STABILITY OF THE VICARIOUS COLD CALIBRATION STATISTIC FOR THE GPM CONSTELLATION

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ABSTRACT

The vicarious cold calibration statistic has been analyzed to determine its stability. Modeled top of atmosphere brightness temperatures representing microwave radiometer observations are computed for the month of July 2005 using a radiative transfer model. The vicarious cold calibration algorithm is applied to the population of brightness temperatures along with two other statistics for comparison. The stability is assessed by perturbing the sea surface temperatures and atmospheric water vapor in the model to simulate a global warming event. The results show that the vicarious cold calibration statistic is the most stable since it has the least variation for the simulated warming event.

Index terms – Microwave radiometry, Calibration

1. INTRODUCTION

NASA's Global Precipitation Measurement (GPM) mission will aid in improving the current limitations on measuring precipitation. In order to perform the precipitation measurements with the desired temporal and spatial resolution, a constellation of satellite-borne microwave radiometers will be utilized. However, a problem arises when using several different radiometers because each radiometer has unique instrumental and orbital characteristics. The radiometers must be inter-calibrated to account for these differences. One way to characterize and correct for these differences is by using a vicarious calibration technique which provides both cold [1] and warm [2] reference brightness temperatures to calibrate the radiometers.

A concern that arises when using the vicarious calibration technique is its stability. For the GPM constellation, it is being used as a way to compare several different instruments to each other that are operating during the same time periods [3]. The technique can also be used as a method for long term trend analysis of climate, involving instruments operating at different time periods over several years. However, this means that the vicarious calibration technique must be sufficiently robust to be invariant to changes in geophysical parameters that would occur. The vicarious cold calibration relies on a natural lower bound on brightness temperatures (TBs) in the microwave that is observed on Earth. The lower bound occurs over the ocean and is dependent on atmospheric and surface parameters, including sea surface temperature (SST) and water vapor burden. In order for the cold calibration technique to be stable, it must be insensitive to varying SST and atmospheric changes. This paper will introduce a study of the sensitivity of the vicarious cold calibration statistic to perturbations in the surface and atmospheric parameters.

2. VICARIOUS COLD CALIBRATION ALGORITHM

The theory behind vicarious cold calibration relies on the fact that, for every frequency, polarization, and earth incidence angle (EIA), there is an SST where the TB is at a minimum. Theoretically, the minimum TB is observed with calm winds at the ocean surface and no clouds or atmospheric water vapor. An increase in atmospheric optical depth due to clouds and water vapor would increase the minimum TB, as would an increase in surface emissivity due to higher surface wind speeds.

However, using just the minimum TB observed as the vicarious cold cal TB would not be very stable, since small perturbations of the atmospheric or surface parameters would raise or lower this value. Instead, to calculate the vicarious cold cal TB point, a polynomial is fit to an inverse cumulative distribution function (CDF) of the TB population histogram and extrapolated down to the minimum observed TB. Since the conditions that produce the precise theoretical coldest possible TB value may not be present in any particular population of TBs, this will reduce the dependence of the vicarious cold cal TB point on small geophysical perturbations. This is also done because noise in the data broadens the distribution about the theoretical minimum TB. To minimize the effect of this noise, the CDF is fit in a region near but higher than the expected vicarious cold cal TB (e.g., 3%-10%) and extrapolated down to 0%.

3. METHOD OF ANALYZING STABILITY

In order to assess the effects that perturbations of geophysical parameters have on the vicarious cold cal statistic, a simple case study is performed. This is done as an introductory study, leaving room for more in-depth study of the statistic to be done in the future. To simulate a population of TBs that would be observed by a microwave radiometer from space, a radiative transfer model is used which accounts for microwave absorption and emission. The inputs to the model are taken from the Global Data Assimilation System (GDAS) of the National Center for Environmental Prediction (NCEP). Included in GDAS are surface parameters of wind speed and SST, as well as atmospheric profiles of pressure, temperature, and water vapor. These fields are provided every 6 hours over the whole globe with a latitudinal/longitudinal resolution of 1°. The month of July 2005 is chosen for this study to illustrate the method. The radiative transfer model is run at the frequencies of the Special Sensor Microwave/Imager (SSM/I) with frequencies of 19.35, 22.235, and 37 GHz and a nominal EIA of 53.1°. These are typical frequencies and EIA used by microwave radiometers observing the lower atmosphere and surface from space.

