First Six-Month (May 1, 2010 – October 31, 2010) Report for

NOAA CDR Project (Award No. NA10NES4400004)

Creating UTH-Related FCDRs from IR and Microwave Sensors Cross Calibrated by In Situ Measurements from Commercial Aircraft

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1. Introduction

The objective of this project is to bring together all the upper-tropospheric humidity (UTH)-relevant radiance data (IR and microwave) from multiple satellites and process them to establish a long-term, global radiance record from which a climate record of UTH variations can be retrieved and UTH research may be conducted. There are two unique aspects for this project: 1) The calibration component: instead of cross checking one satellite with another, we bring in an independent and highly-accurate (RH accuracy within ~ 5%) calibration anchor – the MOZAIC (Measurement of Ozone and Water Vapour by Airbus In-Service Aircraft) project. Figure 1 shows the global distribution of the MOZAIC flights. 2) Emphasis is placed on microwave radiances (183 GHz), which, unlike its IR counterpart (6.7 μm), have been received much less attention before, especially those from the SSM/T2.

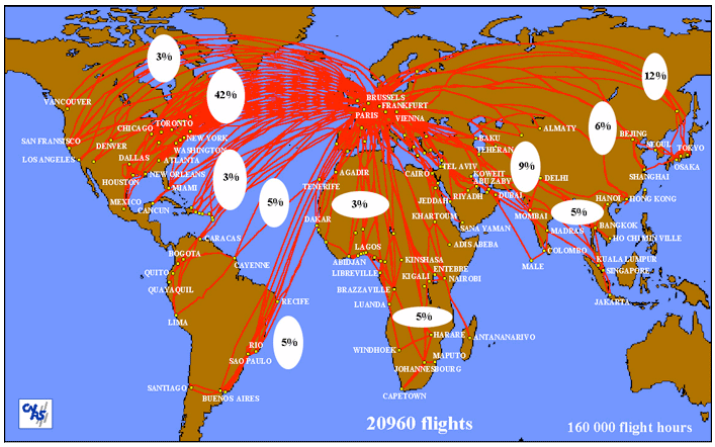

Figure 1. MOZAIC flight distribution. The project started from 1994 and is still ongoing and in transition to becoming a larger system called IAGOS.

2. Research Progress

For the first 6 months (May 1, 2010 – October 31, 2010), we have made progress in the following areas: 1) Obtaining SSM/T2 data from NCDC, 2) Investigating SSM/T2 data continuity and problems with metadata, 3) Preliminary analysis of variations of the SSM/T2 brightness temperatures, 4) Matching MOZAIC and SSM/T2 data in space and time, and 5) Investigating the relationship between SSM/T2 brightness temperatures (183 GHz) and MOZAIC measurements of upper-tropospheric temperature and humidity.

1) Obtaining SSM/T2 data from NCDC

Since one of the emphases of this proposal is on microwave UTH radiances (i.e., 183 GHz), we started from SSM/T2. With the help of NCDC (Dr. John Bates and colleagues), we obtained all SSM/T2 data files (~ 10 years: 1994-2004) from F-11, F-12, F-14 and F-15 and saved them in our local storage system. Our next step is to obtain the rest of the microwave UTH data from SSMIS (Oct 2003 onward) and AMSU-B (June 1998 onward).

2) Investigating SSM/T2 data continuity and problems with metadata

SSM/T2 data are among the least well-studied UTH data for climate purposes, probably because the instruments belong to DMSP (DoD) and it is not DoD's intention to create any long-term climate data record (CDR). Therefore, our first task is to simply run through the data and check if there are any problems with data continuity. We identified at least the following two problems which need to be addressed further:

a) Inconsistent metadata:

DMSP provided a C code to read SSM/T2 data: ssmt2list.c, which, according to the comments, was written in May 1995, i.e., the first few years of the launch of SSM/T2 (code and README file can be downloaded from NOAA CLASS website). This code - ssmt2list.c - converts raw counts into brightness temperature (TB) using two variables: SLOPE and OFFSET, that is, TB = count*SLOPE + OFFSET. The OFFSET value changes in early 1999 from 100 to 20. This was not documented at the NOAA CLASS website. We only learned about this change from a former user, John Forsythe of CSU. This occurs around Line 57 of ssmt2list.c:

```
#define SLOPE(p) ( SV2(p) / 10000.0f)
#define OFFSET(p) ( SV2(p) / 20.0f)  /* 9903915 UTC F12 F14- changed
from 100.0 before to 20.0 after*/
```

