2.4 ADVANCED SOUNDER WORKING GROUP REPORT

Working Group members: Andrew Collard (co-chair), Allen Huang (co-chair), Bill Smith (co-chair), Paolo Antonelli, Alain Beaulne, Bill Campbell, Dong Chaohua, Zhaohui Cheng, David Crain, Mitch Goldberg, Sylvain Heilliette, Sara Hörnquist, Thomas King, Bjorn Lambrigtsen, Allen Larar, Jun Li, Yann Michel, Ed Pavelin, Eric Péquignot, Nikita Pougatchev, Filomena Romano, Stephen Tjemkes, Alexander Uspensky, Banghua Yan, Lihang Zhou

This working group 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 regarding to instrument specification, performance, data processing, and utilization. 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 infrared and microwave sounders and active sensors.

2.4.1 Geostationary Advanced Infrared Sounders

The group expressed disappointment in the cancelling of the HES geostationary advanced infrared sounder. It was noted that the operational status of the instrument resulted in extremely conservative estimates of the cost of the ground segment which in turn resulted in the project being much more expensive than a research mission would be. It was also noted that these concerns were specific to the GOES-R project and should not be interpreted as pertinent to the development of the advanced IR sounder on MTG and FY-4. It was agreed that a research mission is required to demonstrate the utility of a geostationary advanced infrared sounder and that the existing GIFTS instrument would be a good candidate to be flown in the near future.

Recommendation AS-1 to the space agencies

It is recognised that high spectral resolution imaging radiometers on geostationary platforms would be an important part of the future global observing system. It is recommended that a demonstration mission be conducted in the near future. GIFTS is the best current option for such a mission.

2.4.2 Calibration and Validation of Advanced Sounder Data

The need for sufficient characterisation, calibration and validation of advanced sounder observations was recognised by the group. The importance of having a traceable calibration was emphasised, both for pre- and post-launch phases. The requirements for the parameters that need to be calibrated need to be communicated from the data users to the data providers.

Recommendation AS-2 to data users

The group encourages pre- and post-launch instrument characterisation and traceable calibration. Requirements for the parameters to be characterised and their required accuracy should be communicated from the users (i.e., NWP, RT modellers, climate researchers) to the data providers.

The group noted that a variety of differing and complementary data sources are required for full validation of advanced sounders. The identification and correction of contamination in the SSMIS radiances based on NWP comparisons and a detailed knowledge of the spacecraft's orientation while in orbit was noted. Direct comparison with high-spectral resolution observations from aircraft under-flights of satellites provide valuable validation of absolute radiances, instrument line shapes, and derived products. Space agencies should provide adequate resources to allow full synergistic calibration activities.

Recommendation AS-3 to the space agencies

Cal/Val for advanced sounders needs to be an activity which receives sufficient resources. High-altitude airborne sensors, such as those associated with the NAST and ARIES airborne sensors, and upper air reference networks need to be added to complementary data sources, such as NWP, in order to validate the radiances and derived products to the very high accuracy and precision specified by the users.

The validation of the calibration and impressive stability of AIRS instrument was noted. Cal/Val efforts for IASI should similarly concentrate on establishing the in-flight performance of the instrument to a similar degree of accuracy.

Recommendation AS-4 to EUMETSAT/CNES

Cal/Val efforts for IASI should focus on establishing the in-orbit performance in order that early lessons can be learned for pre-flight testing of future interferometer sounders.

A high accuracy spectrometer, in a low inclination orbit (i.e. $<20^{o}$) would have the ability to cross-calibrate all polar orbiting satellites several times per day as well as geostationary satellites in different longitudinal sectors. These cross-calibrated radiances would be useful in the determination of biases between different satellite platforms and applying single station *in-situ* calibration to the entire constellation of satellites by linking cross-calibrated radiances with high temporal frequency. This may complement the existing and planned *in-situ* calibration campaigns for many separate satellites if the radiances from several satellites can be cross-calibrated with a single 'standard' satellite.

Recommendation AS-5 to the science community

The utility of applying the SNO (Simultaneous Nadir Observation) technique for an equatorial (inclination $<20^{o}$ degrees) LEO platform for the purpose of radiometric cross-calibration should be examined. Optimal orbital parameters (attitude and inclination), as well as sensor(s) type, should be determined so that recommendations for possible sensors on future equatorial satellites can be put forward.

