally Nyquist sampled to allow the ability to combine and inter-compare sensors.
- Having full spectral coverage (similar to IASI) was considered valuable.
    - SW water band (1600-2000 cm-1) contains unique information lost on the LW side (1200-1600) due to interference by methane, sulfur dioxide, and nitric acid.
- Need rapid response to warnings such as SO_2/Volcanic ash, flooding, etc.
- One instrument may not meet all the requirements.
- Maintaining a stable orbit (similar to Aqua, Aura and other A-Train satellites) was considered important for climate applications and desirable for weather applications. An important question did arise as to what are the specifications for NPP and are they adequate for climate products.
- Having the same sensor in multiple orbits with similar spatial sampling is desired. (e.g., 9 FOV sampling on both AM and PM orbits would be valuable relative to our current AIRS 9 FOV and IASI 4 FOV system).
- More sampling is needed in the tropics. Fewer orbital gaps (e.g., METOP and NPP are higher altitude and have fewer gaps than Aqua orbit). Alternatively, averaging of low-temperature (high noise) polar scenes could be done to provide a more uniform product with higher weight in the tropics.
- Concepts similar to "sensor web" where one sensor (e.g. a GEO satellite or MODIS) is used to define targets for a higher spatial/spectral (e.g. EO-1/HYPERION) might be valuable. A recent publication discussing optimal spatial sampling of AIRS data is Lazarus (2010).
- For SW infrared, explore low noise, high spectral resolution measurements to capture trace gases (H_2O/HDO, CH_2O (formaldehyde), CH_4). This will require extending the SW coverage of the existing instruments.
- The statement is often made that we need better vertical resolution for infrared and microwave sounders. In the lower atmosphere the effects of natural and collisional broadening of lines is a physical limitation for temperature and moisture sounding that cannot be improved simply by increased spectral resolution. For the infrared this may imply a large increase in spectral resolution. For example, Kaplan et al. (1977) showed that spectral resolution of 0.1 to 0.2 cm^{-1} was required to gain improved vertical information in the 4.3 μm band. Wang (2007) showed that for a given detector sensitivity the trade-off between sensor noise and spectral resolution might favor lower noise rather than increased spectral resolution. Having a large number of microwave or infrared spectral channels will provide better vertical sampling; however, this does not equate to better vertical resolution if the channel spectral width is still large. Higher spectral resolution can provide a significant improvement in channel "selectivity" enabling isolating signals of interest from other geophysical variability. Given that spectral resolution and channel noise are inversely related we need detailed trade-studies to investigate what instrument concepts would be most useful.

Recommendation 3.3.1: There is a need for a detailed OSSE to study optimal design trade-off between spatial resolution, spectral resolution, instrument noise, and temporal sampling.

The overarching consensus was that the weather community desires better instruments but has the conflicting requirement that instruments should have continuity such that the return on investment made in preparation for assimilation is realized because it takes a number of years to understand the subtleties of an individual instrument. The following list of items were discussed briefly:

- There are benefits if several agencies/countries flew the same sensor
  - Redundancy of information
  - Graceful degradation if one sensor fails
  - Instrument calibration problems would be seen earlier, with possible mitigation, if multiple sensors are in-orbit.
  - However, priority should be given to having good instruments.
- Minimize biases between detectors in multi-FOV instruments.
- Improve calibration and mitigate instrument differences as much as possible to provide continuity between sensors. Issues such as cross-track biases, side-lobe corrections, frequency calibration, spatial co-registration of bands and channels are all important to the data assimilation community but they cannot develop instrument specific processing. Instrument teams need to incorporate these corrections into their SDR algorithms.
- Recommendation to adopt World Meteorological Organization (WMO) /EUMETSAT system of defining threshold/breakthrough/objective user requirements.

We returned to the presentations discussed at the beginning of this session. There are significant advances that can be made to microwave sounding of the atmosphere and these should have a high priority. Some of the potential improvements the sounding community could explore are:

- Hyperchannel microwave (while maintaining spatial resolution and low noise) should be explored in more detail. Sreerekha at al. (2007) discussed the impact of adding new channels in 53.1 to 53.4 GHz (between AMSU channels 4 and 5) and 53.8 to 54.1 (between AMSU channels 5 and 6) and improves sounding of hydrometeors.
- Higher frequency channels could improve sounding in certain domains (e.g., 229 and 380 GHz for moisture in polar regions, 118 GHz for tropospheric temperature). Bauer et al. (2005) determined that the 50 GHz region outperformed the 118 GHz region. Sreerekha et al. (2008) determined that

the 229 GHz region increases skill in detecting “marginal” cirrus allowed better utilization of the 183 GHz information and outperforms a system in which more 183 GHz channels are added.

