GEOPHYSICAL RESEARCH LETTERS, VOL. 25, NO.11, PAGES 1927-1930, JUNE 1, 1998

Global warming deduced from MSU

C. Prabhakara[1], R. Iacovazzi, Jr.[2], J.-M. Yoo[3], and G. Dalu[4]

Abstract. Microwave Sounding Unit (MSU) radiometer observations in Channel 2 (53.74 GHz) made from sequential, sun-synchronous, polar-orbiting NOAA operational satellites have been used to derive global temperature trend for the period 1980 to 1996. Christy et al. (1998) emphasize that they find a tropospheric cooling trend (-0.046 K decade^{-1}) from 1979 to 1997 with these MSU data, although their analysis of near nadir measurements yields a near zero trend (0.003 K decade^{-1}). Using an independent method to analyze the MSU Ch 2 nadir data separately over global ocean and land, we infer that the temperature trends over both these regions are about 0.11 K decade^{-1}, during the period 1980 to 1996. This result is in better agreement with trend analyses based on conventional surface data.

1. Introduction

The channel 2 (53.74 GHz) brightness temperature, Ch 2 T_b, measured by the Microwave Sounding Unit (MSU) radiometer has been shown by Spencer and Christy (1990) (SC) to correlate well with surface air temperature and with tropospheric temperature measured by radiosondes. Also, their study revealed the potential to estimate global temperature trend from these MSU data. Adopting basically the SC procedure, Christy et al. (1998) analyzed the MSU data from 1979 to 1997 in two ways, called "T2LT" and "T2". The T2LT path, which utilizes differences between the radiometer measurements along each scan, shows a global cooling of 0.046 K decade^{-1}. The T2 path, which uses the average of the five center most measurements along each scan, indicates a global trend of 0.003 K decade^{-1}.

The results obtained from these studies depend on the calibration of several MSU instruments flown on sequential satellites and on the method of analysis. Also, this entire procedure must have a precision that is substantially better that 0.1 K over a decadal time scale to estimate global temperature trend.

The global trend estimates of Christy et al. (1998) differ from the global warming of approximately 0.1 K decade^{-1} found in analyses of conventional surface measurements (Jones, 1994; Hansen et al., 1995). Although temperature changes in the thick atmospheric region sampled by MSU may differ from that at the surface, Hansen et al. (1995) have shown that a difference in temperature trends as large as reported is unlikely to be caused by natural climate variability. Our objective is to investigate this disagreement by examining the MSU Ch 2 data with an independent procedure for determining the global temperature trend.

2. Method of Analysis

In our study, the calibration procedure developed by NOAA (1997) is applied to MSU raw nadir measurements to derive the T_b needed in our analysis. The nadir measurements are used to avoid spurious temporal effects on T_b at other scan angles, e.g., those resulting from gradual decay in altitude of each satellite during its life (Wentz and Schabel, personal communication). One set of the NOAA satellite series has local equatorial crossing times (LECT) for the ascending/descending nodes close to 7:30 am/7:30 pm, and the other set of satellites has LECT close to 2:30 am/2:30 pm. The first set is referred to as morning satellites, and the latter as afternoon satellites. Typically, these morning and afternoon satellites alternate in the NOAA series. For each morning and afternoon satellite, the nadir data are separated first into land and ocean data sets, and then each one of these subsets is divided according to the LECT to delineate AM and PM data sets. Then, we average these data separately to obtain AM and PM monthly mean values in grid boxes of 2° lat. x 3° lon. between 75 N and 75 S over global land and ocean. Finally, we average the

Table 1. Details of Satellite Data Used in the Present Analysis. M and A Represent Morning and Afternoon Satellites, Respectively.

