NOAA Workshop on Climate Data Records from Satellite Passive Microwave Sounders – AMSU/MHS/SSMT2

Earth System Science Interdisciplinary Center (ESSIC)
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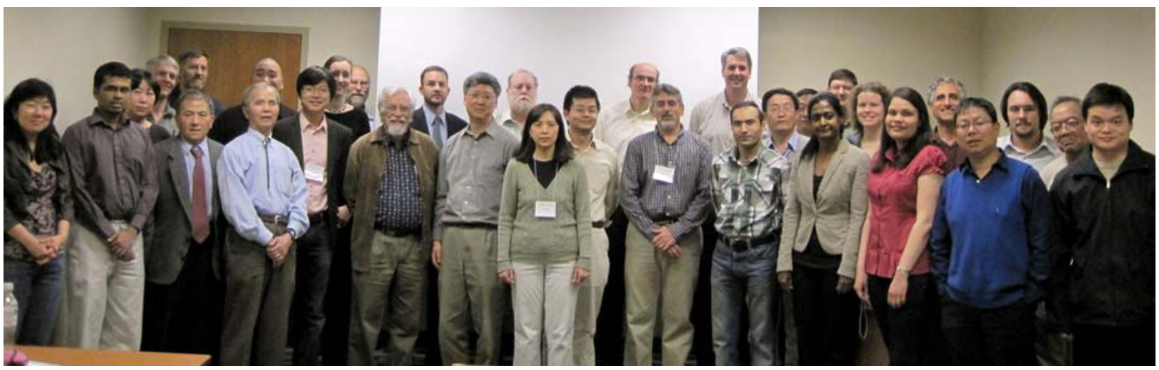

1. Introduction

As part of NOAA's Climate Data Record (CDR) program[1], each CDR project is to convene a workshop during their first year to solicit feedback and direction from experts in the community. As such, this workshop was held to focus on activities related to two CDR projects – one lead by a NESDIS/Center for Satellite Applications and Research (STAR) team (R. Ferraro and H. Meng, Co-PI's) and one lead by the City College of New York (Z. Luo, PI; specific details on each project can be found at the CDR web site). The day and a half workshop was held in conjunction with a NASA lead working group meeting (e.g., The Global Precipitation Measurement (GPM) Mission Intersatellite Calibration "X-CAL" working group lead by T. Wilheit[2]) where some of the same common issues related to Fundamental CDR (FCDR) generation are being developed.

The overarching goals for the workshop were:

[1] http://www.ncdc.noaa.gov/cdr/index.html
[2] http://gpm-x-cal.info

- To allow NOAA's CDR Product Development Teams to interact with AMSU and SSM/T2 data/product users and other CDR developers on relevant aspects of sensor characteristics and intercalibration that will lead to mature CDRs.
- To provide a formal mechanism for input by external parties with expertise on the subject matter, in particular, sensor scientists and engineers.
- To move towards a community consensus approach for NOAA microwave sounder CDRs.

Approximately 40 passive microwave instrument scientists, data users and satellite calibration experts were in attendance. The workshop consisted of some introductory talks on the CDR program and its importance to NOAA by NESDIS managers, then a series of talks by CDR project scientists and other experts in the field related to specific aspects of the AMSU, MHS and SSMT/2 sensors, as well as their applications to hydrological products and upper tropospheric humidity. The meeting concluded with the CDR project PI's leading discussion on the various elements that their projects need to address in order to develop robust FCDR's. It should be pointed out that the STAR lead CDR project focuses on just "window" channels from AMSU-A, -B and MHS (e.g., 23, 31, 50, 89 and 150/157 GHz), as well as the three "water vapor" channels centered around 183 GHz. (There are other CDR projects that address the AMSU "sounding" channels in the 50-60 GHz range).

