**GSICS Microwave Subgroup Technical Workshop Notes**

**February 28 – March 2, 2022**

**Day 1**

**35 Attendees:** Jun Park (KMA), Xiaolong Dong (NSSC), Qifeng LU (CMA), Mark Liu (NOAA), John Yang (UMD), Robbie Iacovazzi (NOAA), Cheng-Zhi Zou (NOAA), Shengli Wu (CMA), Misako KACHI (JAXA), Karsten Fennig (DWD), Craig Donlon (ESA), Raffaele Crapolicchio (ESA), Stefano Casadio (ESA), Tim Hewison (EUMETSAT), Kazuki Kodera (JMA), Arata Okiyama (JMA), David Duncan (ECMWF), Hu “Tiger” Yang (UMD), Keichi (JAXA), Jun Zhou (UMD), Martin Burgdorf (Univ. Hamburg), Manik Bali (NOAA), Emily Liu (NOAA), Ed Kim (NASA), Pradeep Thapliyal (ISRO), Matt Sammons (NASA), Steven English (ECMWF), Hidehiko MURATA (JMA), Manoj Mishra (ISRO), Fred Wu (NOAA), Vinia Mattioli (EUMETSAT), Neerja sharma (ISRO), Niels Bormann (ECMWF), Yong-Keun Lee (UMD), Jieying HE (NSSC), Nimisha Singh (ISRO)

SESSION: *Past, Current, and Future Microwave Instruments*

1. (1100-1105) Welcoming Introduction and Logistics [Qifeng Liu (CMA) and Mark Liu (NOAA) (MW Subgroup Co-chairs)]

The subgroup co-chairs welcomed the participants, and outlined the workshop. Also, Robbie Iacovazzi informed the participants of the MDPI Remote Sensing Special Issue: “Microwave Remote Sensing of the Atmosphere: Current Progress and Future Vision.”

1. (1105-1120) Progress on microwave sensors of FY satellites [Shengli WU (CMA)]

Communicated the past and future of microwave sensors on the FY satellites – e.g., Microwave Radiation Imager (MWRI), Microwave Temperature Sounder (MWTS), Microwave Humidity Sounder (MHS), and WindRad instruments. It also provided some insight into FY-3E microwave instrument performance relative to other sensors.

Q&A

* Cheng-Zhi Zou – What do you mean when you say early morning and drift orbit? Is the FY-3E orbit stabilized?
	+ The FY-3 will have maneuvers to correct for drift. The “drift orbit” satellites are lower-orbiting satellite (~400 km) that will need correction more frequently.
1. (1120-1135) Past, Current, and Future of Russian Microwave Radiometers [Prof. Alexander Uspensky (PLANET)] (MOVED TO DAY 3)
2. (1135-1150) Introduction of The Advanced Radiance Transformation System (ARTS) software package [Tiger Yang (NOAA)]

This talk described the motivation for and the calibration physics related to the ARTS modeling tool. It was made clear that the tool is available to the GSICS community through GitHub.

Q&A:

* Manik Bali – Is there a mailing list that users can access if they need support regarding users of the model?
	+ Tiger - Send an email to Tiger. Something more elaborate may be developed in the future. Maybe use the GSICS Wiki for this? Could this be a subgroup deliverable?
* Manik Bali – Is there a Python version?
	+ It is in the plan.
* Tim Hewison - The Atmospheric Radiative Transfer Simulator (ARTS) has been around since 2006, and your model is not associated with that. Can you call you model something else?
	+ Tiger Yang - Did not realize the name "ARTS" is already taken by the European RTM model when we had the name to the calibration software package. We can change the name of our model, and new name suggestions are welcome.
1. (1150-1205) Developments and future plans of Water-related Microwave Missions in Japan [Misako KACHI (JAXA)]

This JAXA presentation gives insight into the past and next generation JAXA instruments, and applications of these data. Instruments discussed were the Tropical Rainfall Measurement Mission (TRMM) Precipitation Radar (PR) and Global Precipitation Measurement (GPM) Dual-polarization PR. It also discusses the Microwave Scanning Radiometer (MSR) and Advanced MSR (AMSR) on EOS Aqua and Adeos. It also spoke of the GOSAT-GW AMSR-3 and TANSO-3 on and the EarthCare Cloud Profiling Radar (CPR). Each instrument discussion provided insight into Radio Frequency Interference (RFI) Mitigation from past and future instruments.

1. (1205-1220) NOAA-20/JPSS1 ATMS performance and RFI plans for future NOAA sounders [Ed Kim (NASA)]

The current Joint Polar Satellite System (JPSS) Advanced Technology Microwave Sounders on Suomi-NPP and NOAA-20 noise equivalent delta temperature (NEDT), striping indices, and channel-to-channel correlation before and after launch were compared. It also revealed the lack of RFI mitigation techniques applied to the current system, which is slated to exist until 2040. Future missions focus mainly on CubeSat/SmallSat technology that can support microwave sounders that range from 118 to 183 GHz. There is also interest in hyperspectral microwave technology. Regardless of the future architecture, it was expressed that RFI mitigation needs to be reconciled within each mission, and gave some insights into possible approaches.

Q&A

* Tiger Yang – Do you have more info about the NOAA Quicksounder?
	+ Ed – The Quicksounder mission consists of the ATMS Engineering Development Unit (EDU).
	+ This EDU was not intended to fly in space, but it is capable of flying with minor modifications, and comprehensive testing.
	+ A focal point of the mission is to determine if we can operate state-of-art radiometers within the “New Space” paradigm. This paradigm focuses on using SmallSat or CubeSat satellite busses that are cheaper to build and launch, and have a shorter technology refresh cycle. NOAA does not have a lot of experience in this.
	+ CubeSat technology currently may be too small to be able to satisfy the needs of NWP, which needs microwave sensors with channels all the way to 23 GHZ. It will be difficult to do this on a CubeSat. Need to do risk reduction. What happens when we use SmallSats? There is a great deal of things that NOAA wants to learn about SmallSats that will only be gained by on-orbit experience. The small satellite technology is being explored with Quicksat. Operations of how it is controlled.
* Emily – So, the Quicksat instrument is an ATMS, but the satellite will be small? What is the orbit chosen for Quicksat?
	+ Ed – It is a full ATMS instrument and will be characterized the same as the previous instruments. The orbit not determined yet by NOAA.
* Tim Hewison - If the instrument had different oversampling in along-track and across-track directions, would that give a striping index systematically different from 1?
	+ Ed Kim - The difference in time scales between cross- and along-track sampling vs. the noise power spectrum are what lead to ATMS striping. Most passive microwave scanning sensors have the same situation. The cross & along track variances used in the graph involve different amounts of 'normalization' to make 1.0 represent a 'no striping' condition.
1. (1220-1235) The MWR at ESA: toward CIMR [Craig Donlon (ESA)]

