2.4 ADVANCED SOUNDERS

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

Working Group members: Dorothee Coppens (Co-Chair, EUMETSAT), Dave Tobin (*Co-Chair, SSEC/UW-Madison*), *Mathieu Asseray (CNRM/CEMS), Nigel Atkinson (Met Office), Thomas August (EUMETSAT), Nancy Baker (NRL), Alain Beaulne (Meteorological Service of Canada), Chris Barnet (Science and Tech. Corp.), Chris Burrows (ECMWF), Xavier Calbet (AEMET), Philippe Chambon (Météo-France), Junye Chen (GST), Keyi Chen (Chengdu University of Information & Technology), Yong Chen (NOAA/STAR UMD), Chu-Yong Chung (NMSC/KMA), Andrew Collard (IMSG@NOAA/NCEP/EMC), Olivier Coopmann (CNRM, Université de Toulouse, Météo-France, CNRS), David Duncan (ECMWF), Reima Eresmaa (ECMWF), Robin Faulwetter (DWD), Nadia Fourrie (CNRM, Météo-France, CNRS), Louis Garand (ECCC), Dmitry Gayfulin (Hydrometeorological Centre of Russia), Mitch Goldberg (NOAA), Songyan Gu (NSMC, CMA), Vincent Guidard (Météo-France), Liam Gumley (SSEC/UW-Madison), Chawn Harlow (Met Office), Erin Jones (UMD CISESS), James Jung (CIMSS), Eric Jurado (CNES), Norio Kamekawa (JMA), Hee-Jung Kang (NMSC/KMA),Bryan Karpowicz (GESTAR/USRA/NASA GMAO), Dieter Klaes (EUMETSAT), Christina Koepken-Watts (DWD), Bjorn Lambrigtsen (JPL), Stephane Laroche (ECCC), Heather Lawrence (ECMWF), Zhenglong Li (CIMSS/SSEC), Agnes Lim (CIMSS/SSEC), Qifeng Lu (NSMC), Clement Luitot (CNES), Silke May (DWD), Masami Moriya (JMA), Kozo Okamoto (JMA/MRI), Marc Pondrom (DWD), Chengli Qi (NSMC), Kirsti Salonen (ECMWF), A.K. Sharma (NOAA/NESDIS), Eric Simon (UCAR/NRL), Karen St Germain (NOAA/NESDIS), Ruth Taylor (Met Office), Ricardo Todling (NASA/GMAO), Maria Toporov (University of Cologne), Francesca Vittorioso (CNRM, Météo-France, CNRS), Zhipeng Xian (IAP), Hu (Tiger) Yang (University of Maryland), Ryoying Yin (IAP), Dan Zhou (NASA), Lihang Zhou (NOAA/NESDIS/STAR)*

2.4.1 Existing and planned sensors and data

Chinese satellites

The upcoming FY-3E and FY-4B satellites will be launched in the next year. FY-3E will be in the early morning orbit and includes an improved HIRAS with a 3x3 versus 2x2 FOV array and also possible removal of the FY-3E HIRAS spectral gaps. There was a request to have full spectral resolution (FSR) version of the HIRAS data available from the start of the operational mission. FY-4B will include an improved GIIRS, as compared to the research GIIRS on FY-4A. For both platforms, commissioning is expected to take six months, with data available afterwards.

Recommendation AS-1 to space agencies (CMA)

Disseminate the HIRAS and GIIRS data six months after launch if possible, and not only via EUMETCAST but also to the Global User Community.

Recommendation AS-2 to space agencies (CMA)

Consider to make available as soon as possible the HIRAS spectra at full spectral resolution for all bands. This also applies to all future hyperspectral sounders.

Recommendation AS-3 to space agencies (CMA)

FY-3D GIIRS data has good noise performance below the current longwave cutoff of 700 1/cm; CMA to investigate and consider extending the output range of FY-3D GIIRS spectra to ~680 1/cm.

Action AS-1 on ITWG Co-chairs
Bring these recommendations to the attention of space agencies at CGMS.

