Semi-Annual Progress Report:

The Development of AMSU FCDR's and TCDR's for Hydrological Applications

Project Funding Period: May 1, 2010 – April 30, 2013

Reporting Period: May 1, 2010 – October 31, 2010

Principal Investigators: Ralph Ferraro and Huan Meng
NOAA/NESDIS/STAR/CoRP/Satellite Climate Studies Branch
College Park, MD

Scientific Staff: Wenze Yang, Chabitha Devaraj, Isaac Moradi
Cooperative Institute for Climate and Satellites (CICS), College Park, MD

Project Objectives:

This project will properly characterize the AMSU and MHS sensors to generate FCDR's from the Advanced Microwave Sounding Unit (AMSU); channels 1,2,3 and 15 on AMSU-A and all five channels on AMSU-B/MHS. We will then use an existing product generation system to generate TCDR's for hydrological cycle products like precipitable water, rain rate and snow cover. The generation of TCDR's is a necessary step to assess the accuracy of the FCDR's; similar results by multiple methods yield confidence and uncertainty estimates in the CDR's. In order to engage experts in the field, we will hold a workshop during the first year of the project. By project completion, an 11-year (2000 – 2010) AMSU CDR is anticipated. The table below shows the sensors and years of operation that we will use in the project (note that NOAA-15 was placed into operation in 1998, however, there are some uncertainties in sensor health that might prevent us from generating CDR's for 1998 and 1999; additionally, several sensors have limited capability near the end of their data record).

Satellite	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
NOAA-15	May	X	X	X	X	X	X	X	X	X	X	X	X
NOAA-16			Sep	X	X	X	X	X	X	X	X	X	X
NOAA-17					Jun	X	X	X	X	X	X	Dec	
NOAA-18								May	X	X	X	X	X
MetOp-A									Oct	X	X	X	X
NOAA-19												Feb	X

Year 1 Milestones:

From our original proposal, our milestones for the first year are to:

1. Acquire complete data set of AMSU level 1b for all NOAA-15 through N-19 and MetOp-A
2. Acquire and assemble data and metadata for all satellites
3. Organize and hold Water Cycle CDR workshop; factor in feedback to update proposal plan, including final selection of three viable AMSU calibration methodology
4. Begin SNO and RTM calibration; assess preliminary results
5. Begin asymmetry assessment
6. Implement L1 QC checks
7. Collaborate with other SDS projects
8. Present findings at scientific conferences

Progress during the Reporting Period:

Excellent progress has been made during the first six months of this project; these are summarized in items 1 – 8 below (aligned with the milestones above). We are also pleased to report that we are fully staffed with researchers at the Cooperative Institute for Climate and Satellites (CICS); the Satellite Climate Studies Branch is collocated with CICS in College Park, MD. This includes Wenze Yang (April 2010); Chabitha Devaraj (November 2010); Isaac Moradi (January 2011). We also participated at the CDR Principal Investigators meeting in Asheville, NC (August 2010).

1. All level 1b data sets have been acquired and stored on our local processing system.

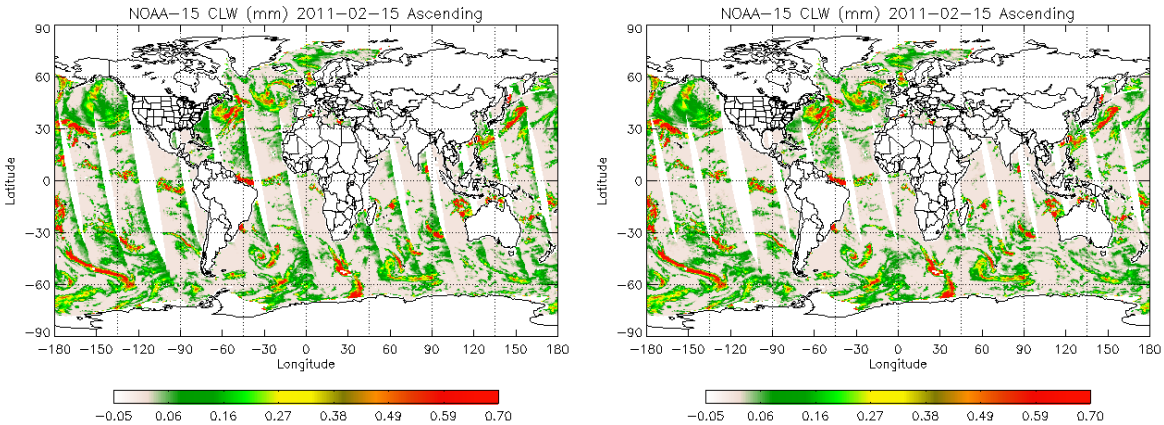
2. We have begun to acquire metadata for the various satellites, including sensor health information and operational processing changes from NESDIS/OSDPD and the MSPPS project log.