The Copernicus Imaging MW Radiometer (CIMR) instrument technology and its data applications are presented. Of special focus is the large deployable mesh antennas that allow the 1.4135, 6.9, 10.765, 18.7 and 36.5 GHz channels to have field of view sizes of 77 km X 43 km, 20 km X 10 km, 20 km X 10 km, 7 km X 4 km, and 5 km X 3 km, respectively. Also discussed were its calibration philosophy of using frequent internal calibrations and less frequent maneuver-based end-to-end calibrations, and using SI best practices to characterize sources of instrument uncertainty. Finally, the approach to mitigating RFI is presented.

Q&A

* Ed Kim – CIMR is moving toward total uncertainty measurement calibration, which SMAP folks called an unbiased metric. Will there be any pre-launch or on-orbit info about the bias term?
	+ Craig Donlon - Relative to what? There will always be some bias, since there is not an absolute standard.
	+ What we try to do is to adopt the Guide to Uncertainty of Measurement developed by standard institutes to characterize the sources of uncertainty for CIMR.
	+ The goal is to directly measure all sources of uncertainty, but this is impossible. But we do try to use as many possible measurement sources to quantify the sources of uncertainty we can get at (Type A uncertainties), and then use physics-based or empirical modeling to characterize the rest (Type B uncertainties).
* Ed - SI traceable microwave standard! Would be wonderful to be able to do this.
	+ CIMR uses a hot load and active cold load for back end calibration.
1. (1235-1250) SMOS Brightness Temperature calibration metrics and results from last 3rd mission reprocessing campaign [Raffaele Crapolicchio (ESA)]

Presented an overview of the Soil Moisture and Ocean Salinity (SMOS) mission. Payload is a L-band interferometric radiometer. It reveals capabilities to infer sea surface salinity, sea ice thickness, soil moisture, cyclone wind speed, etc. To be able to understand and mitigate instrument biases calibration metrics were presented based on Ocean Forward model. Metrics from the main region of the field of view (Alias free) and from the extended region of the field of view were computed and presented. There were discussions of long-term stability and seasonal variability between the reprocessed dataset V7 delivered in May 2021 and previous dataset baseline V6 . Biases at Ascending passes are much more improved in terms of seasonal stability and latitudinal variability, while descending passes improvements are less evident in particular for the latitudinal variability during the eclipse period (Nov-Jan).

1. (1250-1330) Microwave Remote Sensing Past History [Frank Wentz (RSS) (RECORDED PRESENTATION)] Video Link Here and PowerPoint Link Here

A retrospective of microwave remote sensing given from the perspective of Frank Wentz. If covers mainly microwave imaging and its importance to characterizing ocean surface state surface winds, and the use of microwave sounders for detection of tropospheric temperature change.

1. (1330-1400) Discussion Day 1
* Qifeng Lu - Would MW sounder striping affect NWP?
	+ Ed Kim – Defer to Steve English or Emily Liu. NASA performs pre-launch and on-orbit characterization, but not the impact on applications.
* Qifeng Lu – Are there plans for a geostationary microwave sounder.
	+ Craig Donlon – We don’t have a geostationary orbiter. The Arctic measurements from ESA are complementing the Geo measurements from EUMETSAT operational instruments.
	+ Qifeng Lu - FY-4 will have a microwave sounder that will have some window channels in 2025.
* Qifeng Lu – Tiger, nice talk. Do you want to talk more?
	+ Tiger Yang – We want users to use ARTS, and we hope that it will help with their work.
	+ We want a software package to help with the GSICS community and future of microwave instruments.
	+ We think it will be potentially useful for the plethora of planned SmallSat and CubeSat missions and smallsat.
* Robbie Iacovazzi – Will CMA use CubeSat or SmallSat technology?
	+ Qifeng Lu - Only universities. There are some experiments for the wind measurements. This uses reflectivity measurement for wind state over ocean. There is some desire to develop global navigation satellite system radio occultation instruments to obtain enhance temperature and moisture sounding capabilities.
* Cheng-Zhi Zou – Follow up on Geo microwave sounders question from Mark. Will the Geo be used for what?
	+ Qifeng Lu – This is still under evaluation. There are some simulation testing to understand its impact on NWP, but has not gone that far yet. Still evaluating design. Getting funding for buying the instrument.

**Day 2**

**37 Attendees:** Jiancheng SHI (NSSC), Viju John (EUMETSAT), Fabien Carminati (UK MetOffice), Jun Park (KMA), Xiaolong Dong (NSSC), Qifeng LU (CMA), Mark Liu (NOAA), John Yang (UMD), Robbie Iacovazzi (NOAA), Cheng-Zhi Zou (NOAA), Shengli Wu (CMA), Misako KACHI (JAXA), Karsten Fennig (DWD), Raffaele Crapolicchio (ESA), Stefano Casadio (ESA), Tim Hewison (EUMETSAT), Kazuki Kodera (JMA), Arata Okiyama (JMA), Tiger Yang (UMD), Keichi (JAXA), Martin Burgdorf (Univ. Hamburg), Manik Bali (NOAA), Emily Liu (NOAA), Pradeep Thapliyal (ISRO), Hidehiko MURATA (JMA), Manoj Mishra (ISRO), Neerja sharma (ISRO), Yong-Keun Lee (UMD), Jieying HE (NSSC), Nimisha Singh (ISRO), Antonia Gambacorta (NASA), Kurihara (JAXA), Juan LI (CEMA), Timo Hanschmann (EUMETSAT), Yong Zhang (Affiliation Unknown), Min Chen (Affiliation Unknown), Marc (Affiliation Unknown)

SESSION: *Past, Current, and Future Microwave Instruments (continued)*

(1100-1115) Satellite Observations for Global Water Cycle [Jiancheng SHI (National Space Science Center of Chinese Academy of Sciences)]

Utilizes a global water cycle constellation to sense different water cycle parameters – e.g., water vapor, soil moisture, vegetation optical thickness, evapotranspiration, water storage, lakes, snow water equivalent. Several past missions used both active and passive microwave instruments, including space-borne microwave imagers and precipitation radar instruments. More recently, synthetic aperture microwave instruments such as SMOS are being used to deduce soil moisture and ocean salinity. A future synthetic aperture mission similar to SMOS and approved by CNES and CNSA was discussed to combine C-band, X-band and L-band to perform more robust soil moisture measurements. The three frequency can complement each other to make better retrievals.