- Both polarizations for microwave instruments are desired; however, the study of Sreerekha (2007) shows that sensitivity to choice of polarization is very small.
- Improvement in microwave instrument lifetime, can it be increased?

Finally, the needs of the “weather” community are evolving. There are new applications for air-quality and renewable energy. For example, short-term forecasting for renewable energy (wind and solar) might drive more stringent latency requirements. There is potential that in the future there will be requirements for cap-and-trade monitoring that sounders can contribute to. This leads to short-term goals, such as boundary layer sensitivity, higher vertical resolution in the boundary layer, and higher yield in active regions. In general, there is a need to link the sensor specifications to science requirements. For example, we may need higher spectral resolution microwave and higher spatial resolution infrared to improve boundary layer products.

Question 4: How can planned and future sounders complement, or act as a bridge to NASA Decadal Survey (DS) missions?

Sounders complement GPS Radio Occultation (GPSRO) from space, which is not a DS mission but relevant in the context of complementary observations.

- Sounders measure temperature and moisture independently (separate bands) whereas GPSRO has NIST traceability and very low bias; however, to get a usable measurement a very large correction has to be made to account for the ionospheric electron density.
- GPSRO can be used to characterize other instruments.
- Within data assimilation, sounders could be used to separate temperature and moisture signals that are convolved in the GPS measurement (maybe in the sense of T/q covariance).

The only decadal survey mission directly relevant to sounding is the Precision and All-weather Temperature and Humidity (PATH) mission (GEO microwave, Phase III DS). Existing and planned sounders have relevance to calibration and validation of PATH. Continuing development of inter-comparison capabilities is also important. While PATH addresses the need of better latency (15-30 minutes) over the continental United States it does not address global coverage needs and does not incorporate some of the enhancements discussed above for future microwave observations (higher frequencies, vertical resolution, etc.).

The Global Precipitation Measurement (GPM) is a pathway to the Soil Moisture Active Passive (SMAP) mission (LEO L-band radar and radiometer, Phase I DS). There may be useful complementary total column water and precipitation information from sounders.

Sounder trace gas products complement other trace gas missions (e.g., Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS)) and complement solar passive approaches (e.g., JAXA | Greenhouse gases Observing SATellite (GOSAT) "IBUKI", and Orbiting Carbon Observatory (OCO)) leading to better utilization of ASCENDS. Mid-tropospheric sounder products are potentially useful in providing additional vertical information. In this context, sounders have better spatial and temporal coverage that could be used to enhance the boundary layer sensitivity of GOSAT, OCO, and ASCENDS.

For the Climate Absolute Radiance and Refractivity Observatory (CLARREO) mission Phase 1 Interferometer, LEO-precessing, the DS (NRC 2007 p.4-11) recommend suite of infrared operational sounders launched on NPP and NPOESS that can use the Climate Observatory to (1) establish SI traceable accuracy on-orbit, (2) establish an independent analysis of time-dependent bias in calibrated radiance, and (3) form a basis for intercomparison of all operational sounders now and in the future. Specifically, the sounding community should develop observing strategies and test concepts ***before*** CLARREO is launched. CLARREO has limited spatial sampling and having a coordinated sampling strategy and instrument design could take advantage of the synergy between the sounders spatial and temporal sampling and CLARREO's high accuracy.

Overall, it was recognized in this workshop that the sounding community is not well represented within the DS. This was also recognized within the preface to the DS (NRC 2007, p.xiv) in which they state "The recommended portfolio of activities in this survey tries to be responsive to those [budget] changes, but it was not possible to account fully for the consequences of major shocks that came very late in the study, especially the delay and descoping of the NPOESS program, whose consequences were not known even as this report went to press. Similarly, the committee could not fully digest the ramifications of changes in the GOES-R program of NOAA, and it was in no position to consider the implications of possible large-scale reduction in funding and later delay of the GPM." NRC recommendations to restore NPOESS-CMIS and a Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) instrument did not come to fruition, and the majority of concern within the DS appears to be the continuity of Total incoming Solar (TIS) and Clouds and the Earth's Radiant Energy System (CERES) for climate research. The NWP community has lost the advantage of having the same instrument (e.g. Conical Scanning Microwave Imager/Sounder (CMIS) in complementary orbits to provide adequate coverage. The sounding community will only have a minor role in most of the relevant DS missions (e.g., PATH, CLARREO, ASCENDS).