This report summarizes the talks given at the workshop and then addresses some of the critical areas that these projects will be addressing in the next two years, as well as potential methods to characterize the passive MW instruments. Appendix A contains the workshop agenda, Appendix B the workshop participants whereas all of the presentations can be obtained from the workshop web site.[3]

2. Workshop Presentations

- **<u>Overviews</u>**

Brian Nelson, National Climatic Data Center (NCDC), presented a broad perspective of NOAA's CDR program that is being lead by NCDC. He described how CDR's were defined in an NRC Study *"Climate Data Records from Environments Satellites*" where "Fundamental" CDR's (FCDR) are defined as calibrated radiances from a family of sensors whereas "Thematic" CDR's (TCDR) are geophysical variables derived from the FCDR's. From an international perspective, TCDR's are thought of as "Essential Climate Variables". He also presented some specific details related to NOAA's CDR program, including a maturity index and a check list that each of the PI's funded by NCDC are to follow.

[3] http://www.star.nesdis.noaa.gov/star/meeting_CDR2011.php

Mitch Goldberg, STAR, gave some historical perspective to the CDR program and described STAR's involvement in many of the ongoing CDR projects. He also talked about linkages to NOAA's CDR program and the broader international community, in particular, the Global Space-Based Inter-Calibration System (GSICS), which is lead by STAR and is part of the World Meteorological Organizations Coordination Group for Meteorological Satellites (CGMS). He also stressed the "transparency" needed in FCDR generation, i.e., a process that can be reproducible by operational agencies like NOAA once the scientific method has been developed by individual investigators.

- **AMSU-A**

Huan Meng, STAR, provided an overview of the project to develop AMSU FCDR and TCDR for hydrological applications. She gave the background information of the project: the sensors, the satellites and the products, which highlighted the importance of this project. Then she addressed the on-going progress after the first year of the effort, including the scan bias of AMSU-A, AMSU-B/MHS, and geolocation error, which would be further addressed by other presentations during the workshop by the project team members. She also expressed some concern on sensor drift and diurnal cycle in the satellite data, and discussed pros and cons of three potential inter-satellite calibration approaches for window and water vapor channels: simultaneous nadir overpass (SNO), vicarious reference, and double differencing technique.

Tsan Mo, STAR, talked on his most recent research: intersatellite/intersensor calibration of microwave radiometers over Antarctica, aiming to establish a natural site for calibration reference of space-borne microwave radiometers. Using both AMSU-A and MHS 30-day mean near-nadir brightness temperatures (TB) over Antarctica, he inspected two kinds of difference: TB difference between ascending and descending nodes show minimal diurnal variability in the winter months due to the long polar night; TB difference between different satellites/sensors (e.g., AMSU-A on-board NOAA-18 and NOAA-19) provides a practical approach to determine the intersatellite/intersensor calibration biases (ICBs). He also showed the climate trends derived from 15 channels of NOAA-15 AMSU-A measurements.

Wenze Yang, University of Maryland/Cooperative Institute for Climate and Satellites (CICS), presented AMSU-A across scan asymmetry for window channels (e.g., 23, 31, 50 and 89 GHz). He quantified the scan bias by differencing the observed TB from simulated TB over tropical and sub-tropical ocean under clear-sky, and adjusting them according to their nadir value. The bias is asymmetric relative to the nadir. The asymmetry pattern appears to be stable through several years of data examined, but are quite different among those on-board the different NOAA and EUMETSAT satellites. He stated that the asymmetry might be due to sensor errors or asymmetric environment conditions. The angular distribution of precipitable water (PW) showed higher PW at nadir by 10%, generally stable through all years and on all satellites examined to date. Special emphasis was given to stratification of environment variables to identify their impact on across scan asymmetry, and it was revealed that wind speed plays the most important role. He showed at a narrow range near most probable value of environment variables, it is possible to adjust the antenna pointing angle and polarization alignment angle to make the scan bias symmetric. He also displayed vicarious cold reference time series for AMSU-A nadir observations.

