INTER-CALIBRATION OF SATELLITE MICROWAVE RADIOMETERS FOR CLIMATE RESEARCH

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1. INTRODUCTION

Satellite microwave (MW) radiometers provide a reliable means to monitor the variability of several key climate variables. However, it is first necessary to precisely inter-calibrate the radiometers to avoid spurious trends in the retrievals. Generally speaking, the radiometric radiances need to be inter-calibrated at the 0.1K level to obtain sufficiently accurate inter-annual variability and decadal trends in the climate variables. The methodology for achieving this precision inter-calibration is the subject of this talk.

2. COLLECTION OF SATELLITE MICROWAVE RADIOMETERS

There are two basic types of satellite MW radiometers: the imagers and the sounders. The imagers use lower frequency channels (7-37 GHz) to measure surface parameters and columnar atmospheric moisture (vapor, cloud, rain). The sounders use higher frequencies to measure profiles of atmospheric temperature and water vapor. Some sensors like SSM/IS combined both functions into one integrated sensor. Much of our past inter-calibration work has focused on the MW sounders (MSU and AMSU) [1], and this experience is directly applicable to the MW imagers. In this talk, we focus on the MW imagers. The collection of satellite MW imaging radiometers we consider is:

1. Six SSM/I on DMSP F08, F10, F11, F13, F14, and F15
2. Two SSM/IS on DMSP F16 and F17.
3. AMSR-E on NASA’s Aqua spacecraft
4. WindSat on Coriolis
5. TMI on TRMM

These 11 sensors span the time period for July 1987 (first SSM/I) to present. The total data volume is approaching 100 satellite years, with many of the sensors exhibiting a mission life of nearly 10 years.

3. REVERSE ENGINEERING BACK TO COUNTS AND GEOLOCATION

The inter-calibration of 11 sensors over 20+ years requires systematic, objective, and consistent procedures be applied to each sensor. The sensor data that we ingest comes in different forms from different providers. In many cases, the data provider has applied adjustments to the radiances and geolocation. Sometimes these adjustments are not well documented, can change over time, and occasionally are erroneous. The first step in our processing is to reverse-engineer the data (i.e., antenna or brightness temperatures) back to the raw telemetry coming from the counts (i.e., radiometer counts). Also all geolocation data (latitude, longitude, earth incidence angle, etc.) are recomputed using in-house routines that have been extensively verified. Usually adjustments need to be made to the sensor pointing angle and sometimes to the spacecraft attitude to achieve accurate registration of the imagery relative to coastlines, islands, and lakes.

4. INTER-CALIBRATION OF RADIOMETER RADIANCES

The inter-calibration of radiometer radiances is based on computing a difference ΔT_B between the measured brightness temperature T_B and a T_B computed from a radiative transfer model (RTM).

$$\Delta T_B = T_{Bmea} - T_{Brtm} \tag{1}$$

The RTM accounts for emission and scattering from the Earth's surface and absorption in the intervening atmosphere [2]. Only observations over the ocean in the absence of rain are used because the RTM is most accurate for this environment.

The computation of the RTM T_B requires sea-surface temperature (SST), vector wind (W), columnar water vapor (V), and columnar cloud liquid water (L). Values for SST come from Reynolds' Optimum Interpolation SST weekly datasets. Values for W come from satellite scatterometer and buoy measurements. Values for V come from SSM/I retrievals which have been adjusted to match radiosonde and satellite-based GPS occultation measurements. Values for L also come from SSM/I retrievals. The cloud values are calibrated using a statistical histogram method [3] and are validated by ensuring L=0 (on the average) when instantaneous IR measurements indicate clear skies. Only scenes with very low values of cloud water are used for the inter-calibration to ensure there is no rain.

One expects that any systematic errors in the RTM formulation or in the RTM inputs (i.e., SST, W, V, and L), will have nearly the same effect on all satellite sensors, and thus in a relative sense these systematic errors should not significantly impact the inter-calibration.