One of the concerns for stability of the statistic for long term climate study is rising SST. This paper does a simple analysis of how the vicarious cold calibration technique performs under a variation in SST, coupled with a change in atmospheric water vapor content. The simulated top of atmosphere (TOA) TB is determined for each time interval of 6 hours for the month of July 2005 using the fields given in GDAS. The model is then run again with artificially increased SST and water vapor fields to simulate a global warming event. The simulated TBs are then analyzed by using three different statistics to show that the vicarious cold cal method is the most stable. One alternate statistic is the mean of the global TB population, which is highly dependent on atmospheric variability and so it may not be as stable. A third statistic to be compared is the TB at 0.1% of the CDF of the TB population. This differs from the vicarious TB, which is estimated by extrapolating the CDF down to 0% from 3%-10%.

4. STABILITY ANALYSIS

Before performing the study by perturbing the SST and water vapor for July 2005, the radiative transfer model is run on the GDAS fields for the entire year of July 2005 – June 2006. The three different statistics are calculated for each month of the year on the global TB population to look for possible seasonal variability. Figure 1 shows the vicarious cold calibration statistic for the three frequencies at vertical and horizontal polarization. It is apparent in the V-pol channels that there is a seasonal variation in the vicarious cold cal TB. The variation is most notable in the 22.235 water vapor channel, which follows the seasonal variation of global water vapor. The H-pol channels also show noticeable variations throughout the year due to a greater sensitivity in H-pol channels to water vapor compared to V-pol. The other two statistics show similar results to the vicarious cold cal statistic, but with a slightly larger seasonal variation. Figure 2 shows the seasonal variability of all three statistics at the 22.235 GHz channel for both V-pol and H-pol. The maximum variation for the vicarious cold cal statistic is approximately 1.8 K at 22.235V and 2.1 K and 22.235H. In comparison, the other two statistics have variations of 2 K and 2.2 K at 22.235V and 3.3 K and 3.7 K at 22.235H for the 0.1% TB and mean TB statistics, respectively.

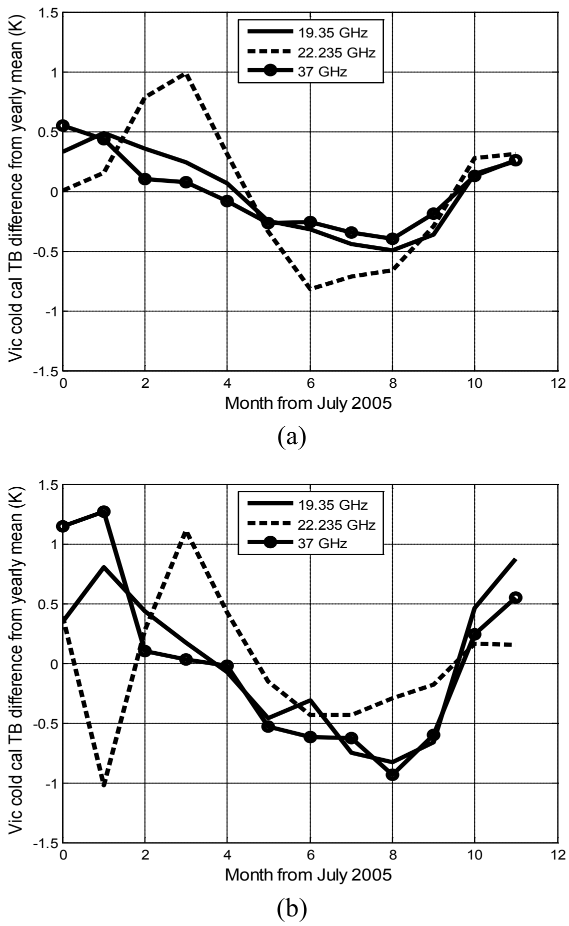

Figure 1: Seasonal variation in the vicarious cold cal TB for SSM/I (a) V-pol and (b) H-pol channels. The vertical axis is the difference in the TB from the yearly mean.