3. A workshop is planned for March 2 and 3, 2011 in College Park, MD.

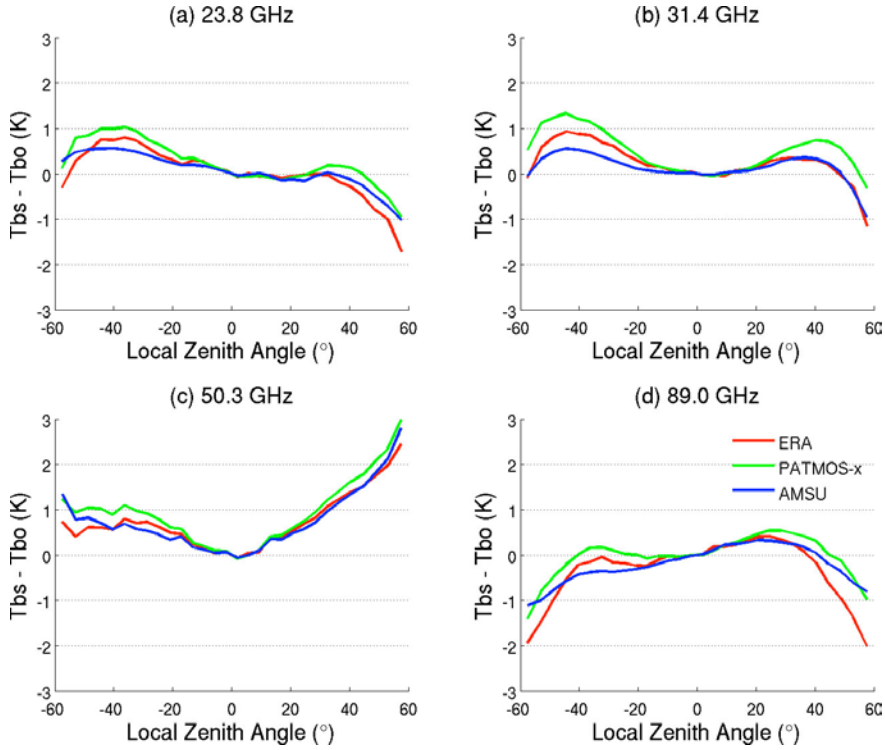
4. The Joint Center for Satellite Data Assimilation (JCSDA), Community Radiative Transfer Model (CRTM) was installed on our local workstations. We have also obtained the European Center for Medium Range Weather Forecasts (ECMWF) reanalysis data sets (ERA-Interim) which provide the needed input to perform the CRTM calculations. Cloud data (PATMOS-x) information was obtained from A. Heidinger for determining cloud free scenes. Results from the use of these data with the CRTM are further described in item 5 below.

5. The majority of our time has been devoted to characterizing the AMSU-A cross-track asymmetry that plagues all of the AMSU-A sensors in operation. Without proper characterization of this affect, large biases will exist in the FCDR and TCDR products. NESDIS develops a first order asymmetry correction soon after satellite launch;

however, this is not suitable for CDR work and is not updated after launch. The figure below shows an example of uncorrected vs. corrected AMSU-derived cloud liquid water (CLW) for NOAA-15 based on the original correction developed. Note how in the original, there is more CLW on the right side of each orbit than the left, but that bias is eliminated after the correction is applied.



AMSU-A window channel brightness temperature (TB's) over tropical and Sub-tropical Ocean under clear sky conditions (as determined from both the PATMOS-x and ERA-Interim data), were compared with CRTM simulated TB's for AMSU-A channels at 23.8, 31.4, 50.3 and 89.0 GHz. This was done to characterize the across scan asymmetry. Some example results for NOAA-18 in January 2008 are presented in the figure below.



Interestingly, the results are quite sensitive to the cloud mask that is being used, including the MSPPS (AMSU) derived CLW product. Work continues to better understand this result.