2.4.3 Research on the benefits of dual polarisation on microwave conical scanners.

The group noted the potential benefits of dual polarisation in the surface sounding channels of SSMIS. The use of these data should be investigated and the conclusions

be considered when designing future microwave sounder systems. This led to a recommendation also picked up by the DA/NWP group.

Recommendation AS-6 to the science community (also DA/NWP-3)

The group encourages research into investigating some of the theoretical benefits of a combined microwave imager sounder (for example it may help with assimilation over difficult emissivity surfaces) relative to the conventional cross-track scanning sounders.

2.4.4 Sounder Field-of-View issue

At ITSC-XIV, considerable discussion was held discussing the impact of the spatial resolution for the CrIS instrument being poorer than that of the current HIRS/4. It was pointed out that there was never an intent to make the CrIS horizontal resolution poorer than the existing HIRS horizontal resolution (i.e., 10 km). Previously, it was recommended that the sounding yield and accuracy of the HIRS/4 be compared with that achieved with the lower spatial resolution (17 km) HIRS/3 instrument. This task was not completed because of optical element motion induced noise on the NOAA-18 HIRS/4. It was suggested that the HIRS/4 on MetOp-1 could be used instead and this change was made to the recommendation. An action was added, requiring the results of any study to be brought before the SOAT (the IPO Sounder Operational Algorithm Team) . A related recommendation (SSSP-4) and action (SSSP-11) is made in the SSSP report (section 2.6).

Recommendation AS-7 to the ITWG

It is recommended that trade-off studies be performed to determine the optimal field of view size for the CrIS, considering existing detector noise performance and the desire to increase the density of cloud free sounding observations as a result of decreasing the field of view size. As a first step, a comparison of the yield of MetOp-1 HIRS/4 clear air data versus NOAA 17 HIRS/3 data should be conducted.

Action AS-1 to whoever performs the above study

Once results are available, this item should be brought before the SOAT and/or JCSDA, to determine if a recommendation to the IPO is justified (i.e. to reduce the CrIS FOV size of 14km to 10km or less).

2.4.5 Objectives and Desirable System Requirements of Advanced IR Sounders

In order to ensure consistency of objectives and adequacy of the capabilities of various international contributions to the global observing system, the ITWG provides the following guidance on the primary measurement objectives and desirable radiometric measurement requirements to be met or exceeded for advanced IR sounders to be carried on future polar and geostationary orbiting satellites.

2.4.5.1 Advanced IR Sounder Primary Objectives

Polar Satellite Sounding Observations: The primary measurement objective for polar satellite sounding radiance observations is to infer temperature and water vapour profiles for Numerical Weather Prediction model initialization. The radiance spectra, or the retrieved profile data, to be assimilated need not be spatially contiguous for this and simultaneous microwave observations are generally available to assist in the interpretation of cloudy hyperspectral IR sounding data.

Geostationary Satellite Sounding Observations: The primary measurement objective of geostationary satellite sounding is the observation of lower and upper tropospheric temperature and water vapour dynamics, as needed to enable the nowcasting (i.e. short-term forecasting) of hazardous weather, and the production of water vapour tracer tropospheric wind profiles, used for regional and global NWP. Spatially contiguous, above cloud, sounding observations are needed to observe the atmospheric processes associated with storm systems and for tracing cloud and altitude resolved water vapour motion winds used for NWP.