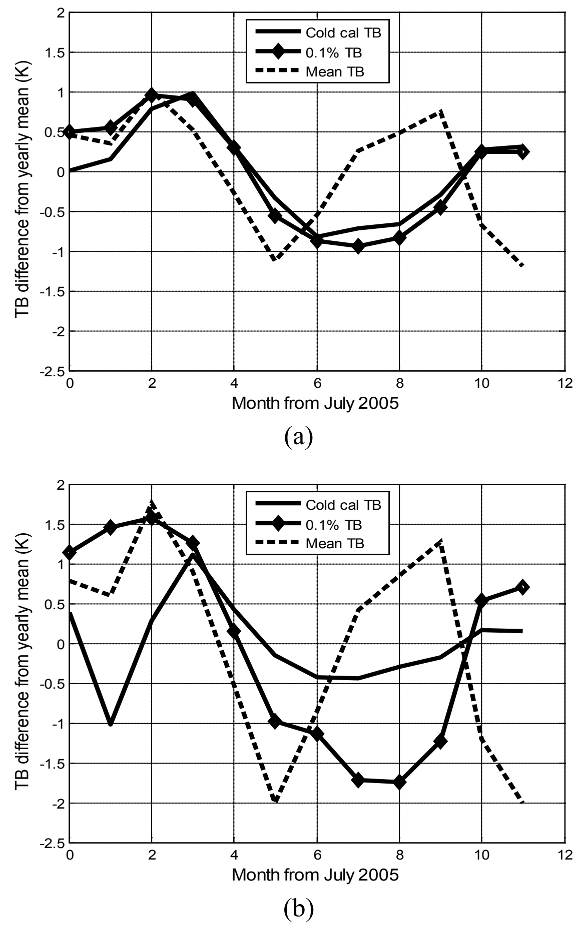

Figure 2: Seasonal variation in three different statistics for 22.235 GHz (a) V-pol and (b) H-pol. The vertical axis is the difference in the TB from the yearly mean.

The next step in the statistical analysis is to see how sensitive the statistics are to perturbations. For the month of July 2005, the three statistics are run with perturbations of SST by +1 K and +2 K and water vapor increase by 10% and 20%. The resulting statistics for the various combinations of these perturbations are shown in Table 1. The column of interest is the one showing the maximum variation in the statistics as the water vapor and SST change. It is readily apparent that taking the mean of the TB population is not a stable statistic. While this statistic appears to be stable during a change in SST but constant water vapor, this situation is not physically reasonable, since rising SST will typically affect the water content of the atmosphere as well.

Comparing the TB found at 0.1% of the CDF and the vicarious cold cal TB shows that these values are very close to one another. However, they deviate the most for the 22.235V channel, showing that using the 0.1% TB statistic results in a greater sensitivity to variations in the SST and water vapor perturbations than does the vicarious cold cal TB statistic. Also, since the horizontally polarized channels are more sensitive to atmospheric water vapor, the variations in the H-pol channels will be even greater for the 0.1% TB statistic as noticed in Figure 2. As an example, at 22.235H, the maximum difference for the 0.1% TB statistic is 2.37 K while the cold cal TB maximum difference is 1.50 K. Although SSM/I does not have an H-pol water vapor channel, there are other radiometers that do where this larger difference matters. This shows that the vicarious cold cal statistic is the best and most stable of these three.

