2.4 ADVANCED SOUNDERS

Web site: http://cimss.ssec.wisc.edu/itwg/aswg/

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2.4.1 Introduction

The Advanced Sounder Working Group (ASWG) focuses on scientific issues affecting the optimal performance of advanced satellite sounder systems. The working group reviews the status of the development of advanced sounder systems and recommends changes pertaining to instrument specification, performance, data processing, and utilisation. For the purpose of this group, "Advanced Sounders" are defined as instruments that present significant new scientific and technological challenges and which require new methods for data processing and utilization. Thus, Advanced Sounders currently include high spectral/spatial resolution passive infrared and microwave sounders and active sensors.

2.4.2 Advanced Sounding from Polar Orbit

Improved sounding from polar orbit has been one of the highly recommended action items from ITWG. The consideration for advancing polar orbiting sounding improvements includes high spatial resolution and denser spatial sampling to increase the density of high quality clear air radiance measurements commensurate with finer grid size of current and future NWP models as well as improvements in absolute accuracy, traceable to radiometric standards, and spectral coverage for the purpose of cross-calibration of instruments of lesser accuracy in geostationary and polar orbits. With recent advancement in sensor technology and impact assessment study from the assimilation of cloud contaminated sounding radiance data, the ASWG reached a general consensus to recommend improvements in horizontal resolution as the highest priority for future infrared sounding instruments.

The ASWG expressed the following concerns and general recommendations:

1) ***Improved Utilization By Forecasting Centers:*** Forecast centers only assimilate a small fraction of the spectral channels and spatial samples of sounding radiance data available. Data denial studies with results presented at the ITSC-20 show that forecast skill improves with the addition of IR hyperspectral sounding radiance data. As a result, **NWP centers should make it a priority to develop the means to assimilate**

the majority of IR hyperspectral sounding radiance data available in order to obtain further improvements in forecast skill.

2) ***Absolute accuracy amongst all detectors within the instrument Field of Regard (FOR):*** Priority should be given to maintain better than 50 mK equivalent brightness temperature calibration match of all sounder FOV radiances over the full brightness temperature measurement range. If this is achieved at the 1b product level, then NWP centers will have a stronger incentive to use all FOV data within the instrument's FOR in NWP models.

3) Intersatellite Instrument Cross-calibration: On-orbit hyperspectral IR sounders offer the best means available today for establishing intersatellite radiance calibration for a fleet of diverse on-orbit IR instruments with various spectral responses. An SI traceable radiance scale having one sigma uncertainty of 35 mK across the IR spectral band (climate class instrument) can be incorporated into systems, such as IASI, CrIS and IRFS, with current technology. The evolution of current sounding systems toward climate class measurement uncertainties should be a priority in the development of future hyperspectral IR sounders. This can be achieved with modest incremental cost of existing systems.

4) Spectral Gaps: Augmenting spectral coverage in the gaps between existing bands of future CrIS instruments can be achieved at a very modest cost. This augmentation can be accomplished without detriment to the existing JPSS mission. Consequently, evolving CrIS into a full spectral coverage instrument should be pursued in order to support a worldwide intersatellite calibration capability in the wavenumber range 650 – 2760 cm^{-1}. This recommendation should be simultaneously coupled with technology insertion to support SI traceable climate class radiance measurements.

5) Instrument Horizontal Resolution: CrIS currently has high signal to noise ratio margin relative to what is needed for EDR production. Forward model noise/uncertainty dominates over instrument observation noise. A SNR degradation up to a factor of 4 will have no significant impact on CrIS EDR retrievals, based upon current NEdN performance and trade studies done at the beginning of the CrIS program. The signal to noise margin is even higher when considering the ability to horizontally average high horizontal resolution clear FOV radiance data. This consideration opens up an opportunity to reduce the FOV size on CrIS to as small as 5km without significant EDR retrieval penalty. Reduction of CrIS FOV size should be pursued on future systems given the current system SNR margin. This will yield significantly more high quality cloud free retrievals. The reduction of FOV size is also expected to improve cloud cleared radiances as a result of increasing the contrast between cloudy and clear FOVs.

6) Hyperspectral IR Sounding at GEO Orbit: Hyperspectral sounding instruments in geostationary orbit enable the derivation of 3D wind vectors for improving NWP. Successful generation of 3D wind vectors having high spatial and temporal resolution has been acknowledged as the highest need from NWP centers for improving weather forecasts. Similar benefits associated with improved severe storm warning are also possible based upon limited experiments/observations from low earth orbit systems. The ASWG recommends that a pathfinder hyperspectral IR sounder mission targeting

moisture cell tracking and 3D wind vector generation at geo orbit should become an applied research priority and demonstrated on-orbit by 2020.

7) ***Complimentarity of GEO and LEO Hyperspectral IR Sounders for 3D Winds:*** Wind observations made from both GEO and constellations of LEO satellite have complimentary capability. Localized severe weather prediction is best served by a GEO platform. Full global coverage for global extended range NWP modeling is better served by constellations of LEO platforms. Thus, the ASWG recommends that both types of systems should be pursued and developed for improved weather forecasting.