There is also concern that the JPSS mission is not sufficient to meet the ***evolving*** needs of the sounding community (as discussed in the text and recommendations above). The NPOESS IORD-II document (Pace et al. 2002) was written before the launch of Aqua, Aura, and METOP and does not incorporate many of these new areas of research into the requirements. Given funding realities, it is unlikely that these will become requirements within the JPSS program either. The DS did not appear to focus on these aspects in their analysis. This context is also relevant in Recommendation 3.2.2.

Summary of Recommendations

Primary Recommendations

Recommendation I: The formation of a US based Sounding Science Team is required to identify the current and future needs of the weather, climate and atmospheric composition communities using data from the IR and MW sounders

Recommendation II: The JPSS enable the full spectral resolution possible with the FM‑1 CrIS on NPP as soon as possible.

Recommendation III: NASA should begin development of an advanced IR sounder with high spatial resolution and improved spectral resolution to be ready to follow the current planned sounders expected to retire in the 2020 timeframe.

Detailed Session Recommendations

SESSION 1: Climate

Recommendation 1.1.1: The value of monitoring long-term variability and extreme climate events should be emphasized in all sounding systems.

Recommendation 1.1.2: Further research to generate new and improved products from AIRS and IASI is needed, especially with regard to cloud and dust microphysical and radiative properties. Improved theoretical techniques are needed for multiple scattering at finer spatial resolution.

Recommendation 1.1.3: Fully characterize IASI performance with increasing cloud cover, using AIRS as baseline. Evaluate 3+ years of IASI products generated by NOAA using an AIRS science team-like algorithm. Compare interannual differences and trends obtained from AIRS and IASI products. Repeat this experiment using a NOAA IASI retrieval algorithm when it becomes available.

Recommendation 1.2.1: Repeat the last recommendation, using CrIS and IASI-B retrievals when these data sets become available.

Recommendation 1.2.2: Develop retrieval algorithms for water isotopes (in addition to water vapor) because isotope observations are needed to constrain faster hydrologic processes. Future sounders should be designed with spectral resolution and coverage to obtain lower tropospheric HDO, as with TES.

Recommendation 1.3.1: High vertical resolution, especially in the boundary layer, is needed to constrain fluxes in next-generation climate models. CO2 (and other gases) for assimilation, along with temperature and humidity, are needed. Higher spectral resolution (as on post-EPS IASI) will improve vertical resolution of sounding of trace gases.

Recommendation 1.3.2: Increased horizontal resolution results in greater cloud contrast within the field of regard, and allows for successful soundings under more cloud conditions than achievable with AIRS. This increases spatial resolution and yield for all retrieved products.

Recommendation 1.3.3: Good radiometry is needed for to retrieve cloud properties. Other important cloud properties that are needed include cloud top temperature, phase, and optical properties.

Recommendation 1.3.4: Collocated visible and IR observations are complementary for cloud characterization.

Recommendation 1.3.5: Collocated microwave observations are needed to characterize state variables in the presence of clouds.

Recommendation 1.3.6: While the Climate Absolute Radiance and Refractivity Observatory (CLARREO) addresses these requirements explicitly, they must be taken into consideration in any future sounder planned for use in climate monitoring.

Recommendation 1.3.7: High spatial resolution improves soundings over land, especially in the boundary layer, because small-scale variability in surface emissivity and topography are better characterized.

Recommendation 1.3.8: High vertical resolution, especially in boundary layer is needed to constrain fluxes in next-generation climate models. A higher spatial resolution (1 km) AIRS-like instrument should lead to improved land and ocean surface skin temperature, spectral emissivities, surface-leaving radiance fluxes, and cloud radiative properties. Improved surface properties will lead to improved profile retrievals in the boundary layer, especially over land.

Recommendation 1.3.9: Monitoring climate trends or small interannual changes require high stability. High stability means day and night separately, and stability at all scan angles.

Recommendation 1.3.10: Multiple satellites mitigate concerns about the diurnal cycle.

Recommendation 1.3.11: The value of annual mean, interannual, and other natural modes of variability should be considered when designing future sounder systems.

Recommendation 1.3.12: GPS is needed to complement sounding.

SESSION 2: Composition

Recommendation 2.2.1: The full spectral resolution possible from CrIS be achieved for NPP and future flight units

Recommendation 2.2.2: An assessment be made of the total composition products and retrieval accuracy of CrIS compared to the other IR sounders currently in orbit.

Recommendation 2.3.1: Multi-spectral approaches should be considered, either through co-boresighting different instruments or extending the spectral range of IR sounders, to obtain near surface trace gas information.

SESSION 3: Weather

Recommendation 3.1.1: Add SSMIS to list of instruments covered in these questions.