Q&A

* Tiger Yang – Propose L-band synthetic radiometer. what is the revolution?
	+ Jiancheng SHI - 10 km. It has 12 m antenna.
	+ The instrument design like SMOS, and was proposed by the SMOS team. It will represent an upgraded version of SMOS, and has been approved by CNES and China. It has been delayed because of COVID-19.

(1115-1130) Past, Current, and Future of EUMETSAT Microwave Radiometers [Tim Hewison (EUMETSAT)]

This high-level view of EUMETSAT microwave radiometers focuses on the EUMETSAT Polar System – Second Generation (EPS-SG). In particular, the motivation for and specifications of the planned Microwave Sounder (MWS), Microwave Imager (MWI), and Ice Cloud Imager (ICI) are presented. In addition, a brief summary of the Arctic Weather Satellite, a EUMETSAT sponsored SmallSat that is designed to increase coverage of the Arctic region is also given.

Q&A

* Karsten Fennig - For the MWI-1 and MWI-2, there is planned 20X oversampling. Does EUMETSAT plan to downlink all of these data?
	+ Fabien Carminati – At the UK MetOffice, it is noted that MWI will allow oversampling to be handled in any way. They can also map MWI/ICI together.
	+ Christophe Accadia via Tim Hewison - The product will include all samples.
* John Yang – From your perspective, is hyperspectral microwave sounding important for future missions. Is EUMETSAT interested in this?
	+ Tim Hewison - There is a lot of interest within EUMETSAT, but we have not committed to anything. EUMETSAT has not started planning for the follow-on. From a personal perspective, Tim thinks that it would be very important for GSICS. Such technology could be used to correct for radiometric differences between instruments that have different spectral response. For example, the 183GHz can have a lot of spectral diversity between instruments, which could be accounted for with hyperspectral instruments.

SESSION: *Past, Current, and Future Applications of Microwave Data*

(1130-1150) Microwave soundings in NWP at the Met Office: experience and suggestions for future systems [Fabien Carminati (UK MetOffice) on behalf of John Eyre]

The results of several data denial experiments showed the forecast sensitivity to microwave sounding measurements as a class, and to individual microwave instruments. The importance of having low instrument noise (< 0.1K – 0.2K) and understanding sensor field of view limits (~50km) in temperature sounding channels, and the acceptance of higher resolution and noise floors for humidity sounding channels, were summarized. The impacts of using “all-sky” (non-precipitating region) microwave radiometer measurements was stressed, and problems related to using 118 GHz channel termperature sounding data for NWP mentioned.

Q&A

* Manik Bali – Do you have a set of best practices or tools to study for impacts of instrument data on NWP skill? Are you using one model or and ensemble of models to do your analysis?
	+ Fabien Carminati - If the analysis is based on several models, it gives a better idea of state of instruments. Manik was pointed to a paper by Candy B et al 2021 (Met Office)
* John Yang – If 118 GHz is not good for temperature sounding data, then what can they be used for?
	+ Fabien Carminati – They can be assimilated to infer wind direction and humidity. There also may be situations where temperature sounding is useful.
* Tim Hewison – Can you shed some light on the saturation of footprint size?
	+ Fabien Carminati – We use a global model. The problem has to do with the scale of meteorological features, or their aspect ratio. Need to increase vertical resolution to make horizontal resolution smaller.
	+ For our NWP models, there is not priority for higher resolution. Currently, ATMS is mapped to AMSU resolution. The next generation model may have a higher resolution – e.g., < 1km instead of 5km resolution, but this is not a priority.
* Karsten Fennig – Can you please give us the link to the MWIPP plans?
	+ Fabien Carminati - Please see the MWIPP plans here: <https://nwp-saf.eumetsat.int/site/download/documentation/mwipp/NWPSAF-MO-DS-044_EPSSG.pdf>
* Viju John - Hyperspectral microwave sounder instrument development
	+ There are some activities going on in UK regarding microwave hyperspectrral instrument, HYMS
	+ [https://www.ralspace.stfc.ac.uk/Pages/UK-Government-funds-the-Hyperspectral-Microwave-Sounder,-a-new-sensor-for-tracking-extreme-weather--.aspx](https://www.ralspace.stfc.ac.uk/Pages/UK-Government-funds-the-Hyperspectral-Microwave-Sounder%2C-a-new-sensor-for-tracking-extreme-weather--.aspx)
* Unknown Questioner - Could you elaborate why EUMETSAT put so many efforts on submillimeter observations?
	+ Christophe Accadia via Tim Hewison - Please take look to the following presentation: <https://www.eumetsat.int/media/7731> and the EUMETSAT ICI webpage at: <https://www.eumetsat.int/eps-sg-ice-cloud-imager>

(1150-1210) Direct assimilation of Microwave observations in the CMA-GFS system [Juan LI Center for Earth System Modeling and Prediction of CMA (CEMC)]

The history of CMA assimilation of microwave radiometer measurements into their NWP systems was provided. The CMA Global/Regional Assimilation PrEdiction System (GRAPES) 4d-Var system, and cloud and striping detection and mitigation results, were presented. Results showed NWP performance improvements when using the current FY-3E MWTS and MWHS instruments compared to assimilating the early FY-3A MWTS sensors data. In addition, the VIRR instrument is no longer needed to support cloud clearing since the MWTS now has window channels at 23 and 36 GHz. Furthermore, striping mitigation was shown to be smaller with FY-3E, because it has less noise than previous generations.