8) Increasing FOV Number Within Existing IR Sounder FORs: Although useful to increase the number of detectors and therefore density of FOVs (i.e., 6 x 6 vs. 3 x 3 or 2 x 2 detector arrays), since the probability of obtaining a clear field of view within the instruments FOR, the ASWG feels that this achievement is less important than any of the concerns, 1 through 7, listed above for NWP applications of the data. This is because FOV data is ultimately thinned in NWP models and small FOV size with good SNR provides sufficient sampling with good quality EDRs even if small gaps exist between FOVs. In addition, rotation of the CrIS field of regard with scan angle will always produce gaps in FOV coverage no matter how dense the FOR is packed with FOVs. Growth of FOV density beyond 6 x 6 will require alternate detector focal plane technology and represents a significant upgrade expense. Consequently, increasing the CrIS FOV number beyond 6 x 6 should be pursued as a lower priority since the cost penalty also extends to data rate and ground processing resources. In any case, recommendations 1 and 2 above must be resolved first before any benefit can be obtained by increasing FOV density further.

Recommendation AS-1 to Space Agencies

Consider the following priorities for the development/improvement of the next generation of advanced infrared sounders.

The prioritized recommendation lists from the highest are:

1. High spatial resolution to improve the probability of a uniform scene with the instrument FOV (i.e., all clear or all cloudy)*.

2. Spectral coverage from shortwave to longwave without gaps – to facilitate improved inter-satellite instrument cross-calibration.

3. Adopt/adapt calibration approaches traceable to international standards – to improve absolute radiometric calibration in order to achieve measurements closer to climate quality.

*Although maintaining FOV contiguity is also desired in order to increase the spatial density of the data and associated probability of obtaining clear FOVs within the instruments Field of Regard (FOR), increasing the spatial resolution alone would provide significant improvements in both radiance data assimilation and sounding retrieval.

Action AS-1 to ITWG Co-Chairs

Bring this recommendation to the attention of Space Agencies at CGMS.

In order to support these recommendations, it also necessary to:

- Coordinate NWP centers to generate high resolution (1-3 km) nature runs to support OSSE to demonstrate the NWP benefits of these measurement improvements, and

- Request satellite agencies to continue to support and accelerate advanced sounder IFOV size OSSE studies.

Recommendation AS-2 to Space Agencies

Coordinate with NWP Centres the generation of high resolution (1-3 km) nature runs.

Action AS-2 to ITWG Co-Chairs

Convey this recommendation to Space Agencies.

The ASWG noted with interest that a 1 km nature run is being performed by NASA GMAO. The 7 km nature run being basically completed a 1,5 km nature run has started. Plans exist to double the number of levels.

In this context the following action was accepted by Stephen English:

Action AS-3 to Stephen English

To investigate higher resolution nature runs at ECMWF and report back to ASWG.

Studies have shown that the co-located high spatial resolution imaging data provide valuable sub-grid cloud information that greatly improves the assimilation of cloud contaminated sounder data. Such background-independent information is crucial for the cloud detection over land surfaces where background knowledge of surface emission is relatively poor. AVHRR statistics in clusters within IASI field-of-view have proved useful to assisting the cloud detection. There is easy access to collocated imager data currently only in the case of IASI. An aggregate VIIRS radiance product is becoming available soon for the use with CrIS, but should only be considered as an intermediate step as it still relies on the accuracy of the VIIRS cloud mask.

Recommendation AS-3 to Space Agencies (NOAA)

Support further developments towards performing cluster analysis on imager pixels within advanced IR sounder field-of-views and providing statistical information of the collocated imager radiances as part of the sounder radiance observations. (The ASWG recommends that satellite agencies adopt the IASI/AVHRR approach to co-locate CrIS/VIIRS observations and provide radiance cluster and other analysis information in the CrIS SDR file.)

Action AS-4 to ITWG Co-Chairs

Convey this recommendation to Space Agencies (and NOAA in particular).

The development of future MW sounders as an advance of current MW imaging/sounding radiometers with conical and cross-track scanning should include an increased number of channels, especially upper level sounding channels, as well as spatial resolution improvement. As a result the resolution should be close to the one of advanced IR sounders. Besides, the efforts should be focused on refining the technologies for on-board and post launch radiometric calibration in order to provide consistent accuracy of the radiance measurements. Also it will be useful to maintain a constellation of early morning, morning and afternoon polar satellites with advanced MW sounders onboard.

SNPP and JPSS-1/2 ATMS have a temperature sounding capability near the 50-60 GHz O2 absorption line. In strong precipitation and severe storm conditions, these channels can be severely impacted by scattering from large ice and liquid phase hydrometeors, which can significantly degrade the quality of the temperature profiles. Also, the double O2 sounding also allows for deriving the cloud hydrometeor profiles as demonstrated in a recent study published in GRL by Han et al. (2015).

Recommendation AS-4 to NOAA

Future JPSS instrument enhancements should consider adding 118 GHz O2 band to the baseline design to advance the microwave sounding capability for the retrieval of precipitation over land and sea, including light precipitation and snowfall.