After November 2000, however, another change occurs, either in SLOPE, or OFFSET, or both, because TB suddenly goes out of bound. Neither OFFSET value (100 and 20) is able to convert the raw counts to the correct TBs. Our next step is to contact DMSP to sort out what changes have been made in the metadata after November 2000. Once this issue is resolved, we will post these changes on the NOAA CLASS website to facilitate future users.

b) Missing files and "bad" data record:

We also investigated data inhomogeneity or discontinuity for SSM/T2. Figure 2 shows the ratio of number of actual data record versus the expected number based on satellite orbit and scanning pattern. Any value smaller than 1 indicates missing files or "bad" data (as flagged so by a quality variable inside the ssmt2list.c). Analysis of the data files shows that quite a lot of files are missing for F-12 during 1997-1998. There is also an increase of "bad" quality data for that period, especially over the Northern Hemisphere. We plan to sort out these issues with DSMP.

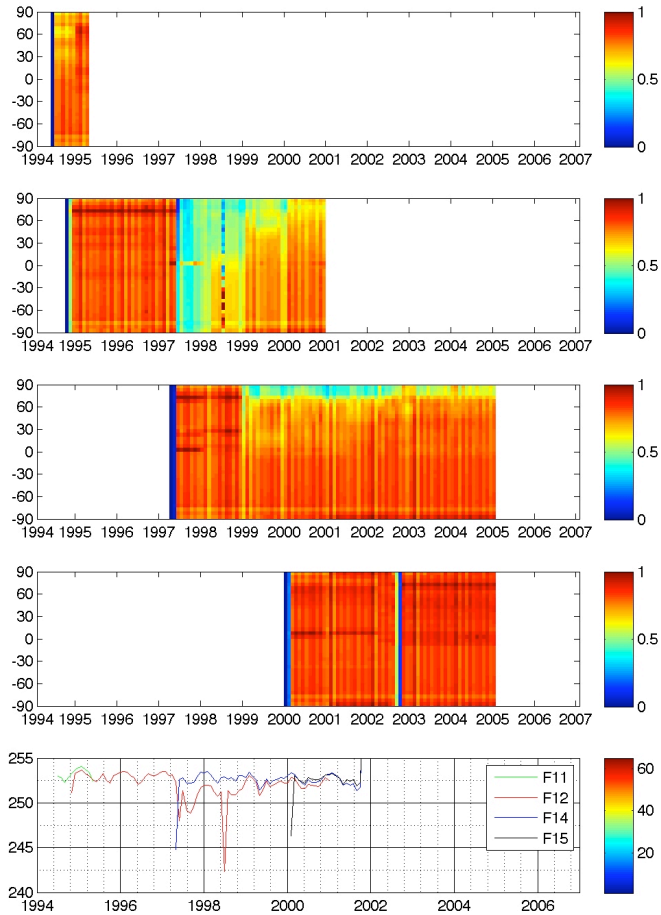

Figure 2. (The top four panels) Ratio of number of actual data records to the expected number based on satellite orbit and scanning pattern. Any value smaller than 1 indicates missing files or "bad" data (there is a quality flag variable which could label a temperature as "bad"). These four panels are, respectively, for F-11, F-12, F-14 and F-15. Abscissa is time and ordinate is latitude. The ratio is calculated for each $5^0 \times 5^0$ grid box every month. (The bottom panel) Monthly and globally averaged brightness temperature (TB) for 183±1 GHz. The color bar for the bottom panel should be ignored (it was put there as a space holder just to make sure the TB time series match the time of the top four panels).

3) Preliminary analysis of variations of the SSM/T2 brightness temperatures

The bottom panel of Figure 2 shows the global and monthly average TB for 183±1 GHz channel. No correction was made to the data at this point, so these are the "raw" averages. Clearly we see some abrupt changes in TB that needs more analysis (e.g., F-12 during 1997). These changes in TB seem to be correlated with the onset of missing files during 1997. We will dig into these problems in great detail.

