

2.4 ADVANCED SOUNDERS

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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 where necessary. 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 Sounder field-of-view issue

Considerable discussion was held regarding the intended spatial resolution for the CrIS instrument. 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).

Recommendation AS-1 to space agencies

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 observations as well as decrease the field of view size. As a first step, a comparison of the yield of NOAA 18 HIRS clear air data versus NOAA 16 HIRS data should be conducted. If the results of these trade-off studies strongly support a change to the CrIS spatial sampling characteristics, a recommendation would be prepared to take to the Joint Agency Requirements Group.

2.4.2 Measurement objectives for Advanced IR Sounders

In order to insure 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 the minimum radiometric measurement thresholds for advanced IR sounders to be carried on future polar and geostationary orbiting satellites.

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 vapor profiles for Numerical Weather Prediction (NWP) model initialization. The radiance spectra, or alternatively the retrieved profile data, to be assimilated need not be spatially contiguous for this application. Simultaneous microwave observations are generally available to assist in the interpretation of clouded 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 vapor dynamics, as needed to enable the nowcasting (i.e., short-term forecasting) of hazardous weather, and the production of water vapor 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 vapor motion winds used for NWP.

Channel cm-1	$\delta\nu$ cm-1	Purpose	Polar		Geostationary			Remarks
			P	δS^1 km	P	δt^2 min	δS^3 km	
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 ₂ O, Cld	1	15	1	15	5	Fundamental Band ⁵ Cls, Sfc., T/Eemis. & H ₂ O
1000-1100	0.6	O ₃	1	15	3	30	5	O3, Stratospheric Wind
1100-1590	1.2	T _s , H ₂ O Aerosol/Dust	1,2	15	2,1	15	5	Water Vapor Flux Trop. Wind Profiles ⁶
1590-2000	1.2	H ₂ O, 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 ⁷
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 and Night Land Utility ⁸

Table 2.4-1. Measurement Threshold for Future Advanced IR Sounders

Table definitions: $\delta\nu$ (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., $2 \times \delta\nu$).

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 limits 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.

Common Advanced IR Sounding Measurement Requirements:

- **NEdT:** A spectrally random noise level of less than 0.2 K, for a US Standard Atmosphere scene temperature at the δt and δS specified above, is desired to optimize sounding vertical resolution. A spatially random noise level of less than 0.4 K, for a US Standard Atmosphere scene temperature at the δt and δS specified above, is desired to minimize the noise in the spatial gradients of the retrieved profiles.
- **Co-registration:** Co-registration means the degree to which different channels see the same scene taking into account optical alignment, field of view response, diffraction, etc. This co-registration error is generally referred to as the C_{ij} error. Hyperspectral radiances are observed within measurement bands (e.g., as provided by a single detector for a FTS instrument or provided by a focal plane array detector module for a dispersive instrument). It is desired to co-register all the fields of view of the tropospheric sensing spectral channels observed within a measurement band, (e.g., $600\text{-}1100\text{cm}^{-1}$, $1100\text{-}2000\text{cm}^{-1}$, and $2000\text{-}2700 \text{ cm}^{-1}$) to within 1% of the window channels (i.e., $C_{ij} \geq 0.99$) within that band (further refinement of the co-registration threshold requires further study). The window channels are used for cloud clearing and for accounting for surface emissivity and surface temperature contributions to the observed radiance as needed for atmospheric profile retrieval. The fields of view of all spectral channels within each measurement band should be spatially contiguous and co-registered as closely as practical with all spectral channels within all other measurement bands. Ideally, one would want all spectral channels to be co-registered to within 2% ($C_{ij} \geq 0.98$).
- **Absolute radiometric accuracy:** An absolute accuracy better than 0.3 K is desired for weather and climate applications of the data.
- **Temporal stability:** A temporal stability of the calibrated radiance measurements that is better than 0.1 K is desired for climate applications of the data.
- **Spectral instrument line shape:** A knowledge and stability of better than $3 \text{ part} / 10^6$ is desired to achieve the high spectral precision needed for high vertical resolution atmospheric profiling, as well as for meeting the desired spatial and temporal stability of the radiance measurements desired for weather and climate applications of the data.

Recommendation AS-2 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 the minimum radiometric measurement requirements for advanced IR sounders to be carried on future polar and geostationary orbiting satellites.