Q&A

*None*

(1210-1230) Space-based Microwave Remote Sensing: Quantitative Techniques and Development in China [Xiaolong DONG (National Space Science Center of Chinese Academy of Sciences)]

An overview of microwave technology development at the National Space Science Center (NSSC) in China reveals several achievements since it began working with microwave technology in 1973, and establishing its laboratory for developing microwave sensors in 1984. The early microwave sensor contributions related to ocean and atmosphere include passive microwave sounders and active radar altimeters and scatterometers. The presentation showed that applications of the instruments include ocean brightness temperature, wave height, wave direction and wind vectors; lunar measurements made in lunar orbit; and atmosphere humidity profiles. Also discussed were prelaunch and on-orbit calibration approaches. Recent focus was revealed to include follow-on to the HY-2 altimeter and scatterometer and the new Interferometric Imaging Radar Altimetry (InIRA). The InIRA instrument will perform wide-swath sea surface height at mesoscale and submesoscale, sea waves and sea winds. It was also communicated that future work includes advanced microwave sounders for FY-3 that integrate temperature and water vapor sounding, and CubeSats that contains several bands around the 118 and 183 GHz.

Q&A

* Tiger Yang –We have been working for several years to use the Moon as a calibration reference. Can we access the CEMWS data from Chang-E 1&2 missions data? If so,where we can get data?
	+ Xiaolong DONG - Data can be obtained from a national astronomical lab. We can contact him for details.

1230 20 A Revised All-sky Radiance Assimilation Framework in the NCEP Global Model [Emily Liu (NCEP)]

The evolution of NCEP global data assimilation and MW assimilation, revised all-sky radiance assimilation framework, and outlook of using MW data were introduced. While, the shift to all-sky radiance included assimilating non-precipitating thick cloudy areas over ocean, the revised framework makes a great number of changes. It includes assimilation of precipitating regions over ocean, use of ATMS SDR instead of TDR data, and adapts the GFDL Cloud Optical Table for precipitating hydometeors. Impacts of these changes to the NWP model were discussed.

Q&A

* Tiger Yang – By using the SDR, you are now using the physical based antenna pattern correction (APC). Is this necessary for NWP, since the results of VarBC and using the SDR agree pretty well?
	+ Emily Liu - Antenna bias is a function of scan angle. In VarBC, we have predictions for bias as a function of scan angle. VarBC is a linear bias correction. It happened that antenna pattern bias are function of scan angle. It has a fourth order polynomial to remove scan angle bias correction. This is why the two agree.
	+ VarBC is not physically based predictor. If there is a more calibration issues, then we will have an issue with that. Physically based correction is necessary.
* John Yang – There have been studies about how to better represent observation error covariance. How do you represent inter-channel correlation? Do you need a good estimate of this for operational error covariance? If so, how do you do this?
	+ Emily Liu - Now we only started estimating inter-channel radiometric error contributions by assuming covariance symmetric from the diagonal of an inter-channel covariance map.
	+ Have successfully done this for IR hyperspectral sounders, but need to revisit correlated observation for microwave for all sky.

SESSION: *Past, Current, and Future of Microwave Fundamental Climate Data Records (FCDRs)*

(1250-1310) Past, Current, and Future of NOAA Microwave FCDRs [Cheng-Zhi Zou (NOAA)]

This presentation summarizes efforts to create FCDRs from NOAA/NASA microwave sounders – e.g., MSU, AMSU and ATMS. It stresses the need to create consistent radiances between satellites, since instrument unique errors related reflector degradation, warm load temperature anomalies, radiation leakage as the antenna moves from earth to calibration target views, satellite changes in local equatorial crossing time, etc. can cause time dependent biases between data sets. The importance of determining reference satellites through analytical justification was stressed. Also, applications of the recalibrated data to climate analysis were shown to improve these analyses, especially in the mid troposphere, upper-troposphere and lower-stratosphere.

Q&A

* John Yang – When you recalibrate, is the noise decreased, and does noise have impact on recalibration?
	+ Cheng-Zhi Zou - No, noise does not change. Only bias and bias drift are changed. The effects of noise usually cancels out when averaged over a monthly time scales.

(1310-1330) Efforts at EUMETSAT on the generation of FCDRs from microwave sounders [Viju John (EUMETSAT)]

This briefing stresses the essential importance of FCDR efforts to detect the nature of global climate changes, and lays out the FCDR development framework created by EUMETSAT. The foundations to the FCDRs rest on the use of infrared and microwave sounder data, and a metrology-based uncertainty approach using the FIDUCEO project framework. An example showed changes in atmospheric moisture using MSU and HIRS. Original work using microwave sounders was based on SSMT, but work has been expanded to MSU, AMSU and ATMS.

Q&A

* Mark Liu – Are the MSU/AMSU and HIRS differences for nadir or all scan angles?
	+ Viju John - All scan angles but have been limb corrected.
* Mark Liu - Before 2007 the water vapor does not change much, but after it increases considerably. Why?
	+ Viju John – Changes are not zero before 2007, just not as pronounced as after.
* Mark Liu - Could it be linked to cloud?
	+ HIRS uses cloud-clear brightness temperature. So, clouds should not be an issue.
* Qifeng Lu – Cost function. Are there some reference observations used as a tool to perform minimization of the cost function?
	+ Viju John - The harmonization is performed at EUMETSAT. Ralph Giering performs the optimization using a tool developed by a company, and not EUMETSAT.