Table 2.4-1 Measurement Thresholds for Future Advanced IR Sounders

			Polar		**Geostationary**			
Channel cm-1	**δν cm-1**	**Purpose**	***P***	**δS[1] km**	**P**	**δt[2] min**	**δS[3] km**	**Remarks**
660-680	0.6	Strat. Temp.	1	100	-	-	-	Polar satellite only
680-800	0.6	Trop. Temp	1	15	1	30	5	Fundamental Band[4]
800-1000	0.6	T_s, H_2O, Cld	1	15	1	15	5	Fundamental Band[5] Cls, Sfc. T/Emis. & H_2O
1000-1100	0.6	O_3	1	15	3	30	5	O_3, Stratospheric Wind
1100-1590	1.2	T_s, H_2O, Aerosol/Dust	1,2	15	2,1	15	5	Water Vapor Flux Trop. Wind Profiles[6]
1590-2000	1.2	H_2O, T_s, Cld	2,1	15	1,2	15	5	Water Vapor Flux Trop. Wind Profiles[6]
2000-2200	0.6	CO, T_s, Cld	3	15	2	60	5	Trace Gas/Air Quality
2200-2250	2.5	Trop. Temp	2	15	2	15	5	Clear Ocean Day and Land/Ocean Night Utility[8]
2250-2390	2.5	Strat. Temp.	4	100	-	-	-	Night-time Utility[8]
2386-2400	2.5[9]	Trop. Temp	4	15	-	-	-	Night-time Utility[8]
2400-2700	2.5[10]	T_s, Cloud	3	15	-	-	-	Clear Ocean & Night Land Utility[8]

Table definitions: δn (spectral resolution, unapodized for the case of an FTS, assuming an instrument self apodization of less than 5%), P (priority), δt (refresh rate), δS (footprint linear resolution). The values given are the threshold requirements with objectives being better by as much as practical from a technology and cost point of view. Priority 1 measurements are required to fulfill advanced sounding primary objectives.

[1] For cloud clearing, the highest spatial resolution is desired

[2] Refresh rate for regional (3000 km x 3000 km) area coverage at full spectral resolution as desired for convective storm applications of the data (i.e., thermodynamic stability and water vapor flux measurement). Broader area coverage (e.g., 9000 km x 9000 km), with 30 to 60 minute refresh rates, is desired for temperature, moisture, and wind profile measurements for NWP applications, but these can be performed at lower spectral resolution (e.g., 2 x δν).

[3] Spatial contiguity is required to observe atmospheric dynamical processes
[4] This band is fundamental for day/night high vertical resolution temperature profiles required for determining atmospheric constituent profile and cloud parameters from hyperspectral radiance emission measurements
[5] High spectral resolution is needed to resolve on-line/off-line radiance determinations of surface reflectance/emissivity and to separate water vapor/cloud/dust contributions
[6] High spectral resolution provides shortwave window observations, near the edges of these bands, as needed for cloud clearing. Either longwave (1100-1590 cm^{-1}) or shortwave (i.e., 1590-2000 cm^{-1}) sides of water vapor band can be priority 1. Having measurements covering both longwave and shortwave sides of the water vapor band will optimize the water vapor profile accuracy throughout the atmospheric column. Thus, if one side is chosen as Priority 1 then the other side becomes a Priority 2.
[7] Spectral resolution resolves CO lines and provides shortwave window observations near 2000 cm^{-1} desired for cloud clearing, surface temperature, and cloud property estimation.
[8] Reflected sunlight complicates the daytime utility of these data for cloudy sky and/or land surface conditions.
[9] A spectral resolution of 0.05 cm^{-1} is desired to resolve the contribution from in-between the absorption lines.
[10] The AIRS 2616 cm^{-1} channel, with 2.5 cm^{-1} resolution, has been found useful for cloud detection and sea surface temperature measurement.

Recommendation AS-8 to the space agencies

In order to ensure consistency of objectives and adequacy of the capabilities of various international contributions to the global observing system, it is recommended that space agencies follow the ITWG guidance on desirable radiometric measurement requirements to be met or exceeded for advanced IR sounders to be carried on future polar and geostationary orbiting satellites.

2.4.6. New Initiatives for Geostationary Sounding

At ITSC-XIV, it was recommended that studies be conducted to identify the requirements for future microwave sounders, both for polar and geostationary orbits. These studies are still required.

Recommendation AS-9 to the research community and space agencies

It is recommended that relevant organizations conduct studies to identify the capabilities of microwave sounders and develop consensus user measurement requirements for future systems. This should be done for LEO as well as GEO. It is recommended that this information be consolidated in a table similar to that presented above for the IR sounder.

Action AS-2

Bjorn Lambrigsten to make a draft table summarising the requirements for microwave sounding systems.

2.4.7 International Geostationary Laboratory

The IGeoLab initiative to promote international cooperation to place and test advanced sounders (e.g., GIFTS and MW) in geostationary orbit was also noted. This initiative should be supported.