Satellite / Years	Overlap Period	$(T_{PM} - T_{AM})$	
		Ocean	Land
M NOAA6 1980-81	N/A	0.198 K	0.473 K
A NOAA7 1982-84	w/ NOAA6 Jan 1, 1982 - Dec 31, 1982	0.042 K	1.482 K
A NOAA9 1985-86	w/ NOAA6 Nov 1, 1985 - Oct 31, 1986	0.011 K	1.422 K
M NOAA10 1987-88	w/ NOAA9 Dec 1, 1986 - Feb 28, 1987	0.263 K	0.447 K
A NOAA11 1989-91	w/ NOAA10 Jan 1, 1990 - Dec 31, 1990	-0.023 K	1.412 K
M NOAA12 1992-94	w/ NOAA11 July 1, 1991 - June 30, 1992	0.248 K	0.534 K
A NOAA14 1995-96	w/ NOAA12 Jan 1, 1995 - Dec 31, 1995	0.035 K	1.519 K

---

[1] NASA/Goddard Space Flight Center, Greenbelt, MD.
[2] Raytheon STX, Greenbelt, MD.
[3] EWHA Womans University, Seoul, South Korea.
[4] CNR, Cagliari, Italy.

Paper number 98GL01300.
0094-8534/98/98GL-01300$05.00

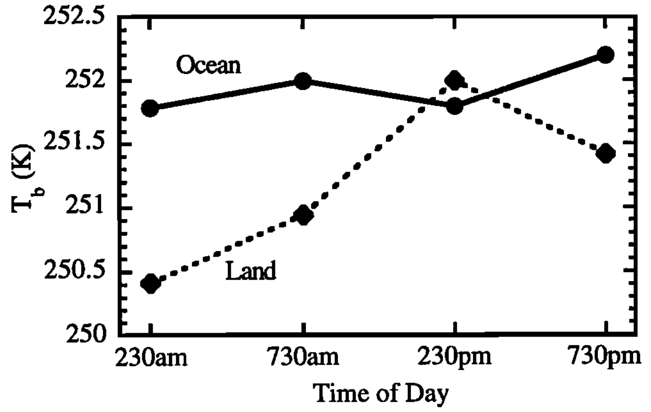

Figure 1. 1982 annual-mean diurnal cycle for global ocean and land.

cosine-weighted grid box values to get monthly-mean global values for AM and PM on land and ocean. Data from the grid boxes containing coastlines, representing about 11 % of the global data, are rejected.

For the purpose of developing a long-term continuous time series, we remove the annual cycle in the MSU monthly-mean T_b over global land and ocean. We do this by averaging the data, starting January 1 and ending December 31, over one or more discrete years (see Table 1). In this way, we calculate for each of the successive NOAA satellites an average Ch 2 temperature for AM (T_{AM}) and PM (T_{PM}) and for land and ocean over a two or three year period. Note that these temperatures contain, in addition to inter-annual variability, long-term change in global temperature.

Removal of diurnal cycle effects from these data is also required because successive satellites have differing LECT, which causes discontinuities in the T_b time series. Calibration differences among the MSU instruments also add to these discontinuities. Furthermore, we find that the instrument calibration has a bias that depends on exposure to sunlight, and thus on LECT. This is demonstrated in Figure 1, where we show the MSU Ch 2 derived annual-average diurnal temperature cycle over land and ocean utilizing the 1982 annual mean AM and PM data from NOAA 6 and NOAA 7. The obvious underestimation of the 2:30 pm temperature over ocean reveals a diurnally dependent calibration problem that is probably related to the instrument exposure to sunlight. This calibration problem can modify the discontinuity between the data of successive satellites.

The operational satellites are launched such that there is temporal overlap of successive satellites (Table 1). In order to remove the above mentioned calibration and diurnal effects in the MSU data from each succeeding satellite, we estimate an adjustment term ΔT with the aid of the overlapping data of the preceding satellite. ΔT is given by the difference between the one-year mean temperatures of consecutive satellites during the period of their overlap. By applying such adjustments to the data of all but the first satellite in the series, we obtain a consistent long-term record of temperature from which the global temperature trend can be estimated.