Robert Iacovazzi, STAR/Earth Resources Technology, Inc., gave overview of AMSU-A inter-satellite calibration bias analysis using the SNO method. He introduced the concept of SNO events, and created an operational AMSU-A SNO Ensemble dataset, mainly around 80° north and south latitude. He discussed SNO uncertainty and biases for POES, MetOp-A and Aqua AMSU-A. He also stressed that by introducing bilinear interpolation and screening SNO events for anomalous scene inhomogeneity, the number of events would decrease largely, but the bias confidence intervals (STD) at surface channels would decrease 68% (76%) on average over nearest-neighbor collocation. Finally, he addressed the problems in the SNO events between Microwave Sounding Unit (MSU) and AMSU-A, such as frequency and band width differences, calibration and diurnal-cycle related TB biases, and examination of residual biases.

Cheng-Zhi Zou, STAR, presented an update on the development of MSU/AMSU/SSU sounding channel FCDR and upper air temperature TCDR. This project is highly related to the effort lead by Ferraro and Meng and is also supported through NCDC's CDR program. He mentioned the large user communities of the sounding channel CDR product, as it is highly regarded as an independent signature of climate temperature trends through its 30-year time series of MSU and AMSU-A. He also described their CDR development system, as well as their achievements on MSU, SSU and AMSU-A. He emphasized the results of the AMSU-A inter-calibration using the SNO approach, further validated the SNO results using GPSRO data, and compared them with similar products from other groups such as the University of Alabama-Huntsville, Remote Sensing Systems, GPS and NOAA operational calibration, in which all comparisons show advantages of the SNO approach. He also talked about several issues regarding the assimilation of the recalibrated MSU/AMSU data into NOAA's reanalysis system.

- **AMSU-B/MHS**

Chabitha Devaraj, University of Maryland/CICS, presented the AMSU-B/MHS scan bias and asymmetry research work which is a part of the AMSU CDR project supported by the NOAA CDR program. She discussed the approach and results from the previous work by S. A. Buehler (2005) on across scan asymmetry in AMSU-B. She described the methodology developed to characterize AMSU-B/MHS scan bias and asymmetry using the Community Radiative Transfer Model (CRTM). She also presented some preliminary results of MHS scan bias characterization in NOAA-18 using 2008 data through the stratification of different environmental conditions.

Jörg Ackermann, European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), presented the EUMETSAT activities for CDR generation with special emphasis on MHS. He described MHS validation using SNO's and illustrated how orbit drift of the satellites can provide unique opportunity to look at SNOs over all latitudes. He pointed out that the non-uniform bias for all latitudes is due to the temperature dependence of bias. He also mentioned that they are looking at NWP "O-B" statistics for inter-calibration and using other instruments such as AMSU-A and HIRS over all latitudes. He also presented Metop-A MHS Antenna Correction and Noise Equivalent Delta T. Synergy between NOAA and EUMETSAT CDR programs should be pursued.

- **SSM/T2 and Beyond**

Johnny Luo, CCNY, discussed their ongoing work to recover DMSP SSM/T2 data (unlike any NOAA dataset, SSM/T2 are poorly archived and documented) and to use temperature and moisture measurements from on board commercial aircraft (Measurement of Ozone and Water Vapor by Airbus In-Service Aircraft or MOZAIC) to calibrate SSM/T2 water vapor radiances (near 183 GHz). Since radiances from near 183 GHz are mainly sensitive to upper-tropospheric humidity (~500-300 hPa), they constructed a high-accuracy temperature and humidity profile data set from aircraft ascents and descents based on 15 years of MOZAIC data and matched the data set with SSM/T2 overpasses. This provides a means to inter-calibrate SSM/T2 from different satellites. SNO (simultaneous nadir overpass) has also been tried and results are presented.