6. Not started yet.

7. We are working closely with our colleagues at NOAA/NESDIS (C. Zou, PI) and Colorado State University (C. Kummerow, PI) on their AMSU (sounding channels) and SSM/I CDR efforts. The main areas of engagement are with the use of the CRTM model, calibration techniques and data set acquisition. As described in item 4 above, we are working with A. Heidinger on use of his cloud products. Additionally, we have initiated collaborations with J. Luo (CCNY) on his SSM/T2 CDR effort (which is similar to AMSU-B/MHS). The March workshop is being held in conjunction with him.

8. The following presentations were given during the reporting period:

- Huan Meng, Wenze Yang, Ralph Ferraro, Development of AMSU-A Fundamental CDR's. Conference and Characterization and Radiometric Calibration for Remote Sensing (CALCON), August 23-26, 2010, Logan, UT.

- Wenze Yang, Huan Meng, Ralph Ferraro, Development of AMSU-A Fundamental CDR's. 17th AMS Conference on Satellite Meteorology and Oceanography, September 27-30, 2010, Annapolis, MD.

- Wenze Yang, Huan Meng, Ralph Ferraro, Development of AMSU-A Fundamental CDR's. NASA GPM-Xcal Working Group Meeting, October 21-22, 2010, Ashville, NC.

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Satellite	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
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NOAA-16			Sep	X	X	X	X	X	X	X	X	X	X
NOAA-17					Jun	X	X	X	X	X	X	Dec	
NOAA-18								May	X	X	X	X	X
MetOp-A									Oct	X	X	X	X
NOAA-19												Feb	X

Year 1 Milestones:

From our original proposal, our milestones for the first year are to:

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5. Begin asymmetry assessment
6. Implement L1 QC checks
7. Collaborate with other SDS projects
8. Present findings at scientific conferences

Progress during the Reporting Period:

Excellent progress continues to be made during the second six months of this project; these are summarized in items 1 – 8 below (aligned with the milestones above). We are pleased to report that essentially all of the milestones have been met (aside from item 6 which will be worked on in year 2).

1. Completed in the previous reporting period.

2. We continue to acquire metadata for the various satellites, including sensor health information and operational processing changes from NESDIS/OSDPD and the MSPPS project log.

3. A CDR workshop was held on March 2 and 3, 2011 in College Park, MD and was attended by over 40 participants. A web page containing the presentations and workshop summary report can be found at http://www.star.nesdis.noaa.gov/star/meeting_CDR2011.php. A meeting summary article was also submitted for publication in *Eos;* a brief synopsis is presented below.

   Several key issues were identified at the workshop that needs to be addressed by the NOAA CDR projects. These include: satellite and sensor attitude, high quality "meta data" on the sensors, antenna sidelobe effects, sensor RFI, sensor nonlinear calibration error, orbital drift and decay, and asymmetry in environmental conditions. 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 subsequent improvements can be addressed in follow on efforts and through continued synergy with other similar programs at organizations like NASA and EUMETSAT. The project PI's (Ferraro, Meng, Luo) and their teams received valuable feedback on their ongoing efforts from the experts in the field that will greatly

benefit their projects over the next two years.

4. The Joint Center for Satellite Data Assimilation (JCSDA), Community Radiative Transfer Model (CRTM) was installed on our local workstations. We have also obtained the European Center for Medium Range Weather Forecasts (ECMWF) reanalysis data sets (ERA-Interim) which provide the needed input to perform the CRTM calculations. Cloud data (PATMOS-x) information was obtained from A. Heidinger for determining cloud free scenes. Results from the use of these data with the CRTM are further described in item 5 below.

5. In the reporting period, our team continued on characterizing the AMSU-A cross-track asymmetry in a thorough and systematic way. We investigated the asymmetry pattern for different satellites over different years, and found that the asymmetry pattern appears to be stable through several years of data examined, as shown in Figure 1, but are quite different among those on-board the different NOAA and EUMETSAT satellites, as shown in Figure 2. 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. Previous observed asymmetry seasonality or asymmetry change through time can be explained by environmental changes.

   Specially, we tried stratification of environment variables to identify their impact on across scan asymmetry at three levels from wide to narrow variable spaces: category level, class level, and most probable value (MPV) level. At the category level, each variable is divided into high, mid and low value ranges, and the asymmetry results are averaged in the ranges; at the class level, the three-variable joined space is divided into 27 classes with high, mid and low value ranges for each of the three variables, e.g., class 1 stands for low SST, low PW and low V; at the MPV level, the center is set at MPV, and the variable range is only plus and minus one tenth of the difference between 95 percentile and 5 percentile. An example of stratification comparison at class level is shown in Figure 3. The variable range does play a role in changing the across scan asymmetry pattern, and wind speed has the most significant impact.