Recommendation AS-10 to the space Agencies

The WMO IGEOLAB concept should be supported.

2.4.8 Distribution and Optimal Use of Advanced Sounder Radiance Data in NWP:

The current use of advanced sounder data in NWP is very conservative. The limitations are the cost of radiative transfer modelling and the transfer of large observation datasets from the satellite agencies to the NWP centres. Full use of these data requires the efficient use of all the information in a compressed form. Candidates include Principle Component (PC), reconstructed radiances, and retrievals. Investigations with reconstructed radiances are in progress, as they are most similar to the data already being assimilated. It was recognised that the use of principal components and retrievals would present much larger scientific and technical challenges to the NWP community. In choosing the optimal strategy to use, consideration must be given to the specification of the observation error covariance matrix, quality control, cloud detection and monitoring.

Recommendation AS-11 to NWP Centres

It is recognised that more efficient use of the full advanced IR sounder spectrum is desirable within NWP data assimilation. NWP centres are encouraged to consider research into the direct use of principal components and/or retrievals from advanced IR sounders in assimilation systems.

It was noted that the use of principal components to compress advanced sounder data is fundamentally a lossy technique. For many applications the small amount of lost data may be acceptable, but it can be problematic when the principal components have been generated in such a way that the desired signals are not present. For this reason, care must be taken that for general archiving and transmission of data, the compression scheme should be lossless. Datasets with lossy compression can be distributed if they are identified as such.

Recommendation AS-12 to data providers

It is noted that the use of principal components to represent advanced sounder spectra carries the danger of the loss of signals that are not properly represented in the training set. Care must be taken to ensure that data compression methods used for transmission and archiving of satellite data be lossless.

2.4.9 MW Sounder Deployment with Future IR Sounders

It is desirable to fly microwave sounders with future IR sounders configured in such a way as to enable simultaneous observations (i.e. collocated in space and time). Cloud-clearing will be enhanced and sub-cloud level information will be provided for spatial and temporal continuity. Such MW observations are desired to be obtained together with the observations from future advanced IR sounders.

Recommendation AS-13 to the space agencies

Microwave sounders should be considered to always be flown with future advanced IR sounders, to provide simultaneous observations at the same time and at the same location.

2.4.10 Imagers with Sounding Channels to Support Future IR Sounders

High spatial resolution imaging radiometers which possess one, or more, lower tropospheric IR sounding channels (e.g., MODIS) provide valuable data for cloud-clearing and for the quality control of cloud-cleared radiances from advanced IR sounding instruments. Furthermore, for the case of complex partly cloudy scenes, where cloud clearing is unsuccessful, the imager sounding channel radiances provide valuable information for filling gaps in advanced sounder information otherwise lost below clouds. It is desirable that imaging radiometers fly with future IR sounders and that they possess sounding channels in addition to their "window" channels.

Recommendation AS-14 to the space agencies

Future high spatial resolution imaging radiometers to be flown with advanced IR sounding instruments should possess lower tropospheric IR sounding channels to support the interpretation and enhance the utilization of advanced IR sounding spectrometer observations obtained for cloudy sky scene conditions.

2.4.11 Move to Single Contractor's Responsibility for Satellite Sounder Systems

Historically, environmental satellite systems have been developed by a partnership of government (NASA, NOAA, & EUMESAT, for example), industry and university science communities. While the technological expertise of industry is a key part of the entire system, industry is not well suited to supplying the broad perspective on the use of these future systems nor is it well suited to developing the necessary pre-launch simulations, ground data processing science algorithms, and associated data application approaches. The ITWG believes that the single contractor approach adopted by the NPOESS program, and is currently considered by NOAA for the development of the GOES-R system and any other future operational satellite systems, would tilt the resource balance so that it would undermine the ability of government to provide continuity into the future and would place much of the science community under the financial control of industry, inhibiting the science community from acting as an objective, commercially neutral, body in the development and application of future satellite systems.

Recommendation AS-15 to the space agencies

ITWG strongly recommends that certain elements of future operational satellite systems (e.g., the data processing, algorithm and product development system, the evaluation and validation, and the training and outreach programmes), should be led by government agencies. It is also recommended that the users of the satellite system play a key role in the definition of the characteristics of this system