3. Error Analysis of MSU Ch 2 Time Series

The errors due to instrument noise in the annual global averages of the MSU Ch 2 T_b is estimated to be less than 0.01 K (Christy et al., 1998). The random error in an overlap adjustment term ΔT is thus expected to be less than 0.02 K when there is data overlap of a full year. However, such random error is expected to increase by about a factor of two when the overlap is only three months, as between NOAA 9 and NOAA 10 (Table 1). The random error in the time series of the MSU data used in our analysis is estimated to be less than 0.04 K.

Systematic errors in the MSU data outside the scope of diurnal and annual cycle, and instrument calibration, are more difficult to estimate. Variations in hydrometeors and surface emissivity over land and ocean can introduce contamination in the Ch 2 data (Prabhakara et al., 1995; Shah and Rind, 1995). We estimate the magnitude of this contamination to be on the order of 0.04 K.

There are drifts of the LECT in the satellite orbits. In order to minimize the effect of these drifts, we have limited the data from each satellite to about three years. The effect of these drifts for each satellite can be qualitatively diagnosed from the temperature difference, $T_{PM} - T_{AM}$, over land and ocean, which is presented in Table 1. This difference is about 0.5 K over land and about 0.25 K over ocean for all the morning satellites. Similarly, we notice from the table that for all the afternoon satellites this difference is about 1.5 K over land and about 0.01 K over ocean. These $T_{PM} - T_{AM}$ values over land and ocean are linked to the diurnal temperature cycle specific to those regions and are expected to remain constant. However, from the table we see a variability of about 0.06 K, which is likely a consequence of the satellite drifts. For this reason, we assume a probable error of about 0.03 K exists in T_{PM} and T_{AM}.

Table 2. Unadjusted MSU Ch 2 Temperature T_M over Land and Ocean, and the Corresponding Adjusted Temperature T_M^A. $\Sigma\Delta T$ Represents the Running Sum of Adjustments for Intersatellite Calibration and Diurnal Cycle Differences. Also Given is the Corrected Mean Temperature (K) T_M^A of the Globe, which is the Sum of T_M^As of Land and Ocean Weighted by Their Fractional Areas.

	Ocean			Land			Globe
Satellite	T_M	$\Sigma\Delta T$	T_M^A	T_M	$\Sigma\Delta T$	T_M^A	T_M^A
NOAA6	252.159	N/A	252.159	251.412	N/A	251.412	251.910
NOAA7	251.835	0.304	252.139	251.243	-0.015	251.228	251.835
NOAA9	251.546	0.388	251.934	251.082	0.014	251.096	251.655
NOAA10	252.151	0.115	252.266	251.387	0.157	251.544	252.025
NOAA11	251.645	0.549	252.194	251.200	0.272	251.472	251.953
NOAA12	252.749	-0.526	252.223	251.925	-0.593	251.332	251.926
NOAA14	252.107	0.178	252.285	251.715	-0.282	251.433	252.001