Russian satellites

Regarding IKFS-2 data and the possibility to have direct broadcast: it will be possible but only for the one from 2025 on. We will keep then the recommendation from ITSC-21.

Recommendation AS-4 to space agencies (Roshydromet and Roscosmos)
ASWG recommends establishing a Direct Broadcast capability for the data on the Meteor-M satellite, in particular for the hyperspectral IKFS-2 data.

Action AS-2 on ITWG Co-chairs
Bring this recommendation to the attention of space agencies at CGMS.

Meteor-M N2-2 will be launched in July 2019 and data will be released in 2 or 3 months (probably in January 2020).

Action AS-3 on ASWG co-chairs
To follow the data release date and circulate the information to the ASWG.

European satellites

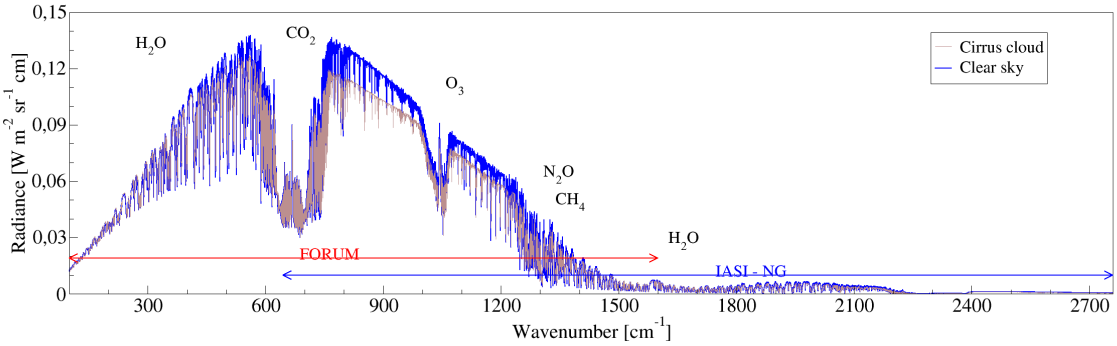
The MTG-IRS mission was presented, showing the interest in such a mission: GEO hyperspectral sounders are providing high spatial and temporal resolution and coverage, a unique dynamic view of the atmosphere, 3D winds, which are important for NWC and NWP. It supplements the forecasts, independent observations, gaining precision and lead-time in issuing warnings.

Particular attention on the amount of data it implies in terms of downlink and dissemination has been addressed. The dissemination will be done in Principal Component with a new methodology called hybrid approach, discussed in section 2.4.3.

Action AS-4 on ASWG co-chairs
To circulate to ASWG members the information on the bandwidth for the MTG IRS L1 PC dissemination as soon as it is available.

The future mission FORUM (Far-infrared Outgoing Radiation Understanding and Monitoring) was presented and discussed. FORUM is an ESA Earth Explorer 9 with a 3-year lifetime mission with the following characteristics:

- 100-1600 cm^{-1}: highly sensitive to upper tropospheric water vapour and to cirrus clouds;
- Nadir viewing only;
- Sun-synchronous orbit at an altitude of about 817 km, flying in tandem with IASI-NG; and
- Ground footprint is a single pixel of about 15 km.



This mission will be further discussed at future ITSC meetings.

2.4.2 Next generation sensors and data

NOAA is moving forward with the pre-phase A for new missions. Several studies on what NOAA could have with LEO/GEO orbits, trying to identify mixed-capabilities and Tundra orbit have been initiated.

Karen St. Germain presented NOAA's view: a constellation with a mission in Tundra orbit, GEO ring, and NOAA imagers.

Note that the GOES-R series and JPSS will carry the same instruments until 2035 which means there is no evolution in terms of instrument improvement.

GEO-LEO trade-off

NOAA is looking at the minimum importance for applications to decide what to do. Currently, the "reference constellation" includes East and West GEO platforms with Imagers, and LEO "Sounder satellites" (IR + MW). The US is thinking of quantity (several small LEO instruments), versus quality. This is mainly for NWP applications. The typical useful lifetime of small satellites is based on 3 years of design life.