The antenna pattern coefficients (APC) that relate antenna temperature to T_B (i.e., spillover and cross-pol) are adjusted to make $\Delta T_B=0$ in a mean sense. In all cases so far, the required adjustment of the APC is within the bounds one would reasonably expect considering the errors in characterizing the antenna. It is this adjustment of the APC that brings all 11 sensors into agreement.

In addition to the overall debiasing done by the APC adjustment, there are also systematic calibration errors varying with time and orbit position that need to be removed. These errors include sun intruding into the hot load and emissive antennas. Sun intrusion seems to be a common error for most of the sensors, but fortunately the emissive antenna problem has only occurred for TMI and SSM/IS. A detailed analysis of ΔT_B plotted versus parameters like sun angles, orbit position, and time of year provides the means to characterize these errors and construct correction tables.

5. EXAMPLE OF SYSTEMATIC ERROR IN SSM/IS

Figure 1 shows the results of applying the ΔT_B technique to SSM/IS flying on the DMSP F16 spacecraft. One can see both the effects of SSM/IS emissive antenna and sun intrusion into the hot load (for details, see Figure 1 caption). We would like to point out that previous SSM/IS calibration and validation activities [4] did not detect the emissive antenna problem at these lower frequencies of 19 and 37 GHz. Yet in the ΔT_B plot, the effect is very apparent even in the lowest 19.35 GHz channel. This is a good example of the effectiveness of the ΔT_B technique for detecting on-orbit calibration errors.

6. CONCLUSIONS

The new inter-calibrated dataset is called Version-7 (it is the 7th version in the evolution of SSM/I). It is our intention to have the T_B datasets for all 11 sensors brought up to V7 level by the end of 2010. In addition, V7 geophysical dataset sets (SST, W, V, L, and rain) will also be generated and will be made freely available to the research community.

7. REFERENCES

[1] Mears, C. A. and F. J. Wentz, The Effect of Drifting Measurement Time on Satellite-Derived Lower Tropospheric Temperature, Science, 309, 1548-1551, 2005.