   The distinctive advantages to stratify at MPV level are as follows: firstly, in the narrow MPV range, there is no angular dependence for environmental variables, thus removes the environmental asymmetry; secondly, even at such a narrow range, we can still capture the across scan asymmetry, which strongly resembles the across scan asymmetry without stratification. Combining these two aspects, it is possible to simulate the polarization component of brightness temperature, and adjust the reflector normal angle and polarization alignment angle at MPV level. For example, by adjusting 0.5° of reflector normal angle, and 0.7° of polarization alignment angle, the scan bias of 22.3 GHz could turn rather symmetric. These findings further demonstrate that the first order asymmetry correction developed by NEDIS is not adequate for CDR

work, and we should build our correction scheme basing on these results.

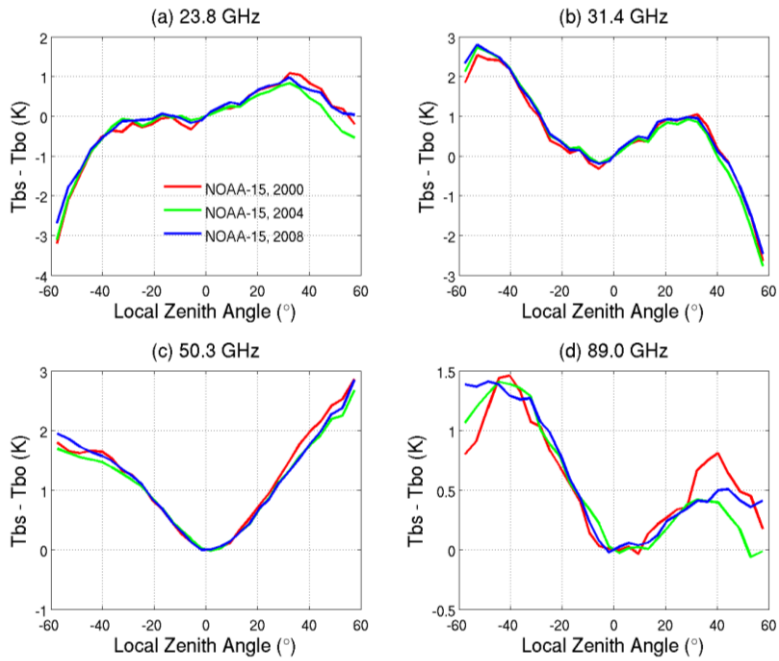

Figure 1. Average differences between the simulated brightness temperatures and the observations from NOAA-15 AMSU-A at (a) 23.8 GHz, (b) 31.4 GHz, (3) 50.3 GHz, and (d) 89 GHz. The observed data are under clear sky and over tropical and subtropical oceans from 30S-30N, whole year 2000 (red), 2004 (green), and 2008 (blue). Note this is the stratification case at most probable value.

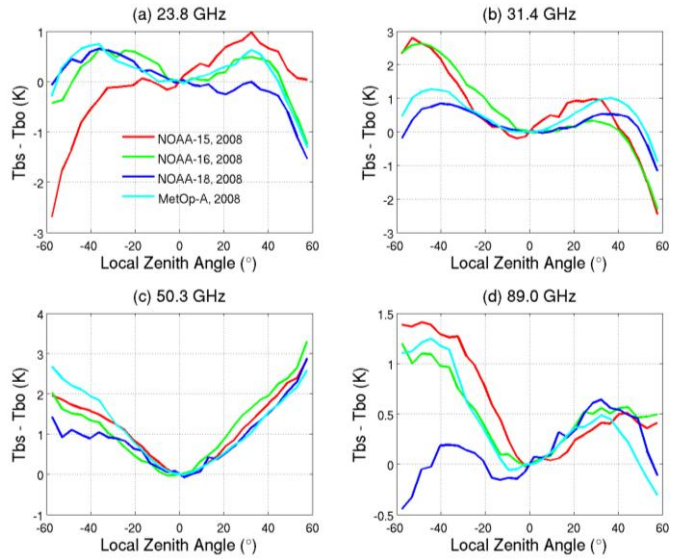

Figure 2. Average differences between the simulated brightness temperatures and the observations from NOAA-15 (red), NOAA-16 (green), NOAA-18 (blue) and MetOp-A (cyan) AMSU-A at (a) 23.8 GHz, (b) 31.4 GHz, (3) 50.3 GHz, and (d) 89 GHz. The observed data are under clear sky and over tropical and subtropical oceans from 30S-30N, whole year 2008. Note this is the stratification case at most probable value.