4) Matching MOZAIC and SSM/T2 data in space and time

Since a unique aspect of this project is use of high-quality temperature and humidity measurements from MOZAIC project to calibrate satellite data, it becomes an important first step to match satellite and aircraft data in space and time. The matched data is our calibration anchor. The basic premise of the matching algorithm is to set up a global grid and place data from the original datasets (i.e., SSM/T2 and MOZAIC) into their respective geographical cells. Our current cell size is $0.1^0 \times 0.1^0$ in space and 30 min in time. Figure 3 shows the number of matches for each month counted within $5^0 \times 5^0$ grid boxes. It is still an open question what is the best size for these cells. Our ongoing research includes a specific study to match the grid cell size to the time window by the upper-tropospheric wind speeds. If needed, we will even consider a variable grid cell as a function of latitude to reflect different wind speed regimes.

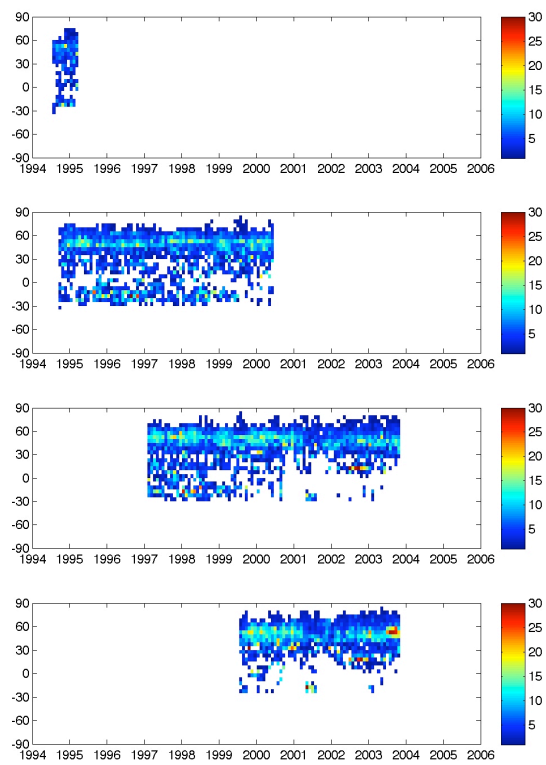

Figure 3. Number of matched MOZAIC-SSMT2 data points at a function of latitude and time (month). The four panels are for F-11, F-12, F-14 and F-15. The basic premise of the matching algorithm is to set up a global grid and place data from the original datasets (i.e., SSM/T2 and MOZAIC) into their respective geographical cells. Our current cell size is $0.1^0 \times 0.1^0$ in space and 30 min in time. But we are still studying what is the "best" cell size.

5) Investigating the relationship between SSM/T2 TB (183 ± 1 GHz) and MOZAIC measurements of upper-tropospheric temperature and humidity

Previous publications (e.g., Berg et al. 1999) has shown that *ln*(RH/cosθ) and TB(183±1 GHz) have good correlation, where RH is the average relative humidity of the upper-troposphere and θ is the viewing angle. Here, we conducted a preliminary investigation of this relationship using matched SSM/T2 and MOZAIC data. To get vertically averaged RH measurements, we only use the matched data during aircraft takeoff or landing. Figure 4 shows *ln*(RH/cosθ) versus TB(183±1 GHz) for RH averaged over two different layers: 300-500 hPa and 100-300 hPa. RH averaged over the 300-500 hPa layer shows better correlation with TB(183±1 GHz) than RH averaged over 100-300 hPa: the R square values are, respectively, 0.66 and 0.53. Currently, we are still in the process of testing the effects of different matching procedures on the scatter in the *ln*(RH/cosθ) - TB(183±1 GHz) relationship. This relationship is the backbone of our satellite calibration procedure since MOZAIC temperature and humidity measurements are quality assured throughout the project lifetime.