(1330-1400) Discussion Day 2

*None*

**Day 3**

**30 Attendees:** Jun Park (KMA), Xiaolong Dong (NSSC), Qifeng LU (CMA), Mark Liu (NOAA), John Yang (UMD), Robbie Iacovazzi (NOAA), Cheng-Zhi Zou (NOAA), Shengli Wu CMA), Misako KACHI (JAXA), Karsten Fennig (DWD), Raffaele Crapolicchio (ESA), Stefano Casadio (ESA), Tim Hewison (EUMETSAT), Kazuki Kodera (JMA), Arata Okiyama (JMA), Tiger Yang (UMD), Keichi (JAXA), Martin Burgdorf (Univ. Hamburg), Manik Bali (NOAA), Ed Kim (NASA), Pradeep Thapliyal (ISRO), Manoj Mishra (ISRO), Neerja sharma (ISRO), Yong-Keun Lee (UMD), Jieying HE (NSSC), Nimisha Singh (ISRO), Alexander Uspensky (PLANETA), Hao Xu (NIM), Yichi Zheng (NIM), Xiaohai Cui (NSSC)

SESSION: *Past, Current, and Future Microwave Instruments*

(1100-1115) Past, Current, and Future of Russian Microwave Radiometers [Prof. Alexander Uspensky (PLANET)] (MOVED FROM DAY 1)

This presentation provided insight into the microwave sounder/imager instruments from on the Meteor-M satellite series. The main instrument developed from this purpose has been the MTVZA instrument first launched in 2001. The GY series first launched in 2009 was 29 channels and replaced the earlier series, while the upcoming GY-MP series to be launched starting 2025 will further expands the instrument to 40 channels and improved spatial resolution. Of particular note was that the 18.7 and 36.5 GHz channels will act as a polarimeter and report the third stokes vector for wind direction. Details were given regarding the post-launch absolute calibration algorithm, which is based on comparison between observed radiances (antenna brightness temperatures) and RTTOV-simulated radiances (sensor brightness temperatures), and linear regression. Stability of on-board radiometric calibration was demonstrated for GY series using the air surface temperature measurements on Greenland Summit station.

SESSION: *Future of Microwave Remote Sensing: Microwave Standards*

(1100-1120) Electromagnetic Measurement Techniques for Materials in the Microwave and Millimeter-Wave Frequency Range [Hao Xu China National Institute of Metrology (China-NIM)]

An introduction into the NIM, and materials permittivity traceability within NIM, are given. It reports that NIM has developed measurement capabilities for characterizing the broadband dielectric parameters of materials from 1MHz to 110GHz that are based on the capacitance method, transmission line method and resonator method. Solids, granular materials and liquids can be accurately measured. Typical metal reflectivity in submillimeter-wave and THz range can be measure with uncertainty ±0.01dB. To be used on-orbit, needs a standard copper sample for calibration, which introduce additional uncertainty. Quasi-optical open resonator are being developed to measure metal reflectivity in submillimeter-wave spectrum.

Q&A

* Robbie Iacovazzi – Can your methods be transferred to on-orbit microwave standards, especially those that measure reflectance?
	+ Hao Xu - For the measurement of antenna and blackbody, it's not easy to accurately measure the extreme small or large reflection signals. We choose the open resonator method to measure the emissivity instead of the traditional free space method. In this case, the parameter that determines the precision is frequency rather than the amplitudes and phases of scattering parameters. To measure the blackbody, except to the measurement system, we should develop accurate calibration method to eliminate most of the error terms, as Dr. Gu in NIST said.

(1120-1140) Full waveform metrology methods with frequency field techniques [Yichi Zhang (China-NIM)]

Full waveform metrology, time-domain techniques and traceability, the frequency-domain approach, and typical applications were presented. The full waveform metrology technology trend represents a change from voltage to waveform measurements. Voltage comparisons will become waveform comparisons at higher frequencies. The motivation for this is the need for traceability of fundamental RF&MW measurement quantities at higher frequencies. A comparison is given of the classical approach of looking at time-dependent voltage variation and errors compared to assessment in the frequency domain. Applications described were the standard of digital modulation signal, over-the-air test of in-band full-duplex antenna systems, and frequency modulation continuous wave calibration for automotive radar.

Q&A

*None*

(1140-1200) Microwave Remote-Sensing Standards at NIST [Dazhen Gu (NIST) (RECORDED PRESENTATION)]

The NIST mission, motivation to create microwave remote-sensing standards, developed approaches and past accomplishments, current development, and future work were discussed. The motivation for NIST to develop microwave standards traces back to the critical importance of microwave sounder brightness temperatures to numerical weather prediction and climate analysis. The traceability of microwave brightness temperature to physical temperature through the Planck radiation law was established, and standard radiometers and standard blackbodies presented. For standard radiometers, the approach is used of thermal noise radiometery in conductive media, but this has not been extended to free space. Creating a transfer standard from standard radiometers for cross-comparison with vendor instruments is difficult because the test environment may affect the performance of the transfer standard. A great deal of effort has been placed most recently on the creation of standard blackbodies, and discussion about blackbody architecture, materials, performance and potential use on-orbit was discussed. Current developments include validating the performance of prototype blackbodies in thermal vacuum and miniaturization of blackbodies for SmallSat and CubeSat instruments. Future developments though are being forces on “quantum-based” radiometer that have a hundred-fold increase the measurement sensitivity, and do not require calibration.

* Tiger Yang - What is current blackbody emissivity and how does it vary over time?
	+ Ed Kim – Dave Walker started research into microwave blackbody standards, which was continued by Derek Houtz and Dazhen Gu, and now Dazhen and others are continuing it.
	+ New conical blackbody is potentially useful for TVAC calibration of ATMS, but has not been used yet. It has a lot of potential, but has not been tested in thermal vacuum.
	+ Emissivity of ATMS is roughly .9999 for ATMS, but have to be careful, as (1-emissivity) is not exact measure of reflectance seen by a radiometer. It is only a rule of thumb.
	+ We do not know how much ATMS emissivity changes. Can do modeling to see how stable it would be in a temperature-controlled environment. But if materials change over time, then the emissivity may change over time. Has not been tested over time.
* Tiger Yang – Indirect way to see degradation is to look at warm counts from radiometer. If the counts change then that may signal blackbody changes. For ATMS we do not see degradation of warm counts. Degradation must be slow.
	+ Ed Kim – It is probably small. To use the counts to detect change depends on the stability of the radiometer. Which is more stable, the radiometer or the blackbody?  How do you know? You have to decide which to trust and it is not clear exactly how you can do this.
* Robbie Iacovazzi – Are NIST best practices used for blackbody construction?
	+ Ed Kim – There is best practices within each company, but not mature standards. There can be instrument simulations to help steer the best design, and gain understanding. The institutional knowledge can be lost as engineers move out of projects or companies.
* Cheng-zhi Zou – Large drift may be caused by emissivity change of warm target, but that has not been documented. But if warm target emissivity changes by 0.0001/decade this could happen. Sidelobe efficiency change of 0.1% can cause 0.3K/decade change for NOAA-15.
	+ Ed Kim – Hard to tell what may be caused.
* Tiger – calibration drift can be caused by warm load or drift in the instrument. Identify the source is difficult, but may find clue from different reference target.