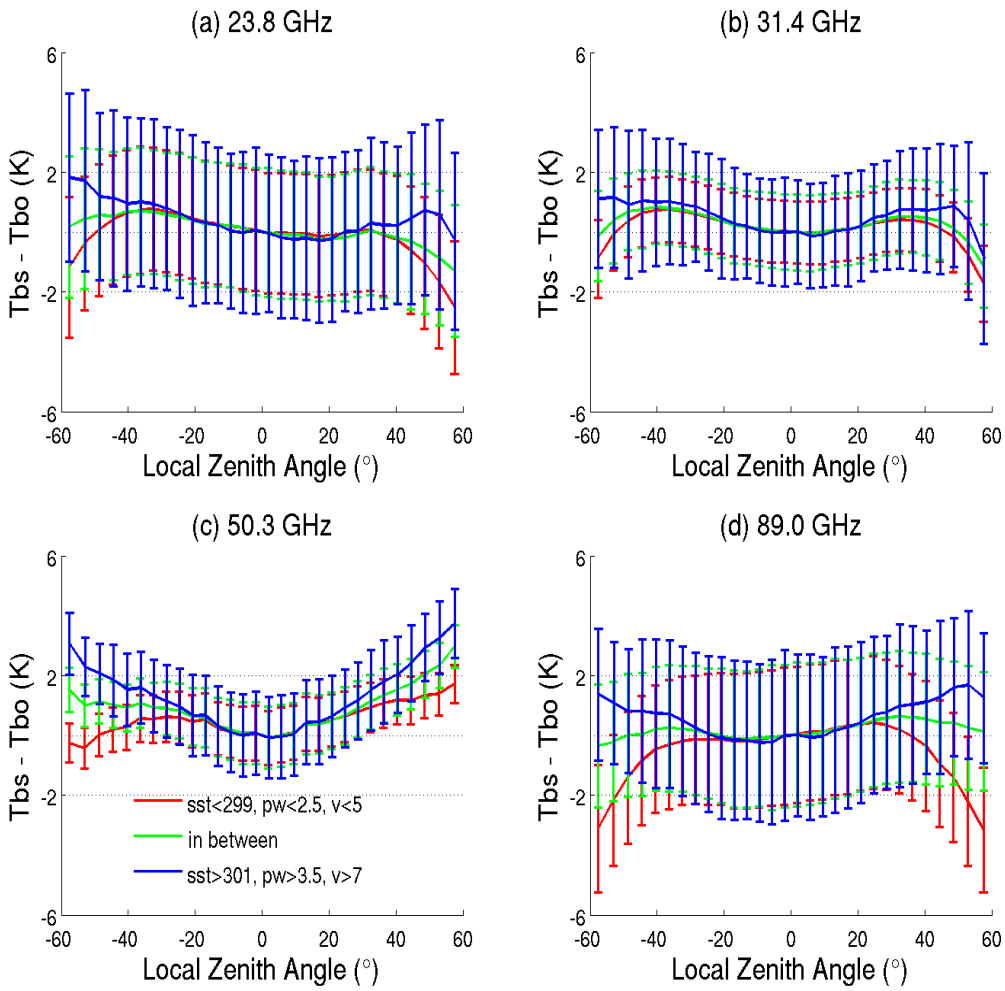

Figure 3. Average differences between the simulated brightness temperatures and the observations from NOAA-18 AMSU-A verses sea surface temperature (sst), precipitable water (pw), and wind speed (v) at (a) 23.8 GHz, (b) 31.4 GHz, (3) 50.3 GHz, and (d) 89 GHz. The observed data are under clear sky and over tropical and subtropical oceans from 30S-30N. The stratification comparison is performed at class level, with class 1 in red, class 14 in green, and class 27 in blue.