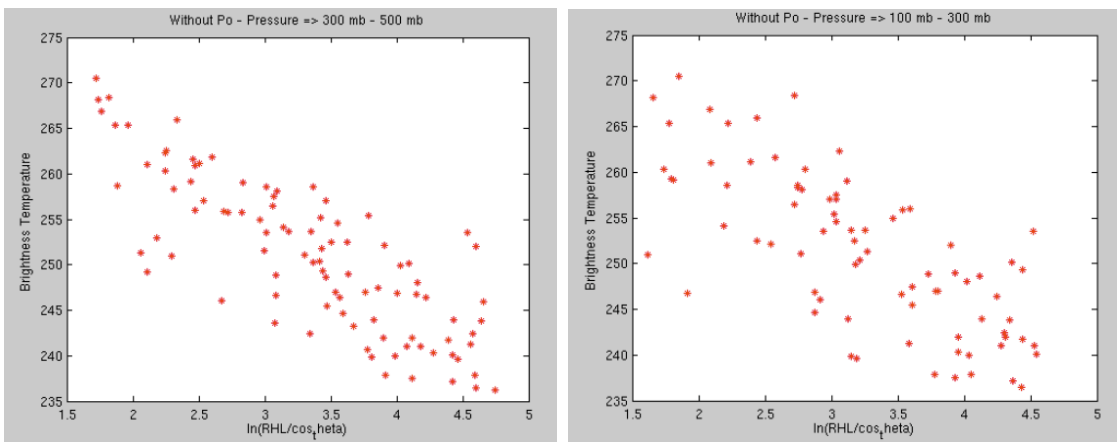

Figure 4. (Left) ln(RH/cosθ) versus TB(183±1 GHz) for collocated aircraft and SSM/T2 data. RH is averaged for 300-500 hPa. θ is the viewing angle. Only data from F-12 is used in this figure. (Right) The same as the left panel, except that RH is averaged for 100-300 hPa.

3. Planned work for 11/2010 – 11/2011

For the next year (11/2010-11/2011), we plan to work in the following areas:

1) Work with DMSP to resolve the metadata inconsistency and missing files for SSM/T2 data; post these changes at the NOAA CLASS website.

2) Obtain more microwave UTH data from other sensors, specifically, SSMIS and AMSU-B; processes them the similar way as did to SSM/T2 data, that is, match with MOZAIC data and analyze the relationship between humidity/temperature and brightness temperatures.

3) Test and develop methods to cross-calibrate these microwave UTH radiances using MOZAIC data.

4) Investigate the contamination by clouds (for microwave channels, it is mostly thick convective clouds that have a noticeable influence on the brightness temperatures).

5) Start to bring in IR UTH radiances (6.7 μm). IR UTH radiances from the GEOs are already in our possession as part of the ISCCP DX data. HIRS UTH data have been studied thoroughly by a NCDC group (Dr. John Bates and colleagues); we will work with them toward building a homogeneous IR/Microawve UTH FCDR.

Finally, we note that by later next year (2011), we will have the new ISCCP pixel-level product with a spatial sampling of 10 km (instead of the old 30 km sampling). This will become a useful ancillary dataset for studying the contamination effect of clouds on microwave and IR UTH radiances.

4. Students Training

A couple of students from NOAA-CREST center of CUNY (one Ph.D. student and one MS student) were hired on a part-time basis through this CDR funding. Their tasks include helping with data downloading and performing simple statistical analysis. The fulltime programmer for this project – Mr. Jeyavinoth Jeyaratnam – was also a recent graduate from NOAA-CREST.

5. Related Publications

Luo, Z. J., D. Kley, R. H. Johnson, G. Y. Liu, S. Nawrath, and H. G. J. Smit, 2010: Influence of sea surface temperature on humidity and temperature in the outflow of tropical deep convection, J. Climate, under review

Luo, Z., D. Kley, R. H. Johnson, and H. Smit 2007: Ten years of measurements of tropical upper-tropospheric water vapor by MOZAIC. Part I: Climatology, variability, transport and relation to deep convection. J. Climate, 20, 418-435

Berg, W., J. J. Bates, and D. L. Jackson, 1999: Analysis of upper-tropospheric water vapor brightness temperature from SSM/T2, HIRS, and GMS-5 VISSR. *J. Appl. Meteorol.*, 38, 580-595

Six-Month (November 1 2010 – April 30 2011) Report for

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1. Introduction & Overview

The objective of this project is to "bring together all the upper-tropospheric humidity (UTH)-relevant radiance data from multiple satellites and process them to establish a long-term, global radiance record from which a climate data record (CDR) of UTH can be retrieved and UTH research may be conducted". There are several unique aspects of the project: 1) *Calibration basis*: instead of just cross checking one satellite with another, we bring in an independent and highly accurate (RH accuracy within ~ 5%) calibration anchor – the MOZAIC (Measurement of Ozone and Water Vapour by Airbus In-Service Aircraft) project. 2) Emphasis is placed on *microwave sensors*, in particular those that have not been well archived in the past, such as SSM/T2. IR UTH measurements, in contrast, have been thoroughly studied in the past (e.g., Bates et al. 1996; 2001). 3) ISCCP 10-km pixel level *cloud product* (e.g., cloud flag and cloud properties) will be attached to the UTH radiances.