SESSION: *Future of Microwave Remote Sensing: SmallSats or CubeSats*

(1200-1220) Photonic Integrated Circuits (PICs) in Space: The Hyperspectral Microwave Photonic Instrument (HyMPI) [Antonia Gambacorta (NASA)]

The importance of hyperspectral – i.e., fine spectral resolution - microwave measurements to improve temperature, water vapor and hydrometeors retrievals from space was stressed. One application of these measurements would be to improved planetary boundary layer (PBL) and free tropospheric 3D temperature and water vapor structure. Photonic Integrated Circuits (PICs) are being developed together with the Application Specific Integrated Circuits (ASICs) into a “PICASIC” module for the purpose of creating the Hyperspectral Microwave Photonic Instrument (HyMPI) that can be eventually manifested on a CubeSat or SmallSat. The PICASIC modular approach enables full-spectrum (10 – 200 GHz) and contiguous spectral coverage with a tunable capability to measure the spectrum with higher resolution where higher structure in the signal is exhibited. The viability of the instrument lies in being able to transform the microwave signal into an optical signal, and isolating spectral regions of interest instead of the entire microwave spectrum. This expedites signal processing that separates the spectrum into channels, and processes signals according to the amount of structure. Preliminary results show significant enhancements in the thermodynamic retrieval vertical structure relative to current operational programs. Future work includes actively engaging stakeholder to finalizing instrument design trade studies and requirements, and deriving a final optimal configuration ready for follow-on airborne flight demonstrations studies.

Q&A

* Robbie Iacovazzi - Why do you use the 63-67 GHz region? Typically, only the left shoulder of the O2 line at 60 GHz is used. Is this information redundant?
	+ Antonia Gambacorta - Improve signal to noise by using 63-67 GHz.
* Mark – Is there any plan to launch a SmallSat and CubeSat?
	+ Antonia Gambacorta - The first prototype will be created in the next year, then a flight demonstration model. It needs to be assembled as an airborne instrument and then consider next steps after learning from this.
* Mark – In the water vapor region between 173-193 GHz be covered by about 500 channels (40 MHz spectral bands) for this region? What is NEDT?
	+ Antonia Gambacorta - Yes, that is the spectral band width for these channels, and NEDT is about 1K.
* Xiaolong – What is the expected sensitivity of hyerspectral channels? What is NEDT you use for the simulation. Radiometeric sensitivity you used to assess performance.
	+ Antonia Gambacorta - The NEDT depends on the spectral region - e.g., less than 2.0 K for less than 100 GHz, 1.5 GHz between 100-150 GHz, and 1.0 K greater than 150 K. These NEDT values were to simulate performance.
* Shengli - What about integration time?
	+ Antonia Gambacorta - We assumed the same integration time as ATMS.
* John - Have you looked at land and ocean difference to see if it makes a difference in your accuracy?
	+ Antonia Gambacorta - Have not done it yet. We started with ocean regions since emissivity is relatively easy to model. Over land we need a good surface emissivity model. We are now using the Southern Great Plains at the ARM site in Oklahoma, USA. The ARM site has surface emissivity, which may help. Need to know the error in the surface emissivity in the hyperspectral to be able to studies.
* John – Other groups working on it taking different approaches. They do not have microwave to optical transformation. Are you aware of these developments, and what are the differences.
	+ Antonia Gambacorta - Does not know, but the group wants collaboration with other sensor development teams. Want to learn from each other.
* Mark – for the spatial resolution for window channel, how big is the FOV?
	+ Antonia Gambacorta - Depends on the antenna. Looking to use SWAP-C as core of instrument. Designed to be employed on a SmallSat architecture. The goal is to achieve 5km in the PBL is the plan for microwave and 1km for IR, but this is a PBL focused study.
* Antonia Gambacorta - Independence of information shows that there can be many more independent pieces of information for Hympi than a heritage microwave sounder.

(1220-1240) The NASA Compact Ocean Wind Vector Radiometer (COWVR) Instrument [Shannon Brown]

Information about the COWVR Polarimetric conical-scanning microwave radiometer that is now operating on the ISS was presented. The goal of COWVR was to reduce complexity of sensor design and still meet the requirements of the meteorological community for wind speed and direction. The design allows fore and aft measurements of the same location, and also allows the antenna to scan without having to simultaneously scanning the sensor receiver and electronics. It improves error substantially by allowing wind speeds to be measured down to 5 m/s.