2.4.3 Calibration and validation of Advanced Sounder data

The importance of calibration/validation (Cal/Val) activities associated with future advanced atmospheric sounders was discussed, and concern was expressed over a perceived lack of emphasis being placed in these areas in planning for upcoming missions (i.e. METOP, NPP, and NPOESS). Post-launch Cal/Val activities are critical for verifying the quality of the entire measurement system for advanced sounders (i.e. the sensor, processing algorithms, and direct/derived data products), and is a prerequisite step for optimising post-measurement data usage by the operational weather, climate research, chemistry, and broader scientific communities. The $1 \text{ K} / \text{km}$ layer and $15 \% / 2 \text{ km}$ layer product accuracy, coupled

with the very high radiometric accuracy and precision requirements imposed on the hyperspectral sounding spectrometers, makes adequate Cal/Val for these instruments problematic (i.e., the use of radiosondes and NWP model forecasts alone cannot provide sufficient validation to the levels of accuracy and precision required).

Recommendation AS-3 to the space agencies

Cal/Val for advanced sounders needs to be an activity which receives sufficient resources. While radiosondes and NWP fields can provide a basic validation, high-altitude airborne sensors, such as those associated with the NAST and ARIES airborne sensors, and upper air reference networks (see Climate WG Report) need to also be included in order to validate the radiances, and derived products, to the very high accuracy, and precision, specified for advanced sounding instruments.

2.4.4 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 modeling and the transfer of large observation datasets from the satellite agencies. 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. 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.

In the day-1 METOP system, EUMETSAT cannot distribute the full IASI dataset on the GTS in near-real-time. A subset of 300-500 channels will therefore need to be distributed. A method for choosing such a subset using C. Rodger's selection method based on degrees of freedom for signal has been described in the poster presented at ITSC-XIV, by Collard and Matricardi.

Action AS-1

NWP centers should review the channel selection method proposed at ITSC-XIV to ensure that the channels selected will meet their initial requirements for NWP applications and provide any comments to the ITWG Co-Chairs.

Recommendation AS-4 to advanced sounder research community

The advanced sounder research community needs to consider issues such as: (1) the ability to detect cloud such that the impact of undetected cloud on the observed radiances is less than 0.2K, (2) the correct usage of Principal Components (PCs), (3) effective and efficient quality control (particularly for PCs), (4) the continued development of fast models in super channel or PC space, that are robust, fast and sufficiently accurate, and (5) the quantification of the observational and forward model error covariance matrices.

2.4.5 New initiatives for geostationary sounding

The progress, since ITSC-XIII, of advanced MW sounder/imagers for geostationary orbit was reviewed. In particular, the progress made with the synthetic aperture approach was reported at the meeting. The IGeoLab initiative to promote international cooperation to place a MW sounder/imager in orbit was also noted. As a result of these discussions the following recommendation was formulated.

Recommendation AS-5

It is recommended that relevant organizations conduct studies to identify the functions of microwave sounders, identify users, and develop consensus measurement requirements for future systems. This should be done for LEO as well as GEO sounders. It is recommended

that this information be consolidated in a table similar to that presented above for the IR sounder.

Recommendation AS-6

For future microwave sounders, it is recommended that efforts be devoted to improving radiometric sensitivity and horizontal spatial resolution. It is further recommended that scattering models, which will enhance rain rate estimates and enable retrieval of vertically resolved rain, be further developed.

2.4.6 MW Sounder deployment with future IR Sounders

Examples were shown at ITSC-XIV of how microwave sounders provide data that can assist the interpretation of cloudy IR observations and provide valuable information for filling gaps in advanced sounder information below opaque cloud levels. 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 continuity. Such MW observations are desired for future advanced IR sounders.

Recommendation AS-7 to space agencies

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

2.4.7 IR 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 incurred 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-8 to space agencies

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

2.4.8 ATMS noise performance compared with actual AMSU performance

The current ATMS specification is consistent with the AMSU performance specification, which is significantly inferior to actual AMSU performance. The polarization of the ATMS in all channels is horizontal while it is vertical for most AMSU channels.

Recommendation AS-9 to space agencies

A study should be undertaken to determine the impact of horizontal and vertical polarization for future MW sounders, taking into account the impact on “clear sky” information content as well as the ability to detect clouds and precipitation. The goal of this study should be to compare the AMSU and ATMS systems to determine what is best for future microwave sounders. The study will also inform users what they can expect from the ATMS data.

2.4.9 Low inclination orbit for satellite cross calibration

A high accuracy spectrometer in a low inclination orbit (i.e. $<20^\circ$) 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 can be cross-calibrated with a single 'standard' satellite.

Recommendation AS-10 to science community

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

2.4.10 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), 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 to the development of future satellite systems (e.g., the GOES-R system), 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-11 to space agencies

ITWG strongly recommends that certain elements of future satellite systems (e.g., the data processing, algorithm and product development system, the evaluation and validation, and the training program), be led by government agencies, together with its academic teams, in partnership with industry. It is also recommended that the users of the satellite system play a role in the definition of the characteristics of this system.

2.4.11 Transmission of Recommendations

Action AS-2

Advanced Sounders WG Co-Chairs to forward recommendations to specified groups by end of 2005.