Over the past 6 months (November 1 2010 – April 30 2011), our research efforts focus on the following areas:

- Clean up and repackage raw SSM/T2 data obtained from NCDC.
- With the help of Hilawe Semunegus (NCDC), work with NOAA NGDC to rescue missing SSM/T2 data. This is an ongoing work.
- Matching SSM/T2 with a subset of MOZAIC data that correspond to aircraft take off and landing (which give temperature and humidity profiles).

Another highlight of the past 6 months is a CDR community workshop we hosted, together with Ralph Ferraro's team, in College Park, MD (March 2 – 3 2011). A website was developed for this workshop and all presentations can be found from there: http://www.star.nesdis.noaa.gov/star/meeting_CDR2011.php. And the workshop report has been submitted to *EOS*.

2. Research Progress

2.1 Cleaning up and re-packaging raw SSM/T2 data

Raw SSM/T2 data refer to the NSS.SMT2 files archived by NESDIS, which we obtained from NCDC. Close scrutiny of these data files show that they need some "clean up". Several problems were identified and we are working to address them:

1) Although most of the files are organized as one file per orbit, occasionally some files extend into the next orbit and the next file starts from the beginning of the same orbit. This will result in a double count problem if we simply average the records to generate long-term UTH variations. So, our first task is to granularize the raw data files, that is, save one orbit of data per file and eliminate redundant segments.

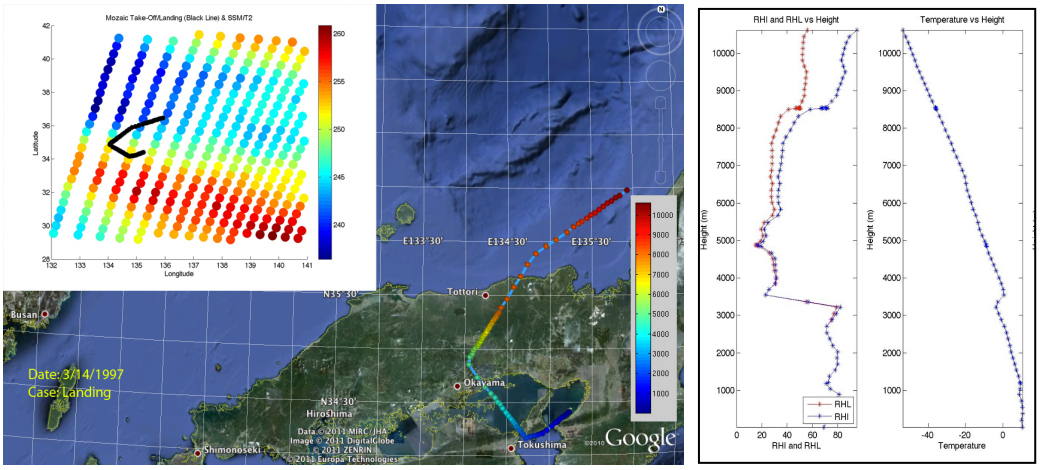
2) To facilitate analysis by future users, we also rewrote the SSM/T2 data records from the original simple binary format to a more convenient format – netCDF.

2.2 Rescue missing SSM/T2 data (work in progress)

With the help of Hilawe Semunegus (NCDC), we are now working with NOAA NGDC to rescue missing SSM/T2 data. As of now, we obtained two months of SSM/T2 data from NGDC. We are working on 1) writing up a program to automatically archive the data, and 2) compare the NGDC's record with that of NCDC. The two records should exactly match each other, but our preliminary analysis showed otherwise. So, we are trying to understand why. This is work in progress.