The across-scan bias and asymmetry in AMSU-B/MHS was initiated during the reporting period, using a similar method that was adopted for AMSU-A. Using the Community Radiative Transfer Model (CRTM), the AMSU-B/MHS channel brightness temperature (TB's) over tropical ccean under clear sky conditions (determined using PATMOS-x) were compared with CRTM simulated TB's for AMSU-B/MHS channels. Figure 4 presents the preliminary results of MHS scan bias characterization in NOAA-18 2008 data using stratification of different environmental conditions for the window channels.

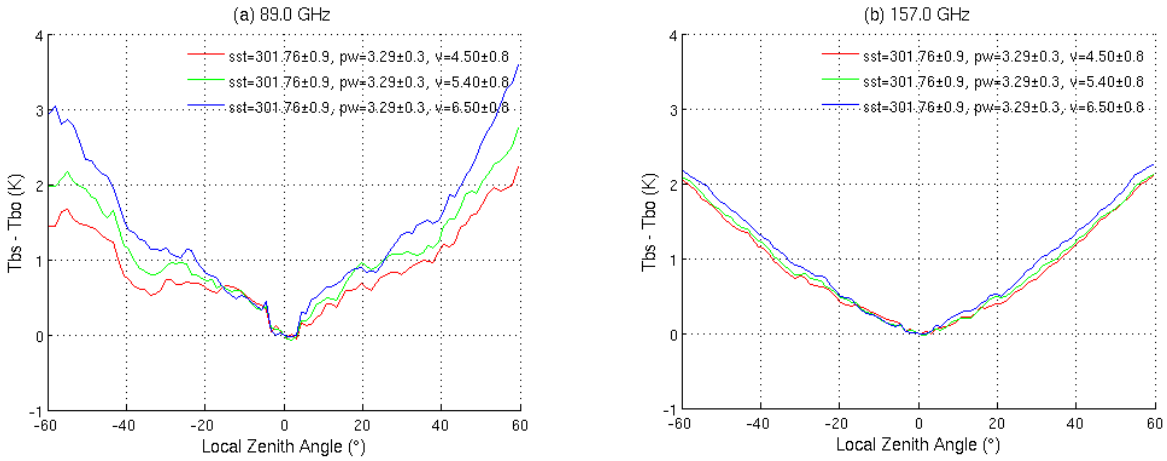

Figure 4. Average differences between the simulated brightness temperatures and the observations from NOAA-18 MHS verses sea surface temperature (sst), precipitable water (pw), and wind speed (v) at (a) 89 GHz and (b) 157 GHz. The observed data are under clear sky and over tropical oceans for all of 2008. The different colors represent different conditions of SST, TPW and surface wind speed.

Another important problem related to the AMSU/MHS sensors is the geo-location error. There are three different sources for geo-location errors that include satellite ephemeris data, time offset and satellite and sensor attitude errors (error in pitch, roll, and yaw, PRY). NOAA has made efforts to minimize the errors in the ephemeris data and satellite clock error. We have examined the error that has originated from the satellite and sensor attitudes, i.e. the pitch, roll and yaw (PRY). The geo-location error can be distinguished from the differences between ascending and descending data. In the case of geo-location error, the difference maps show large differences between ascending and descending brightness temperatures along the coastlines (see Figure 5). We have already investigated two methods to apply the error in PRY. The first method calculates the satellite position using two adjacent scan lines and then applies the PRY corrections to calculate the new geographical coordinates. This method showed a large bias which we assumed to be unreasonable. The second method is based on propagating the satellite ephemeris data to calculate the satellite position and then applying the PRY correction. This method has been compared to the current method that is in use by NOAA/NESDIS and has shown good accuracy. We are still investigating this method to make sure that it has works over the period of record for each satellite. After verifying the method, we will implement an iteration method to find the best PRY set and then will apply the PRY corrections and will calculate new geographical coordinates and local zenith angles. This will then be the first layer of corrections applied to the level 1 data before any other corrections are applied.

