Comparison of microwave radiometer brightness temperature over a hot reference area

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Abstract— **Nadir-looking microwave radiometers are flown on different altimeter missions to correct the altimeter range for water vapor and cloud liquid water path delay in the troposphere. Actually four sensors, TOPEX, JASON-1, ERS-2, and ENVISAT micro-wave radiometers (MWR) provide continuous measurements and the aim of this paper is to compare their measured brightness temperatures over the same hot reference continental area.**

I. Introduction

Quantitative application of satellite observations requires the absolute calibration of the observed raw radiance data to convert them into brightness temperature (TB). Calibration techniques of the thermal channels rely on onboard calibration employing two reference points. A space view is measured frequently by most of satellite radiometers and is taken as a practical zero radiance. A second target, a warm black body load, is generally selected so as to bracket the range of Earth TBs measured. In the case of JASON-1 radiometer (JMR), the choose of new instrument design to reduce the cost in hardware, complexity, size, and power leads to the fact that the calibration points will no longer bracket the Earth TBs and absolute calibration will involve an extrapolation form, rather than an interpolation between reference points. External absolute references, such as the use of independent references for TB are necessary to assess the accuracy of the in-flight calibration. Indeed, in the case of JMR the cold sky horn has been replaced by a trio of internal noise diodes, which provide a hot reference point above that of JMR's warm black body load. This approach to radiometer has never been tried by a flight mission and one obvious cause for concern is the increased sensitivity, in the case of an extrapolation, to non-linearities in the instrument behavior. We will focus here on the high end of the TB range.

The approach taken in this analysis is to determine a standard reference by using the measurements of AMSU-A radiometer on NOAA-16 satellite over selected regions of the Amazon rain forest. AMSU-A provides a high spatial and temporal sampling of the Earths surface for a large range of frequency and has two window channels near the ones used on altimeter missions (AMSU-A, 23.8 GHz and 31.4 GHz). The advantage of AMSU-A instrument over SSM/I (which is also used for the JMR calibration process) is that in the development of the reference for TB with this latest, one step involves the transferral of SSM/I inferred hot reference TBs at an incidence angle of 53.1^o in blackbody regions to JMR TBs at nadir viewing [1], whereas two field-of-views (fov) of AMSU are at near nadir local zenith angle so we have measurements directly comparable with radiometers TBs on altimeter missions.

Accurate calibration of the radiometer is essential, this analysis provides a brightness temperature comparison of different radiometers at the high range of the TB values on a selected area.

II. AMSU-A as a standard reference

An Amazon area ranging from 4.0^oS to 6.5^oS latitude, and 65.7^oW to 67.5^oW longitude, shown on Figure 1, has been selected using long-time series of TOPEX and ERS2 MWR TBs for its spatial and temporal stability along with insurance that the choosen area is sampling by both radiometers [2]-[4] and their respective follow-on, JASON-1 and ENVISAT, which have been placed on the same orbit than their predecessor. A river mask has been applied to discard measurements over the river that flows through the area and that induces colder TBs than the surrounded forest. This area presents also small vertically and horizontally polarized TB difference (mean is approximately 1 K) as measured by the SSM/I radiometer at its two window channels of 19.35 and 37.0 GHz [1], which characterize regions with high atmospheric opacity and an optically thick vegetation canopy. The measured TBs are almost independent of frequency (the surface temperature seen by the sensors is only slightly frequency dependent due to the difference in penetration depths into the medium), the region is approximate black body in behavior. It is then reasonable

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to assume that difference between average TBs of ERS-2, ENVISAT, TOPEX, and JASON-1 radiometers should be small over this region even if their frequency sampling are not exactely the sames.

TABLE I.
AMSU-A BRIGHTNESS TEMPERATURES OVER THE AMAZON FOREST AREA. THE STATISTICAL INDICATORS WERE COMPUTED WITH THE NIGHTIME AND DAYTIME PASSES RESPECTIVELY FOR THE FOUR SEASONS.

Nighttime	TB, Mean +/- Standard Deviation, K				N
	23.8 GHz		31.4 GHz		
winter	286.0	1.1	283.1	1.5	185
spring	285.5	1.0	282.2	1.4	163
summer	285.5	0.9	282.3	1.1	155
autumn	286.3	0.8	283.3	1.0	138
All year	285.8	1.0	282.7	1.4	641

Daytime	TB, Mean +/- Standard Deviation, K				N
	23.8 GHz		31.4 GHz		
winter	290.9	2.1	288.5	2.3	107
spring	290.5	2.0	288.1	2.2	106
summer	290.3	1.5	287.9	1.7	111
autumn	291.8	1.9	289.5	2.0	94
All year	290.9	1.9	288.5	2.1	418

TABLE II.
BRIGHTNESS TEMPERATURES OVER THE FREQUENCY RANGE FROM 18.0 TO 37.0 GHZ AT NADIR AND FOR NIGHTTIME HOURS.

	TB, Mean, K								N
freq (GHz)	18.0	18.7	21.0	23.8	31.4	34.0	36.5	37.0	
AMSU-A (nadir)	-	-	-	285.8	282.7	-	-	-	641
ERS2	-	-	-	285.7	-	-	291.9	-	3937
ENVISAT	-	-	-	290.2	-	-	287.6	-	258
TOPEX[1]	278.6	-	278.1	-	-	-	-	277.6	2160
JASON-1	-	282.5	-	284.6	-	282.0	-	-	198
SSM/I (nadir)[2]	-	284.2	-	283.4	-	280.5	-	-	14564

[1] 18.0 GHz measurements corrected for the drift in Ruf's report [2].
[2] use of Ruf's algorithm for the transferral of SSM/I inferred TBs at an incidence angle of 53.1^o to nadir viewing.