Eric Fetzer, JPL, talked about NASA's equivalent water vapor CDR using AIRS/AMSU (in this sense it should be called TCDR in NOAA's terminology or Level 2 product by NASA). Much of the presentation discussed how cloud contamination affects the sampling and quality of the water vapor product, since AIRS/AMSU is a combined IR and microwave sounder. Other A-Train instruments (such as CloudSat) can help quantify these impacts and clean up the product. AIRS results are compared to MLS for the upper-troposphere. Finally, Eric made the remark that, to improve sampling and achieve higher vertical resolution for water vapor product, one of the best options is to send a hyper-spectral microwave sensor to orbit.

Calvin Liang, UCLA, presented a climate variability study using multi-sensor products from the A-Train. Specifically, he studied the inter-annual variation of upper-troposphere/lower stratosphere (UT/LS) temperature and water vapor in the tropics. Two major variation modes, namely, ENSO and QBO, are shown to superimpose on one another and have different signatures on the tropical UT/LS region. A-Train observations present an excellent opportunity to understand these variability and connection to tropical clouds and convection. This presentation is not directly related to CDR development but is a good example of how CDR can be used to address climate variability questions.

- **<u>Other Topics</u>**

Fuzhong Weng, STAR, presented Empirical Model Decomposition(EMD), a non-linear trend analysis method that appears to be useful in CDR applications. This method is based on direct extraction of the trend from the data. He compared the EMD and linear methods for deriving the TB trends in AMSU-A channels. The conclusion was that EMD can derive the trend evolution while the linear trend can bias toward the data set at a particular data point. The EMD trends may be best connected from the different platforms by requiring the continuity. The cross-calibration of the instruments may not be required.

Isaac Moradi, CICS, talked about the geolocation error in AMSU data. There are three different sources for geolocaion errors including satellite ephemeris data, time offset and satellite and sensor attitude errors (error in pitch, roll, and yaw). He presented a pure mathematical method, developed by NOAA, to correct the error in pitch, roll, and yaw. Difference maps (i.e., the TB difference between ascending and descending orbits) are used to quantify the geolocation error. The error was satellite and sensor related and can be up to one pixel shift in along and/or cross scan direction. He used the Australian coastlines for the evaluation.

William Blackwell, MIT/Lincoln Labs, talked about the ATMS CDR. ATMS, which will be flown on the NPP (October 2011) and JPSS satellites, has 22 channels compared to AMSU/MHS which has 20. Pre-launch tests verified the radiometric performance, accuracy and stability of the sensor, which will exceed that on AMSU/MHS. The radiometric sensitivity and also the sensor linearity are better than expected. The requirements for the 7 years ATMS climate data records are: water vapor: 2% (threshold), 1% (goal); tropospheric temperature: 0.05K (threshold), 0.03K (goal); stratospheric temperature: 0.10K (threshold), 0.05K (goal). The general conclusion was that ATMS is an excellent sensor, and well-calibrated but it is not perfect (and characterization is not perfect). Therefore, cross-track biases to be expected, and polarization correction probably needed for CDRs. These will be an excellent extension to the AMSU CDR's under development.

R. Chen, STAR/I.M. Systems Group, Inc., talked about Jason radiometer cross-calibration. The Jason series of satellites measures global mean sea-level rise, for which the stability requirements is 1 mm/yr. The object of the study was to develop a system to monitor and cross-calibrate the Jason 1, 2, 3 radiometers (AMR). Data from other microwave radiometers at SNO locations were also used. According to the SNO cross calibration, over ocean, a 0.48 K/yr drop in the AMR measurements relative to MetOp/AMSU is detected until the beginning of 2010. Over land, the trend is smaller, however, the available SNO events are limited. Future AMSU/SSMI FCDR will be used for cross-calibrating Jason radiometers to further reduce uncertainties and establish consistency.