	+0% water vapor			+10% water vapor			+20% water vapor			Maximum Variation (K)
	+0 K	+1 K	+2 K	+0 K	+1 K	+2 K	+0 K	+1 K	+2 K	
Mean TB (K)	194.80	194.96	195.15	196.48	196.65	196.83	198.13	198.30	198.48	3.68
0.1% TB (K)	175.00	174.87	174.73	175.29	175.10	174.96	175.50	175.33	175.20	0.77
Cold cal TB (K)	175.48	175.33	175.17	175.71	175.51	175.36	175.86	175.67	175.56	0.69

(a)

	+0% water vapor			+10% water vapor			+20% water vapor			Maximum Variation (K)
	+0 K	+1 K	+2 K	+0 K	+1 K	+2 K	+0 K	+1 K	+2 K	
Mean TB (K)	220.69	220.81	220.88	223.24	223.36	223.49	225.61	225.73	225.87	5.18
0.1% TB (K)	183.45	183.21	183.02	183.91	183.70	183.51	184.38	184.16	183.99	1.36
Cold cal TB (K)	182.26	182.03	181.92	182.57	182.21	182.09	182.65	182.52	182.16	0.73

(b)

	+0% water vapor			+10% water vapor			+20% water vapor			Maximum Variation (K)
	+0 K	+1 K	+2 K	+0 K	+1 K	+2 K	+0 K	+1 K	+2 K	
Mean TB (K)	216.35	216.35	216.36	217.73	217.73	217.74	219.12	219.12	219.13	2.78
0.1% TB (K)	202.06	201.85	201.63	202.31	202.07	201.88	202.55	202.31	202.09	0.92
Cold cal TB (K)	202.55	202.36	202.11	202.76	202.47	202.26	202.95	202.73	202.45	0.84

(c)

Table 1: Performance of three statistical methods on a population of TBs for the month of July 2005 at the V-pol channels of (a) 19.35 GHz, (b) 22.235 GHz, and (c) 37 GHz. The last column shows the maximum variation in the calculated TB over all the perturbations of increased SST and water vapor content for each method and frequency.

5. FUTURE STUDY

This paper is an introduction to a more in-depth analysis of the stability of the vicarious cold cal statistic which will be performed in the future. Instead of artificially increasing the water vapor and SST fields, the vicarious cold cal analysis can be performed on actual geophysical perturbations. For example, an El Niño event will cause perturbations in these fields, and the stability of the statistic can be analyzed over one of these events. Also, the stability can be analyzed over different regions on the globe. This would include dividing up the TB population into different hemispheres or latitude bands and performing the analysis on these smaller regions instead of on a global population.

6. CONCLUSION

The vicarious cold calibration statistic is currently under study as a means of monitoring and ensuring the accurate calibration of long term satellite microwave radiometer data sets for climate trend analysis. In order for this statistic to be a valid reference for climate studies, it must be stable. This paper looked at a simple case study of how the vicarious cold cal statistic performed under variations in SST and atmospheric water vapor. It also compared the statistic to two other possible statistics that could be performed on a TB population. Perturbing the SST and water vapor showed that using the vicarious cold calibration method resulted in the most stable statistic.

REFERENCES

[1] Ruf, C.S., "Characterization and Correction of a Drift in Calibration of the TOPEX Microwave Radiometer," *IEEE Trans. Geosci. Remote Sens.*, 40(2), 509-511, 2002.

[2] Brown, S., and C. Ruf, "Determination of a Hot Blackbody Reference Target over the Amazon Rainforest for the On-orbit Calibration of Microwave Radiometers," *AMS J. Oceanic Atmos. Tech.*, 22(9), 1340-1352, 2005.

[3] McKague, D., C. Ruf and J. Puckett, "Vicarious Calibration of Global Precipitation Measurement Microwave Radiometers," *Proc. IEEE International Geoscience and Remote Sensing Symposium*, Boston, MA, Vol. IV, 459-462, 7-11 July 2008.