* Cheng-Zhi Zou – Does this instrument have a thermal control system?
	+ Shannon Brown - Thermal control is hybrid active-passive thermal control. Want to avoid active thermal control near electronics, so this is passively controlled. The spin mechanism is actively controlled with a thermal stability to about a degree or so.
* Cheng-Zhi Zou – Do the COWVR instrument have a blackbody?
	+ Shannon Brown – COWVR has electronic calibration each scan using a Dicke Switch, and noise diodes that are correlated that can resolve polarization. It also contains a blackbody that is used every five days to see if there is a drift in the noise diodes. A six-month to one-year period of calibration using ocean measurements fine tunes the calibration sources.
* Cheng-Zhi Zou - How do handle change in Ocean?
	+ Shannon Brown - Ocean calibration is performed one-time only. It is performed using a radiative transfer model (RTM) that can be used to establish observed minus simulated brightness temperatures, so the natural variability is removed through the RTM. Looking at global mean over a long time period. The only assumption is that the ocean temperature the sensor is measuring one scan direction is the same temperature over another scan direction.
* Mark – Slide 21 – You use three components of the Stokes vector for the calibration. Why not use four?
	+ Shannon Brown - The fourth Stokes vector is invariant to polarization rotation. It has a zero mean. Cannot decouple the fourth Stokes into the other vectors. It is small anyway.
* Tiger Yang – Do you use a digital electronic backend for TEMPEST-D and COWVR?
	+ No, because not mature at the time. Analogue was only available. Future version will use digital backend, since it eliminates some complexities of using analogue circuitry.
* Tiger Yang – Do you have a publication about the stability related to using the noise diode. How is the status of noise diode in TEMPEST-D?
	+ Shannon Brown - TEMPEST-D uses a blackbody. Sentinel-6 has a noise diode. Several papers have been published on noise diodes. The performance does vary depending on the circuitry between the diode than the radiometer. So, drift can be 0.1% to several percent over a decade. Need to have a way to check the noise diode and to recalibrate it. Sometimes we used an external blackbody target to calibration the noise diode once every 5 days.
* Tiger Yang – will you publish this with your results?
	+ Shannon Brown – They were published in 2014
* Robbie Iacovazzi – How are the wind speed and direction retrieved from the instrument validated?
	+ Shannon Brown - Comparison of retrieved wind versus buoys and numerical weather prediction fields.
* John Yang – Is there electronics redundancy for this instrument?
	+ Shannon Brown - No. It is a demonstration research model, so does not require this.
* John Yang - How cold is the internal cal target?
	+ Shannon Brown - Noise diodes are 200-300K, and calibration points are around 300K.
* John Yang - What testing was performed on the ground?
	+ Shannon Brown - Spent a lot of time to perform characterization of the S-parameter at the component, sub-system and system levels of integration. Verification of performance was assured at each level of integration, and we got the same answer at each step.
* Tim Hewison – Can get hardware back after it is used since it is on the ISS? Will this be considered? If so, what would you do?
	+ Shannon Brown – This is a one-way trip only. It will be pushed off the station in three years. If we got it back, we would want to test circuitry changes, noise diodes changes, and styrofoam degradation. Main reflector changes are not expected because it uses all aluminum.
* Tim Hewison – The instrument uses 33.9 GHz, which is not in the protected band.
	+ Shannon Brown – We chose this band because it has been used in the past, and we wanted to use a single waveguide. The nature of this waveguide is that it has a frequency cutoff at about 35GHz, so we needed to keep the band.
* Tim Hewison – Are you encountering RFI?
	+ Have been operating since 2001 at this frequency for altimeter instruments. We see more RFI at 23 GHz. The only interference we find at 33.9 GHz is from space debris tracking in Kwajalein. We use no RFI filtering.

(1240-1300) The NASA Temporal Experiment for Storms and Tropical Systems - Demonstration (TEMPEST-D) Instrument [Prof. Steven C. Reising (CSU) (RECORDED PRESENTATION)]

TEMPEST-D was a technology demonstration mission to enable millimeter wave radiometer technologies on a low-cost, short development schedule. The mission reduces the risk, cost, and development duration for a future TEMPEST mission, which would provide the first ever temporal observations of cloud and precipitation processes on a global scale. TEMPEST-D was sponsored by the NASA's Earth System Science Pathfinder (ESSP) program and managed by the Earth Science Technology Office (ESTO). For TEMPEST-D, JPL developed a mm-wave radiometer payload that operates at five channels from 89 to 182 GHz and fits in a 4U volume within the 6U CubeSat.