3. Key Issues, Potential Solutions and Follow on Activities

AMSU and MHS measurements are subject to an array of bias sources. Some of the more noticeable sources are: satellite and sensor attitude errors, antenna sidelobe effects, polarization twist, sensor RFI, sensor nonlinear calibration error, and asymmetry in environmental conditions, etc. These factors can cause biases in sensor measurement including cross scan bias, systematic bias, and bias in local zenith angle (LZA). How to adequately correct these biases is the key to the successful creation of AMSU/MHS CDR. It is recognized that not all biases can be solved within a three year project, rather, those that have proven solutions and cause the greatest uncertainties in the FCDR should be addressed first. Over time, this approach reduces the overall uncertainty in both the FCDR and TCDR's, and advances the data along in the CDR "maturity model", where then further improvements can be made in follow on efforts.

Satellite orientation and sensor mounting issues lead to geolocation and LZA errors, which consequently causes cross scan bias. To correct for geolocation error, the satellite and sensor attitudes are combined into a set of three attitude variables. The navigation method developed by Kigawa and Weinreb (2002) are employed to derive geolocation with given attitude. The adjustment to each of the three variables is derived by evaluating the difference between ascending and descending measurements along coastlines. LZA can be corrected once the adjustments to attitude variables are attained.

Cross scan bias is the consequence of several sensor and calibration issues. After geolocatioin error is removed, the remaining bias will be collectively characterized with the aid of NESDIS Community Radiative Transfer Model (CRTM) and consequently corrected. To minimize the environmental effect, data will be filtered by certain criteria such as homogeneous surface and clear sky condition. Some of the AMSU/MHS data are assimilated in the reanalysis data that are used to run CRTM. Since scan bias correction is performed before the satellite data are assimilated, a set of data denial experiments will be conducted to investigate the impact of any residual scan bias on reanalysis output. This exercise is to ensure that the input data to CRTM do not introduce any artifact (scan bias) to simulations. Other approaches will also be experimented to validate the cross scan bias in measurement as quantified by CRTM.

Sensor RFI is a major bias source for NOAA-15 and a minor one for NOAA-17. Correction methods have been developed by previous studies and are applied in operational product systems that use the satellite data. However, there has been report (Surussavadee and Staelin, 2010) of residual RFI for NOAA-15 and NOAA-16 AMSU-B sensors that requires additional correction. The RFI issue will be investigated in this project.

Because of the lack of SI traceability for satellite passive microwave measurements, systematic bias in the AMSU/MHS observations will be corrected through inter-satellite calibration. The six POES satellites (e.g., NOAA-15, -16, -17, -18, -19 and MetOp-A) have three pair-wise overlapping periods since 2008 due to orbital drift. The overlapping makes it possible to perform inter-satellite calibration using Simultaneous Nadir Overpass (SNO) or Double Difference (DD) techniques. The traditional SNO application in polar regions proves to be very challenging for window channels due to heterogeneous surface (Iacovazzi & Cao, 2008). However, a method developed by Mo (2010) is promising for accomplishing this task which takes advantage of the long Antarctic winter months with almost 24-hr nighttime. Under such conditions, there is minimum or no diurnal cycle in the AMSU/MHS measurements. By taking monthly (or longer time period) averages, one can further smooth out the effect of surface and atmospheric heterogeneity, and enhance systematic signal. Then it becomes possible to inter-calibrate all the POES satellites by comparing the averaged AMSU/MHS measurements.

One of the AMSU/MHS CDR project goals is to generate TCDR's for several hydrological products (e.g, rainfall, total precipitable water, snow cover, etc.). The possibility of using these products to validate the bias correction for sensor measurements will also be explored. The successful generation of these TCDR's will demonstrate the accuracy of the FCDR's; it is likely that some iteration will be required for certain FCDR channels if biases are still found in a particular TCDR.