Recommendation 3.1.2: Product developers should provide averaging kernels and/or error co-variance matrices in addition to quality control for all retrieval products

Recommendation 3.1.3: NWP center(s) should undertake an objective evaluation of the use of cloud cleared radiances, specifically, in regions where profiles have shown large impact.

Recommendation 3.2.1: Add MIS to list of instruments in this question.

Recommendation 3.2.3: The sounding community should encourage multi-sensor characterization and inter-comparisons for long-term sensor validation.

Recommendation 3.2.4: The spectral resolution of the CrIS short-wave and mid-wave bands should be increased to the full optical capability of 0.625 cm^{-1}.

Recommendation 3.2.5: The CrIS SDR team should adopt the calibration approach that ensures the "best" performance even if the current approach meets specification. Specifically, this applies to inter-calibration of FOVs and non-linearity corrections.

Recommendation 3.3.1: There is a need for a detailed OSSE to study optimal design trade-off between spatial resolution, spectral resolution, instrument noise, and temporal sampling.

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Appendix A

Agenda

AGENDA
NASA SCIENCE COMMUNITY WORKSHOP
ON POLAR ORBITING IR AND MW SOUNDERS
Nov. 1 - 2, 2010
Marriott Greenbelt

Monday Nov. 1, 2010 *A.M. Light Refreshments: 7:30 - 8:00*

		PLENARY SESSION 1: ROOM A/B	
All		Welcome and introductions	8:00 AM
Tom Pagano	JPL	Meeting Objectives, Agenda and Logistics	8:30 AM
Moustsfa Cahahine	JPL	AIRS Team Leader Historical Perspective	8:40 AM
Ramesh Kakar	NASA HQ	NASA Perspective	8:50 AM
Mitch Goldberg	NOAA	NOAA Interests in Hyperspectral Sounding	9:10 AM
Lou Uccellini	NCEP	NCEP Perspective	9:30 AM
BREAK			***10:00 - 10:20***
Andrew Dessler	Texas A&M	Recent work on the water and cloud feedbcks and thoughts on the way forward	10:20 AM
Joao Teixeira	JPL	Sounding of the cloudy boundary layer	10:45 AM
Cathy Clerbaux	CNRS	Atmospheric composition with IASI	11:10 AM
Peter Shluessel	EUMETSAT	Post-EPS user and mission reaquirements for future sounders	11:35 AM
LUNCH			***12:00 - 1:30***

		BREAKOUT GROUP MEETINGS, ROOMS A,B & C: 1:30 - 4:30	
Chris Barnet (Chair)	NOAA	Breakout Group: Weather (Room A)	1:30 - 4:30
Joel Susskind (Chair)	GSFC	Breakout Group: Climate (Room B)	1:30 - 4:30
Kevin Bowman (Chair)	JPL	Breakout Group: Composition (Room C)	1:30 - 4:30
BREAK			***3:00 - 3:20***
		Breakout Groups Continue until 4:30	
		Room Configuration back to A/B: 4:30 - 4:45	
All		Wrap Up (Day 1)	4:45 PM
ADJOURN			***5:00 PM***

AGENDA
NASA SCIENCE COMMUNITY WORKSHOP
ON POLAR ORBITING IR AND MW SOUNDERS
Nov. 1 - 2, 2010
Marriott Greenbelt

Tuesday Nov. 2, 2010 *A.M. Light Refreshments: 7:30 - 8:00*

PLENARY SESSION 2: ROOM A/B			
All		Summary Presentation Reviews	8:00 AM
Chris Barnet (Chair)	NOAA	Breakout Group Summary: Weather	9:00 AM
BREAK			***10:00 - 10:20***
Joel Susskind (Chair)	GSFC	Breakout Group Summary: Climate	10:20 AM
Kevin Bowman (Chair)	JPL	Breakout Group Summary: Composition	11:10 AM
LUNCH			***12:00 - 1:30***
All		Report Synthesis	1:30 PM
BREAK			***3:00 - 3:20***
All		Planning and Next Steps	4:30 PM
ADJOURN			***5:00 PM***

Appendix B

Additional Participants/Registrants

Alcott, Gary (NASA/GSFC GES DISC)

Avery (UMBC)

Bahethi, Om (SSAI)

Benson, Craig (GEST)

Berkoski, Leonard (NGES)

Bingham, Gail (SDL)

Cebula, Richard (SSAI)

Cember, Richard P (IPO)

Chang, Tiejun (NOAA/STAR/IMSG)

Chapman, David (UMBC)

Chen, Xiongwen (Ala A & M Univ)

Cornett, Robert (SSAI)