AMSU-A is a cross-track, line-scanned radiometer with two low frequency channels at 23.8 GHz and 31.4 GHz that are useful for our purpose. Note that the 23.8 GHz channel is a common channel for AMSU-A, ERS-2, ENVISAT, and JASON-1. The sensor scans in a stepped-scan fashion and covers 30 discrete field-of-views (fov). The scan pattern and geometric resolution correspond to a 50 km diameter cell at nadir and a 2343 km swath. On-board calibration is obtained by viewing the cold space cosmic background temperature ($\sim$2.7 K) and an internal blackbody target every 8 seconds for each scan line. Fovs 1 and 30 are the extreme scan positions of the Earth views, while fovs 15 and 16 are at 1^o40 and -1^o40 from the nadir direction respectively. Since the NOAA-16 is in a circular sun-synchronous near-polar orbit, the selected area is overflown twice a day at respectively around 02:00 local solar hour (LST) and 14:00 LST.

To include a wide range of temperature conditions, AMSU-A measurements for one full year, 2002, have been used. Measurements are taken during the day and night passes to evaluate the stability of the TBs values. The TBs from fovs 15 and 16, closest to the nadir path, have average values greater than 280 K and standard deviations of less than 2 K as summarized in Table 1. Note that the standard deviation of the brightness temperatures gives some indication of land inhomogeneity, since most variability in the brightness temperature can be assumed to come from the surface. The statistics computed show that this region has small TB differences between 23.8 and 89.0 GHz (not shown) and at a given frequency over season particularly for the nighttime measurements. A small increase in the mean TB is evident from nighttime to daytime. Both nighttime and daytime TBs show quite stable values over the four seasons. The variation over seasons and the standard variation at night tend to be less than those in the day. For this reason the nighttime data will serve as a standard reference over this area to compare the different sensor TBs to assess their consistency.

III. Microwave radiometers on altimeter missions

Four along-track nadir viewing radiometers are currently flying, TOPEX, JASON-1, ERS-2, and ENVISAT. Their purpose is to provide both accurate path delay corrections over ocean for use by the radar altimeters, and accurate brightness temperatures everywhere, over ocean as well as over land, for use in related research areas. Applications in atmospheric studies (surface energy heat), in land studies (soil moisture and surface emissivity), or for ice characterization (ice boundaries and surface ice properties) would all benefit from highly accurate brightness temperature measurements. JASON-1 and ENVISAT have been recently launched, on December 7, 2001 and March 1st, 2002 respectively. So the computed statistics, presented here, lie on smaller time series than for the other instruments. Since TOPEX and JASON-1 operate in a non-Sun synchronous orbit (orbit inclinaison of $\sim 66^o$), the overpasse LST are fairly uniformly distributed over a day long, whereas ERS2 and ENVISAT have both specific nighttime and daytime passes due to their orbit inclinaison at 98.5^o (sun-synchronous orbit) around respectively 22:00-23:00 LST and 09:00-11:00 LST. These latters provide coverage of high latitude ocean, ice sheet and surface land areas not covered by TOPEX or JASON-1. For TOPEX and JASON-1, we only used data that are measured in the same LST interval than AMSU-A. Note that the SSM/I instrument on DMSP F-13 (also included in this study) overflies the area between 05:00 and 07:00 LST while AMSU-A precedes it at around 02:00 LST, this difference in viewing time could lead to a few tens of K in difference with lower values at dawn hours.

We use the opportunity offers by TOPEX, sampling at all hours and a long time serie available, to evaluate the variation of TB over a day long. The largest amplitude is observed during the day, there is also a small variation over the nighttime hours. This feature has to be kept in mind when comparing nighttime TB values between different radiometers, the differences could range from a few tens up to 4 K between dusk and dawn. A difference of 1-2 K would be normal to observe between nighttime TB measurements of AMSU-A and ERS2/ENVISAT ones. We use the Brown and Ruf's algorithm for SSM/I TBs to transfert them in JASON-1 radiometer configuration.

Results, average values, over the nighttime hours are displayed in Table 2. The observations are in agreement with what we could expect. Topex exhibits the smallest values at all its frequencies. JASON-1 TBs (reprocessed data for cycles 17-22, so they would have the same calibration coefficients that became incorpored into the JASON-1 standard processing starting with cycle 23 and data up to cycle 42 have been used) are in quite good agreement with what we expected. The 18.7 GHz channel presents although a slightly small value, since a slight decrease of TB is observed usually with increasing frequency. ENVISAT TBs (calibration coefficients version of October 2002) are a little bit larger than the other TBs. ERS2 23.8 GHz channel is in good agreement with the same one on AMSU-A, JASON-1, and SSM/I (at nadir). The second channel of ERS2 at 36.5 GHz provides too high values. In summary, if some differences between TBs, up to about 2 K, could be attributed to small difference in frequency or in local time difference of measurements, larger differences represent rather a flaw in the calibration that would need some adjustment to guarantee accurate brightness temperature calibration. We assume here that our conclusions are based on comparison with AMSU-A as a standard reference for TB which is in a good overall agreement with other radiometers as we can see in this analysis.

IV. Conclusion

A quantitative assessment of the consistency of nadir-viewing radiometers has been performed and results were presented in this analysis. The frequency range varies between 18.0 and 37.0 GHz. We used AMSU-A TBs at nadir-viewing measurements as our hot standard reference TB over a specific Amazon forest area which is approximate black body region. Differences of averaged TB values up to $\sim$ 2 K could be related to frequency difference and local time difference of measurements. Some adjustments are recommended in regard to statistics shown in Table 2 for the two last radiometers launched. ENVISAT TBs are slightly high for both its two channels. JASON-1 first channel could be fine tuned in order to provide a slightly higher TB values at this high end of its variation interval.

References

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