Action AS-5 to Mitch Goldberg

Convey this recommendation to NOAA.

The new ATMS sounding capability with double O2 bands will allow JPSS to generate microwave observations that are compatible with those from EUMETSAT and CMA polar missions which all considered adding this 118 GHz band in their current and future baseline microwave sounding systems.

The ASWG discussed the availability of new microwave technologies and noted that bolometer technology at 90 GHz and beyond has reached a level of maturity to achieve a successful implementation. It is necessary and beneficial to establish a dialogue between providers and the user community to achieve progress in the implementation.

Recommendation AS-5 to Space Agencies and Users

Establish a dialogue between providers and users of microwave soundings on the potential and capabilities of bolometer technology at 90 GHz and beyond.

Action AS-6

Steve English to act as the interface and provide related documentation.

The group discussed and noted with satisfaction the beneficial role and impact of microwave soundings in NWP and the need to maintain this capability.

Recommendation AS-6 to Space Agencies

Maintain and evolve the current microwave sounding capabilities for future systems.

Recommendation AS-7 to Space Agencies

Maintain and evolve the capability of microwave mesospheric sounding capabilities beyond SSMIS.

Action AS-7

ITWG Co-chairs to relay these recommendations to Space Agencies via CGMS.

The group identified the need to pursue the advancement of microwave sounding capabilities via a microwave hyper spectral sounding capability. This could be from either GEO or from a constellation of micro-cube sats in polar orbit.

Recommendation AS-8 to Space Agencies

Conduct studies to pursue high temporal resolution hyper spectral microwave sounding capabilities for future systems.

Action AS-8

ITWG Co-chairs to relay this recommendation to Space Agencies via CGMS.

2.4.3 Advanced Sounding from Geostationary Orbit

The group discussed the potential to perform microwave sounding from geostationary orbit and noted that technology seems to have reached a level of maturity now to allow a successful implementation in orbit.

Recommendation AS-9 to NASA

To implement the PATH mission.

Action AS-9

ITWG Co-chairs to bring this recommendation to the attention of NASA.

Recommendation AS-10 to Space Agencies

To pursue further development and implementation of microwave sounding missions in order to achieve global coverage of geostationary microwave sounding.

Action AS-10

ITWG Co-chairs to relay this recommendation to Space Agencies via CGMS.

2.4.4 SI Traceable Reference Instruments for Improved Climate Observatories

The AS working group continues to believe that advanced climate observatories to benchmark the Earth's climate could provide opportunities to cross-calibrate operational sounding instruments to SI-traceable standards. Techniques like CLARREO could lead to climate quality measurements. This would increase the value of soundings for documenting and quantifying the climate state and decadal trends.

Recommendation AS-11 to space agencies

Develop, test, and implement an SI Traceable radiometric standard in space as soon as feasible.

Action AS-11

ITWG Co-chairs to re-iterate this recommendation to Space Agencies via CGMS.

2.4.5 New Technologies and Opportunities

The ASWG discussed the increasing use of small platforms and cubesats and their potential for implementing advanced sounding capabilities. It was noted that studies are currently ongoing to investigate the potential of such platforms. It was also noted that with the advancement of technology to establish high quality instruments on small satellites, the possibility to test associated micro-instruments on large operational polar platforms becomes a feasible option.

2.4.6 Ground Truth Sites

The ASWG has expressed concern over the recent closing of the tropical DOE ARM-sites (in operation since 1996), namely the Tropical Western Pacific (TWP) sites located either at

Manus Island, Papua New Guinea, Nauru Island, Republic of Nauru, or Darwin, Australia. The ARM TWP stations were located in the tropical western Pacific warm-pool, a region of key importance in terms of interannual climate anomalies (e.g., ENSO) as well as a heat engine driver the earth's atmosphere-ocean system. With the exception of the NOAA Aerosols and Ocean Science Expedition (AEROSE) campaigns (two being conducted in 2013, and one scheduled for Nov-Dec 2015), along with the TWP launches in 2013-2014 and PMRF launches in 2012-2014, the SNPP CrIS/ATMS cal/val program is now without a regular tropical ground truth site.

As time progresses and RAOB truth data are collected at other dedicated (e.g., ARM SGP, NSA, ENA) and reference (e.g., GRUAN) sites, we will find ourselves increasingly with a sample skewed toward extra tropical locations, and JPSS Long-Term Monitoring (LTM) will be compromised for EDRs/SDRs in the tropics. GRUAN sites-of-opportunity have also been utilized as part of the dedicated/reference validation strategy however as these sites launch radiosondes at synoptic times, good collocations with SNPP overpasses tend to be limited to sites located over northern Europe (i.e., near the Prime Meridian). As of this writing, there are no tropical GRUAN sites that collocate well with SNPP overpasses.

Recommendation AS-12 to Space Agencies

Re-establish regular dedicated radiosondes at one of the ARM TWP sites, or at a comparable tropical site (e.g., PMRF).

Action AS-12

ITWG Co-chairs to relay this recommendation to Space Agencies/Providers.