DeFelice, Tom (Caelum Res. Corp)

Demoz, Belay (Howard University)

Diao, Minghui (Princeton University)

Eckermann, Stephen (NRL)

Esplin, Mark (SDL /USU)

Evans, Keith (JCET/UMBC)

Fertig, Elana (JHMI)

Fish, Chad (SDL /USU)

Friedman, Steven (JPL)

Guo, Guang (NOAA/NESDIS/STAR)

Hanna, Rafik (NOAA)

Herdies, Dirceu (GEST/UMBC- GMAO/NASA)

Huang, Jingfeng (UMBC/GEST, NASA/GSFC)

Hui, Lu (NCAR)

Imasu, Ryoichi (University of Tokyo)

Istvan, Laszlo (NOAA/NESDIS & UMD)

Jeong, Myeong (UMBC)

Kakar, Ramesh (NASA)

Kataoka, Fumie (Remote Sens Tech Ctr Japan)

Kaye, Jack (NASA)

Kicza, Mary (NOAA)

Kidder, Stanley (CIRA/Colorado State Univ)

Kim, Edward (NASA GSFC)

Laszlo, Istavak (NOAA)

Lee, Tsengdar (NASA)

Li, Zhanqing (UMD)

Liberti, Gian Luigi (ISAC-CNR)

Liu, Hui (NCAR)

Liu, Xu (NASA LRC)

Lynnes, Christopher (GES DISC)

Fujishin, Mark (JPL)

Garrett, Kevin (NOAA)

Gleason, James (NASA Goddard)

Goldberg, Mitch (NOAA)

Grotenhuis, Michael (NOAA/ERT, Inc.)

Lyu, Cheng-Hsuan (NASA/GSFC/Caelum/U.MD-GEST)

Manning, Evan (JPL)

Mao, Jianping (NASA)

Mitomi, Yasushi (Remote Sens Tech Ctr Japan)

Moghaddam, Baback (JPL)

Moses, John (NASA/GSFC/ESDIS)

Motteler, Howard E. (UMBC)

Mundakkara, Rama (NOAA)

Nalli, Nicholas (Dell Services - NOAA/NESDIS/STAR)

Newhouse, Rodgerick (Scitor)

Nguyen, Phuong (UMBC)

Oreopoulos, Lazaros (NASA-GSFC)

Ouzounov, Dimitar (NASA GSFC)

Pagano, Tom (JPL)

Parkinson, Claire (NASA GSFC)

Pawson, Steven (NASA GSFC – GMAO)

Pinker, Rachel (University of Maryland)

Pu, Zhaoxia (University of Utah)

Ray, Sharon (JPL)

Rodriguez, Antonio (EUMETSAT)

Roelofs, Larry (GST)

Santanello, Joseph (NASA/GSFC)

Schiffer, Robert (UMBC)

Schou, Paul (UMBC)

Schreier, Mathias (JIFRESSE/JPL)

Selkirk, Henry (GEST/UMBC/NASA)

Singh, Ramesh (Chapman University)

Stan, Cristiana (COLA)

Strow, Larrabee (UMBC)

Stuhlmann, Rolf (EUMETSAT)

Theobald, Mike (GES DISC)

Tian, Baijun (JPL)

Tobin, David (UW/SSEC)

Todling, Ricardo (NASA)

Uccellini, Louis (NOAA)

van Delst, Paul (JCSDA@NCEP/EMC)

Vane, Deborah (JPL)

Vermeesch, Kevin (SSAI)

Vogel, Ron (NOAA/NESDIS/STAR)

Vollmer, Bruce (NASA GSFC)

Wallace, Julie (Humanity and the Environment)

Wamsley, Paula (BATC)

Warner, Juying (UMBC/JCET)

Wei, Zigang (JCET/UMBC)

Whiteman, David (NASA/GSFC)

Williams, Darrel (Global Sci &Tech, Inc.)

Wilson, Robert (UMBC)

Wiscombe, Warren (NASA/GSFC)

Wong, Sun (JPL)

Xiong, Jack (NASA/GSFC)

Xiong, Xiaozhen (Dell & NOAA/NESDIS/STAR)

Ye, Hengchun (CSU, LA)

Yoe, Jim (NOAA/NWS & JCSDA)

Yu, Fangfang (ERT, Inc@NOAA)

Zavodsky, Bradley (MSFC/NASA/SPoRT)

Sun, Fengying (NOAA/NESDIS/STAR)

Suraiya, Ahmad (NASA GSFC)

Zhang, Kexin (NOAA/STAR)

Zhou, Daniel (NASA LaRC)

Zondlo, Mark (Princeton)