Particular attention has been put on having IR+MW sounders on the same platform; the imagers could be on another one. Most important is to ensure good inter-satellite calibration and consistency for both IR and MW.

Action AS-5 on Karen St. Germain

To provide information on the new NOAA trade study mission.

Action AS-6 on ASWG Co-chairs

To organize ASWG members and provide feedback to NOAA on all aspects of the proposed mission(s).

Recommendation AS-5 to space agencies

To keep IR and MW sounders together on the same platform.

Recommendation AS-6 to space agencies

To study whether or not to have the imager on the same platform.

Recommendation AS-7 to space agencies

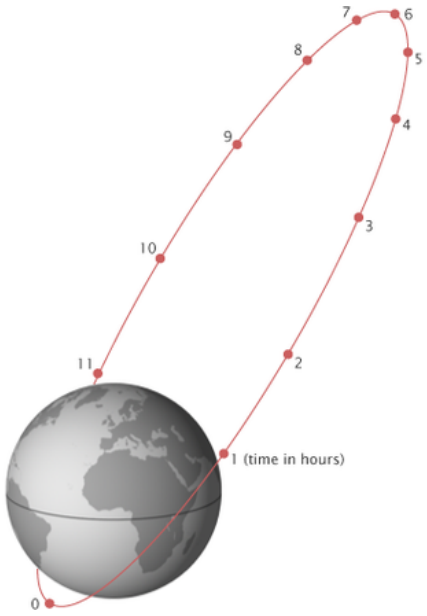
To keep good inter-satellite calibration and consistency for both IR and MW.

Action AS-7 on ITWG Co-chairs

Bring these recommendations to the attention of Space Agencies at CGMS.

Tundra orbits

For the Tundra orbits, ECCC has studied largely those orbits, and while they are considered a good option, they are not the preferred option.



Action AS-8 on Louis Garand

To send documentation on those studies to ASWG.

2.4.3 Efficient dissemination of Hyperspectral IR data

From the last CGMS: Develop efficient standardized data handling for high-resolution imaging and hyperspectral instruments, employing novel methods like dissemination of hyperspectral infrared data based on Principal Component Analysis.

EUMETSAT has presented their hybrid PC methodology for MTG-IRS L1 products to address all user needs (including Atmospheric Composition). EUMETSAT reported that they have initiated several studies with NWP centers to assimilate PC. DWD and Meteo-France have observed no difference when using PC in comparison with original radiances. More study results are expected in the future from the Atmospheric Composition user community.

The hybrid method of EUMETSAT has already been endorsed by the NWP WG at ITSC-21.

Moreover, which noise should we use when using PC? The answer was that the observation error matrices can and should be constructed in the same way as is done empirically when using original radiances, i.e., to include error correlations coming at least from the forward modelling.

Recommendation AS-8 to ASWG

To look at available PC and give feedbacks to ASWG co-chairs.

Recommendation AS-9

The hybrid method of EUMETSAT should be taken as the best practice to establish PC for IRS on MTG.

Additionally, as opposed to using a relatively small subset of spectral channels that are used in some applications, PCs enable the full information and signal-to-noise advantage of high spectral resolution spectra to be conveyed to the users. Refer to appendix A for more information on this topic.

Recommendation AS-10 to NWP centers

To investigate the use of theoretical PC reconstructed radiances, for a representative set of spectral channels, to be used in the radiance assimilation process.

2.4.4 Re-iterating previous high priority ASWG recommendations

Recommendation AS-11 to satellite agencies (NOAA, JAXA)

Consistent with numerous previous ITWG and ASWG recommendations, and consistent with the WMO Integrated Global Observing System (WIGOS) Vision for the Global Observing System in 2025 and 2040, the ASWG strongly recommends that space agencies develop and implement plans to fill the gaps in IR hyper-spectral sounding within the Geostationary constellation.