2.3 Matching SSM/T2 with MOZAIC ascending/descending measurements

Brightness temperatures at 183 GHz (TB183) are affected by temperature and water vapor from a thick layer from 200-600 hPa (Berg et al. 1999). One of the ways to calibrate TB183 is to use temperature/humidity sounding, coupled with a radiative transfer model, to calculate TB183 and then compare the calculation with collocated observation. A number of previous studies adopted this approach using radiosonde data (e.g., Buehler et al. 2004; Moradi et al. 2010). However, RH measurements from operational radiosondes suffer accuracy and precision problems in the cold upper troposphere (Elliot and Gaffen 1991; Wang et al. 2003). Therefore, we plan to use high-accuracy humidity measurements from MOZAIC to drive radiative transfer models to conduct the calibration (note that small uncertainties in temperature measurements are not a major concern). The first step is to obtain collocated SSM/T2 data and MOZAIC profile information. The latter requires measurements during aircraft ascents and descents. The upper two panels in Figure 1 shows an example which was taken from a MOZAIC flight near Osaka airport: the color of the track on Google Map shows aircraft altitude; the inlet shows collocated TB183 (color dots) as well as the flight track (dark curve). The lower panel shows global distribution of the matched cases.



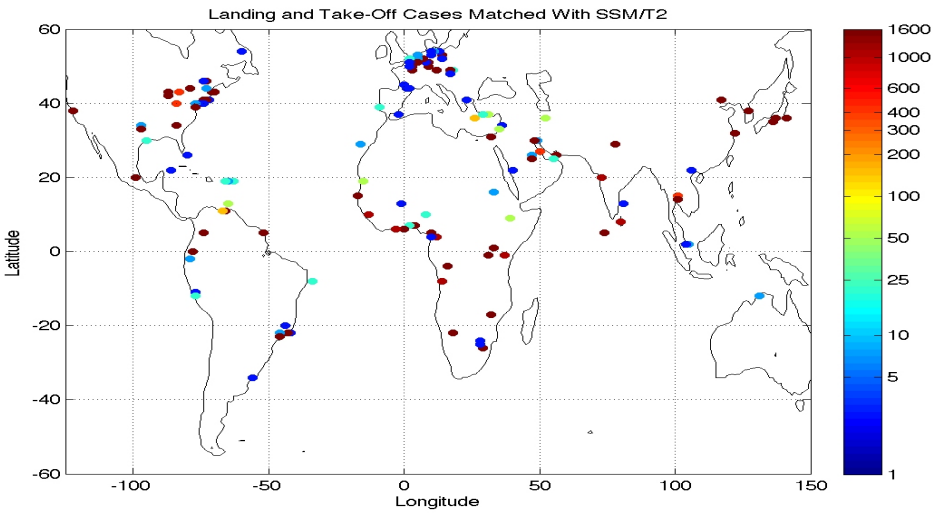


Figure 1. (Upper left) An aircraft landing case (Osaka airport) superimposed on the SSM/T2 183 GHz brightness temperatures. (Upper right) The temperature and RH profiles along the descending as shown in the upper left panel. (Lower) Ascending and descending cases matched to SSM/T2. The color of each dot represents the number of matched cases.

3. Ongoing Work & Future Plans

For the coming year, our research will focus on the following areas:

1) *Continue to work on archiving and rescuing SSM/T2 data:* it will be a legacy of this project to have a clean and complete SSM/T2 record.

2) *Use collocated MOZAIC temperature/humidity profiles (during ascent and descent) to calibrate SSM/T2 data*: we plan to use Community Radiative Transfer Model (http://cimss.ssec.wisc.edu/~paulv/CRTM/) to simulate SSM/T2 brightness temperatures and compare them with observations. This will serve as a calibration for SSM/T2 sensors onboard different satellites.

3) *Bring in other microwave UTH radiance such as AMSU-B*: AMSU-B has very similar channels as SSM/T2. We plan to bring in AMSU-B data and run the same calibration method through them.

4. Students Training

A couple of students from NOAA-CREST center of CUNY (one Ph.D. student and one MS student) were hired on a part-time basis through this CDR funding. Their tasks include helping with data downloading and performing simple statistical analysis. The fulltime programmer for this project – Mr. Jeyavinoth Jeyaratnam – was also a recent graduate from NOAA-CREST.

5. Community Workshop

As part of NOAA's CDR program, two related projects that focus on satellite passive microwave sensors with hydrological application in mind – one led by Ralph Ferraro and the other by us – held a joint workshop in College Park, MD from March 2-3 2011 with the following objectives:

- 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 inter-calibration 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.

Over 40 passive microwave instrument experts were in attendance to discuss various aspects of the AMSU, MHS, and SSM/T2 sensors, as well as their applications to hydrological products. A website was developed for this workshop: http://www.star.nesdis.noaa.gov/star/meeting_CDR2011.php. All presentations were uploaded there. And the workshop report has been submitted to *EOS*.

References:

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