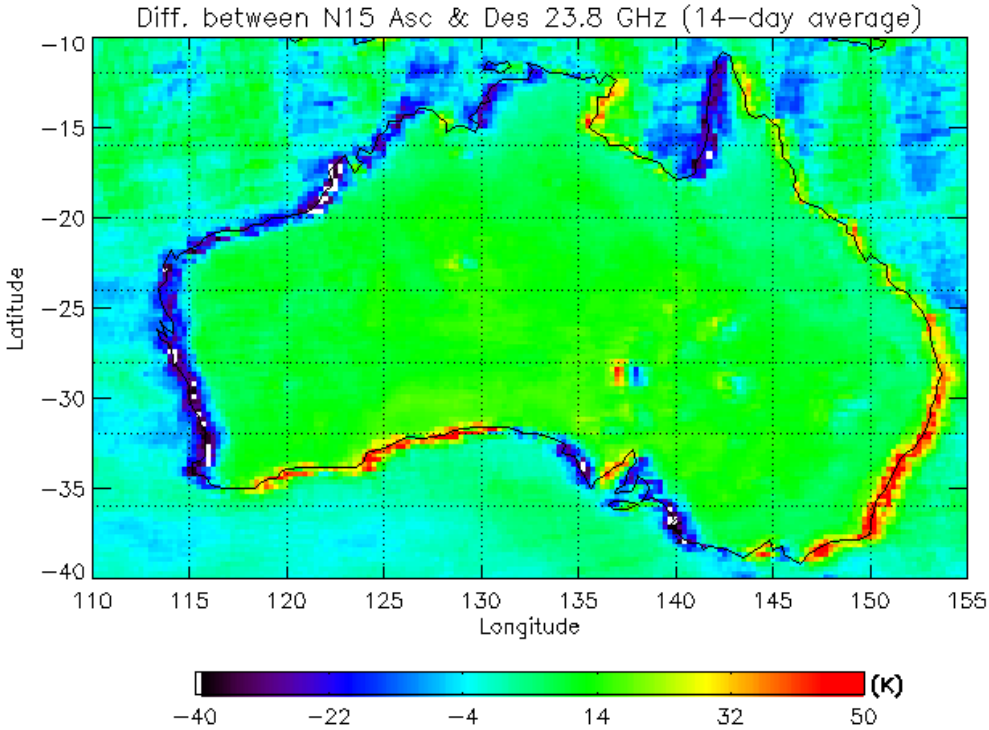

Figure 5. An example of the geolocation error on N-15 for the 23.8 GHz channel where the differences between ascending and descending data are computed over a 14-day period.

6. Not started yet; will be worked in during year 2.

7. We continue to work closely with our colleagues at NOAA/NESDIS (C. Zou, PI) and Colorado State University (C. Kummerow, PI) on their AMSU (sounding channels) and SSM/I CDR efforts. The main areas of engagement are with the use of the CRTM model, calibration techniques, data set acquisition and output formatting/meta data for the CDR program. As described in item 4 above, we are working with A. Heidinger on use of his cloud products. We also have collaborated with J. Luo (CCNY) on his SSM/T2 CDR effort and held the joint workshop in March.

8. The following presentations were given and publications written during the reporting period:

   - W. Yang - Development of AMSU-A Fundamental CDR's. AGU fall meeting, San Francisco, CA., December 2010.

   - H. Meng – Scan Bias Characterization for Generation of AMSU-A CDR. EGU annual meeting. Vienna, Austria, April 2011.

   - H. Meng – Project Overview – The Development of AMSU FCDR's and TCDR's for

Hydrological Applications. NOAA Workshop on Climate Data Records from Satellite Passive Microwave Sounders - AMSU/MHS/SSMT2: College, Park, MD, March 2011.

- W. Yang – AMSU-A Asymmetry for Window Channels. NOAA Workshop on Climate Data Records from Satellite Passive Microwave Sounders - AMSU/MHS/SSMT2: College, Park, MD, March 2011.

- C. Devaraj – AMSU-B/MHS Asymmetry. NOAA Workshop on Climate Data Records from Satellite Passive Microwave Sounders - AMSU/MHS/SSMT2: College, Park, MD, March 2011.

- I. Moradi – AMSU Navigation and Geolocation Errors. NOAA Workshop on Climate Data Records from Satellite Passive Microwave Sounders - AMSU/MHS/SSMT2: College, Park, MD, March 2011.

- Ferraro, R., H. Meng, Z. Luo, W. Yang, C. Devaraj, and I. Moradi, 2011: NOAA Workshop on Climate Data Records from Satellite Passive Microwave Sounders - AMSU/MHS/SSMT2: March 2-3, 2011 at Earth System Science Interdisciplinary Center (ESSIC), College Park, MD.

- Ferraro, R., H. Meng and Z. Luo, 2011: NOAA Workshop on Climate Data Records from Satellite Passive Microwave Sounders - AMSU/MHS/SSMT2: March 2-3, 2011 at Earth System Science Interdisciplinary Center (ESSIC), College, Park, MD. *submitted, EOS.*