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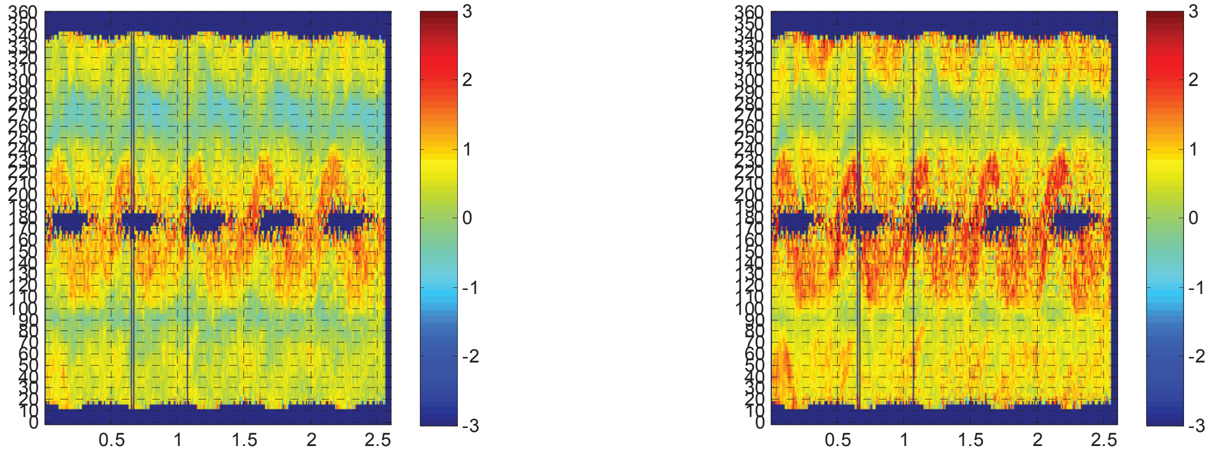
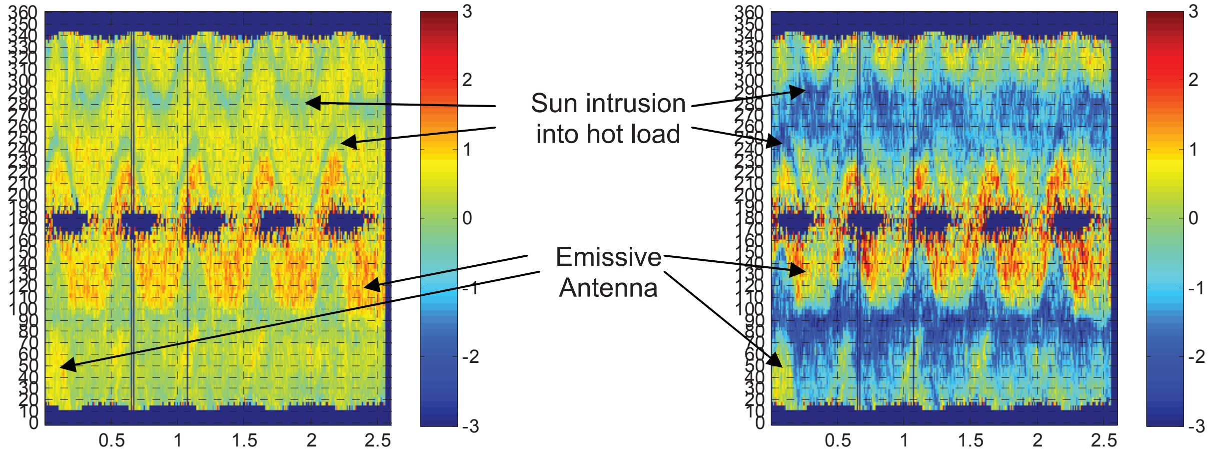
[3] Wentz, F. J., A well calibrated ocean algorithm for Special Sensor Microwave / Imager, Journal of Geophysical Research, 102(C4), 8703-8718, 1997.

[4] Poe, G., Special Sensor Microwave Imager Sounder (F-16) Calibration/Validation Final Report, 848 pp., Naval Research Laboratory, Monterey, CA, 30 November 2005



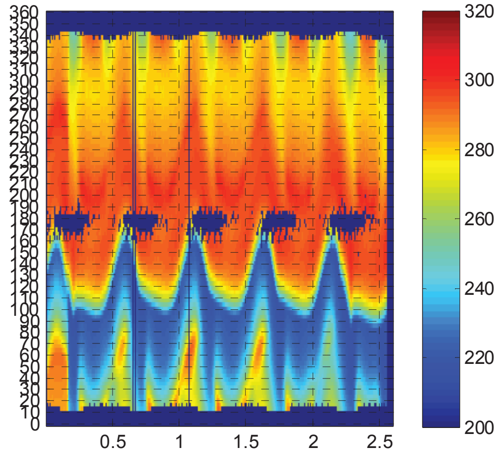
ΔT_B for the SSM/IS v-pol 19.3GHz channel

ΔT_B for the SSM/IS v-pol 22.3GHz channel



ΔT_B for the SSM/IS v-pol 37GHz channel

ΔT_B for the SSM/IS v-pol 92GHz channel



Physical Temperature of Antenna Arm

Fig. 1. The top four images show ΔT_B for the F16 SSM/IS. The x-axis is orbit number going from orbit 200 to 25000. The y-axis is orbit position in degrees (South pole to South pole). The blank areas at the bottom and top of each image is Antarctica and the blanks in the middle are the Arctic, for which there is no ocean data to compute ΔT_B. The bottom image is the physical temperature T_{arm} of the antenna support arm, which is a proxy for the temperature of the antenna. The pattern T_{arm} is clearly visible in all the SSM/IS channel because the SSM/IS antenna is emissive. Also evident is the sun intrusion into the hot load as shown by contours of constant sun angles. These plots show the entire F16 SSM/IS mission from 2003-2008.