Recommendation AS-12 to satellite agencies

The constellation of at least three polar orbits (early morning, morning, and afternoon), each with full sounding capabilities (IR and MW), should be maintained. The overpass times of operational satellites with sounding capability (IR and MW) should be coordinated between agencies to maximize their value.

Recommendation AS-13 to satellite agencies

Implement high spatial resolution and contiguous sampling detector arrays in future hyperspectral infrared sounding instruments.

Recommendation AS-14 to satellite agencies

To develop, test, and implement an SI-traceable radiometric standard in space as soon as feasible.

Action AS-9 on ITWG Co-chairs

To re-iterate these recommendations to space agencies via CGMS.

Appendix A to the Advanced Sounder Working Group report

To: ITWG Advanced Sounder Working Group

From: William L. Smith, Past WG Co-Chair

Background
There generally seems to be a lack of understanding of the source of vertical resolution information content of hyper-spectral resolution measurements. Improved vertical resolution results from the reduced weighting function width, resulting from their higher spectral resolution that acts to avoid the smearing of on-absorption line atmospheric radiance contributions with in-between absorption line atmospheric radiance contributions to individual channel radiances. However, this improvement in individual spectral channel radiance weighting function resolution is only about 15-20%.

Instead, it has been shown that the improved vertical resolving power comes from the order of magnitude improvement in signal-to-noise (S/N) provided by the use of the complete radiance spectrum of hyper-spectral radiances, which contains 1000s of noise independent radiance observations rather than the 10s of channels of observations as provided by multi-spectral satellite sounding sensors (e.g., HIRS and AMSU). An order of magnitude S/N improvement is consistent with the "Square Root Law" defined in probability theory (i.e., the accuracy of $\bar{X}$ n as an estimator of μ is inversely proportional to the square root of the sample size n). The atmospheric signal increases to the first power of the number of spectra radiances being used but the noise, being spectrally random, increases to the square root of the number of spectra radiances being used.

Thus, the S/N of the atmospheric signals being sensed with radiance spectra tends to increase by the square root of the number of spectral channels being used in the atmospheric signal retrieval process. Since 1000/10 = 100, the S/N enhancement of hyper-spectral sounders relative to multi-spectral sounders tends to be an order of magnitude, i.e., square root (100). This S/N enhancement is critical in trying to resolve small vertical scale feature signals contained within a system of low vertical resolution radiance measurements.

Problem
Most Numerical Weather Prediction center users believe that it is proper to use a small subset of the channel radiances, provided by the hyper-spectral sensors, in order to optimize computational efficiency. The rationale is that the information being provided by other channels with weighting functions similar to those channels within the subset are only providing redundant atmospheric information. Although this argument is valid with respect to the atmospheric signal contained in the radiance within single spectral channels, this argument does not recognize the detrimental consequence of channel selection regarding the large reduction in atmospheric vertical feature S/N contained in the small subset of observations relative to that contained in the complete system of observations being used to resolve these vertical features. As a consequence, these hyper-spectral observation data are not being used to achieve their full potential to improve weather prediction. One promising exception is that ECMWF has stated that it is beginning to use PC reconstructed radiances for a representative set of spectral channels. Since the PCs represent the entire spectrum of the hyper-spectral radiance measurements, the desired S/N enhancement of vertical resolution is being achieved by this process, assuming that the exact same PCs are used to create the model background calculated radiances required for the radiance assimilation process.

Also, it is important that the PCs used for the radiance reconstruction process be based on theoretical radiative transfer model calculations of the hyper-spectral radiance spectrum for a diverse sample of surface and atmospheric conditions (e.g., obtained from surface and atmospheric measurement climatology or possibly model background specified surface and atmospheric conditions for a large number of cases). Using radiative transfer calculated radiances, as opposed to actual observations, trace gas, cloud and aerosol, and surface emissivity contributions to the observed radiances can be accounted for without the influence of state variable vs. radiance observation time and location mismatch noise and radiance measurement noise. Both measurement "mismatch" and instrument noise act to decrease the ability of the PCs to extract the full atmospheric information content of the radiance measurement spectra used in the model radiance assimilation process.