Q&A

*None*

(1300-1330) Group Discussion All

Talking Points Relative to GSICS Activities

* Adopting Calibration Best Practices and Standards
	+ ESA CIMR and EUMETSAT FIDUCEO perform instrument uncertainty analysis based on the Guide to Uncertainty in Measurement developed by standards institutes such as NIST and NPL. How can the GSICS MWSG adopt and encourage use of such calibration and analysis best practices?
		- *No input*
* Maximizing Use of Current Microwave Sensor Calibration Technology and Data
	+ Would the GSICS Microwave Subgroup (MWSG) consider adopting software tools such as the Advanced Radiance Transformation System (ARTS) as GSICS MWSG products or tools? What processes would need to exist for the subgroup to do this?
		- Tiger Yang – ARTS can be used tool, but want to limit access to GSICS and get feedback from the group before having wider availability.
		- Manik Bali – Is there a users’ guide for ARTS?
			* Tiger Yang - No, there is no formal guide, but can use the briefing to acquire and install ARTS.
			* There is also a README file that helps to install and compile the software.
			* References are given that act to describe the theoretical basis for the tool.
			* User’s guide is in the plan after getting feedback.
			* To access ARTS can be done by email request to Mark and Tiger at this time.
		- Cheng-Zhi – This is not the official ATMS calibration algorithm?
			* Tiger Yang – Updates to the ATMS algorithm are first developed in ARTS before it is tested and operationalized. It has been a very important testbed.
			* Mark Liu – Advantage of this software is that it is not specific to ATMS. Could be useful tool for climate studies since it can be applied to many different instruments. Each instrument would demand a different Processing Coefficient Table to operate that is appropriate for that instrument.
		- Cheng-Zhi Zou – Can it handle errors such as calibration drift?
			* Tiger Yang - If you want to handle errors such as drift, you will add a correction algorithm into the software. Unless the calibration algorithms between instruments is different, then the ARTS package works very well.
			* Mark Liu – If you want to get detailed information about data sets from less complex instruments such as MSU, you may have to go to the L0 data.
	+ Microwave measurements of the moon are important to correct for moon-in-spaceview radiance contamination, and to support lunar calibration of microwave channels. Could the data from the CEMWS microwave sounders on Chang-1 and -2 lunar satellites be useful to the GSICS MWSG? If so, is it possible to get these measurements, and can the subgroup distribute them to the user community?
		- Tiger Yang – Developed a lunar model with disc-average lunar brightness temperature. Need observation truth for the moon. We use ATMS measurements, which are only full moon measurements. We need measurements from other lunar phases.
		- Chang-E 1 has frequencies up to 36 GHz, which would be used to calibrate the lunar RTM model, and improve the model performance.
		- Robbie Iacovazzi – Can we leverage on the Lunar Calibration Subgroup to help the microwave effort?
			* Tiger Yang – Majority of effort in the optical bands. Martin from Hamburg is interested in using the moon for calibration. Developing a lunar model is important.
		- Cheng-Zhi Zou – Can you measure stability using the moon as a calibration source for different instruments and create time series from this?
			* Tiger Yang – Paper was published using ATMS data from S-NPP. Used lunar measurements to evaluate instrument stability. We now are collecting all lunar data from S-NPP ATMS to assess stability of these instruments. It is a radiometrically independent source that depends only on scan geometry, which can be characterized.
			* Martin Burgdorf – Support Tiger’s idea. Thinks the moon can be used to assess the stability of AMSU-A, and some of the calibration parameters that are arising in these instruments.
			* Cheng-Zhi Zou – Needs to be performed to the 0.002 K/year. Hopefully this can be done. If the noise is too large, then this cannot be achieved. Maybe try this first on S-NPP, and then the heritage instruments.
			* Martin Burgdorf - Wants to get the funding.
		- Robbie Iacovazzi – How well do we need to know the antenna pattern?
			* Martin – This needs to be characterized from lunar intrusions.
		- Robbie Iacovazzi – How can you build the response and know the stability at the same time?
			* Tiger Yang – The only thing you need to know is the gain. You will have the solid angle of the antenna, and we don’t expect this to change on orbit. As long as we have a good lunar model, and we can characterize the antenna at a given solid angle, then that is not expected to change over time. This then can be used to track the stability. If we have the antenna pattern for AMSU-A that is great, and if not, we can characterized the antenna using the lunar intrusions and lunar model.
			* Martin Burgdorf – The Chang-E 1 data could be used to make the lunar model better, which would feed back positively to the analysis.
			* Tiger Yang – Lunar model can generate brightness temperature as a function of lunar phase. Full moon has highest radiance. As long as the lunar data is detectable though, you can use the model to predict the brightness temperature of the moon for its given phase and track the instrument response.
	+ Maintaining heritage microwave sounders is considered to be very high priority for NWP. What role does the GSICS MWSG have to encourage agencies to extend the on-orbit lifetime of their sounders?
		- Cheng Zhi Zou – GSICS Executive Panel can talk about this to managers. Usually new instruments get the most manpower, and older generations get less maintenance and analysis.
		- Robbie Iacovazzi – We have to show that NWP really wants this and bring it to managers.
		- Cheng-Zhi Zou – The managers want to hear from NWP, and not just from GSICS.
		- Qifeng Lu – CGMS Working Group 2 has a gap analysis for the microwave constellation is completed every year. This provides recommendations for new satellites to maintain requirements. For older satellites, if they show usefulness, then CGMS encourages them to be maintained. If they are having issues, then finding budget can be very difficult.
		- NWP always asks for this maintenance on a regular basis. WMO has a group provides support for this.
		- Mark Liu – This recommendation can be discussed at the Annual Meeting to see if there is a mechanism to get documents and see if there is anything we can add.
		- Qifeng Lu – GSICS reports to CGMS. At CGMS we could potentially send the request to coordinate on this effort.
		- Mark Lui – To do climate-quality data from legacy sounders, we need more support.
* Exploiting New Microwave Sensor Technology and Lessons-Learned
	+ What role can the GSICS Microwave Subgroup play in providing information that supports the development of new microwave sensors and their calibration? For example …
		- Development of microwave instruments with118 GHz sounding channels is becoming more common. Can the GSICS MWSG act as an “exchange-agent” of findings related to the benefits and limitations of emerging microwave sensor technologies?
		- How can all GSICS MWSG members utilize or learn about the calibration and performance of new sensors such as the upcoming ICI?
			* Mark Lui – Using 118 GHz by itself cannot replace 50-60 GHz channels. The 118 GHz adds information. High spectral resolution microwave sensor may be able to add information, since it will have all legacy and new channels.
	+ Hyperspectral microwave instruments could be important in reconciling radiometric differences between microwave instruments with channels that have slight different spectral response. How can the GSICS MWSG be given access to such important data sets for inter-calibration studies?
		- Robbie Iacovazzi – Will we have access to Hympi data?
		- Antonia Gambacorta – We can use the Hympi data to create data from instruments at their native resolution, which could be useful for climate research from legacy sounders.
		- Mark Liu – For aircraft measurements from hyperspectral, when will this happen?
		- Antonia Gambacorta – No sooner than 3-5 years. Depends on the next announcements for opportunities.
* Building Relationships with the Microwave User Community
	+ How can the GSICS Microwave Subgroup enhance the working relationship between microwave instrument developers, operators, and NWP center or satellite application facility developers?
		- Tiger Yang – GSICS members have abundant knowledge on instrument calibration, and these people are capable of acting as the interface between the instrument vendor and NWP scientist. The GSICS platform seems ideal to share information about instrument anomalies, and validate improvements to calibration algorithms. This information can be delivered to NWP centers to improve quality of their models.
		- Robbie Iacovazzi – Also, when we learn about anomalies, this becomes good feedback to help shape instrument requirements.
		- Tiger Yang – Yes, for example the reflector emission correction may be used to improved the design of other instruments or their algorithms.
		- Cheng-Zhi Zou – The communication between NESDIS and NCEP is not necessarily at the same level. GSICS may be able provide a candidate that give presentations to NWP providers get their interest regarding calibration and working with the calibration community. Usually NESDIS knows more about NWP issues that they know about or understand calibration issues.
		- Qifeng Lu – ITOVS meeting the RTTOV-WG, the NWP people monitor performance, and they will share their findings. Usually feedback is given to them from the satellite community. GSICS has no direct way to communicate with the NWP community as the RTTOV-WG. For technical communication, there is no link to the NWP centers for GSICS.
		- Tiger Yang – ITOVS is a good platform, and need to keep engaged with the NWP community and keep them informed about issues. At ITOVS, we told them to use SDR and not TDR for ATMS. We showed the evidence that the SDR is better. At some point it got into the NCEP model and the results are good. ITOVS is a good platform.
		- Robbie Iacovazzi – Maybe this can be discussed at the Annual Meeting.
		- Tiger Yang – Recommend a GSICS representative to ITOVS and CEOS, and invite members of the NWP community.
		- Manik Bali – NWP and GSICS Microwave Subgroup are closely linked, and they can help gauge the performance of update calibration. We want to be able to use NWP to be able assess our system, but we need to understand the variability of NWP assessment approaches. Maybe GSICS needs to propose a best practice of NWP assessment of calibration impacts. Fabien’s talk was a good representation of this.