SSM/T2 and related calibration face two primary issues: Missing data and undocumented change in metadata and the lack of high-quality atmospheric humidity measurements for calibration (operational radiosondes lack sensitivity to upper-tropospheric humidity, which is the key parameters affecting SSM/T2 water vapor channel radiances). The first issue will be resolved by contacting instrument specialists in the U.S. Air Force who were involved in the original SSM/T2 program to obtain the complete data record (some progress has already been made, thanks to H. Semunegus of NCDC). Once the raw SSM/T2 data are all in place, our first job is to turn them into raw CDR in netCDF format to facilitate future use by other users. W. Berg of Colorado State University (and a co-PI in a related CDR program focusing on the SSM/I sensor) volunteered to share their expertise in quality controlling and archiving SSM/I data. The second issue will be dealt with using MOZAIC temperature and humidity measurements during aircraft taking off and landing, which provide the high-accuracy humidity profiling capability. Then, the CRTM will be used to calibrate SSM/T2 humidity channels.

4. Summary

A highly successful workshop on AMSU/MHS/SSMT2 CDR's was held on March 2 and 3 in College Park, MD. The project PI's (Ferraro, Meng, Luo) and their teams received valuable feedback on their ongoing efforts from the 40 or so experts in the field that were in attendance, and learned about the current status of passive microwave sensor calibration efforts from related CDR projects and those underway as part of NASA's GPM "X-Cal" team. This information, summarized in this report and further articulated in section 3, will be used to advance the current status of our projects and ultimately lead to useful CDR's from these sensors.

5. References

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Kigawa, S., and M. P. Weinreb, 2002. An algorithm for correction of navigation errors in AMSU-A data. *NOAA technical report NESDIS 110*.

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Surussavadee, C., and D.H. Staelin, 2010. Global Precipitation Retrievals Using the NOAA AMSU Millimeter-Wave Channels: Comparisons with Rain Gauges. *J. Appl. Meteor. Climatol.*, 49, 124–135.

Appendix A – Workshop Agenda

Wednesday March 2		
100 pm	Welcome, goals, logistics	R. Ferraro, H. Meng, J. Luo, A. Busalacchi
Session 1 - Overviews		
115 pm	CDR Program - Precipitation	B. Nelson
130 pm	STAR's Contributions to the CDR Program	M. Goldberg
Session 2 - AMSU-A		
145 pm	AMSU CDR Project - Overview	H. Meng
200 pm	Intersatellite/Intersensor Calibration of Microwave Radiometers over Antarctica	T. Mo
230 pm	AMSU-A Asymmetry	W. Yang
300 pm	**Coffee Break**	
315 pm	A Brief Overview of AMSU-A Intercalibration using the SNO Method	R. Iacovazzi
335 pm	An update on the NOAA MSU/AMSU/SSU sounding CDR development	C. Zou
Session 3 - AMSU-B/MHS		
355 pm	AMSU-B/MHS Asymmetry	C. Devaraj
415 pm	EUMETSAT Activities for CDR with Special Emphasis on MHS	J. Ackermann
445 pm	Discussions - AMSU-A, AMSU-B, MHS	All
515 pm	**Workshop Ends for the Day - Possible Group Dinner at 600 pm**	
Thursday March 3		
Session 4 - SSMT/2 and Beyond		
830 am	SSMT/2 and MOZAIC: Bringing Together Satellite and Aircraft Long-Term UTH Measurements	J. Luo
900 am	An A-Train Water Vapor CDR using Cloud Classification	E. Fetzer
930 am	A Multi-Sensor Perspective on the Tropical Interannual Variability of Humidity and Clouds	C. Liang
1000 am	**Coffee Break**	
Session 5 - Other Topics		
1020 am	Non-linear trends in AMSU	F. Weng
1050 am	Geolocation Errors in AMSU/MHS	I. Moradi
1110 am	Optimizing and Validation of ATMS CDR's	B. Blackwell
1140 am	Monitoring the JASON-2 AMR Stability using SNO Observations from AMSU and MetOp and NOAA	R. Chen
1200 pm	**Eat-In/Working Lunch**	
1230 pm	Plenary - List and rank major sources of errors, and difficulty in resolving them, etc.	All
230 pm	Wrap Up	
300 pm	**Workshohp Ends**	

Appendix B – Workshop Participants

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