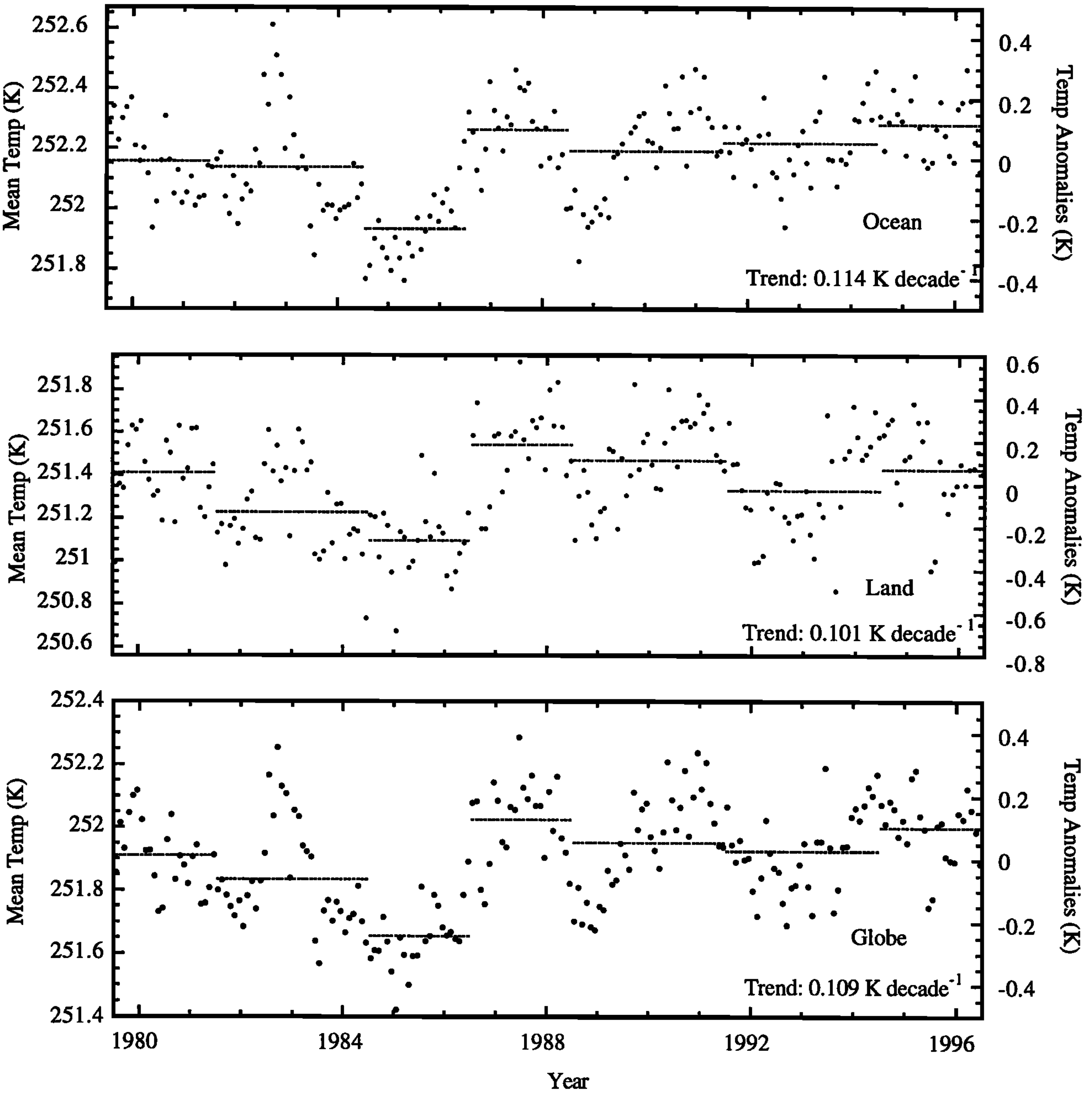

Figure 2. Corrected MSU Ch 2 ocean, land, and globe temperatures for 1980 to 1996. Solid lines (see left ordinate) are mean temperatures deduced from NOAA 6, NOAA 7, NOAA 9, NOAA 10, NOAA 11, NOAA 12, and NOAA14. Dots (see right ordinate) are monthly temperature anomalies with respect to the 17 year mean annual cycle.

MSU data do not contain sufficient information to quantitatively determine the combined effects of hydrometeors, surface emissivity, and drifts on the annual global averages of Ch 2 T_b. However, from the above discussion, we arrive at a gross estimate of this joint error to be on the order of 0.06 K.

The nature of the hydrometeor, surface emissivity, and drift effects differ between land and ocean. For this reason, independent analysis of the trend over land and ocean is made in this study to increase the confidence in our method.

4. Results and Conclusions

We present in Table 2 values of the two or three year mean temperatures, T_M, over land and ocean derived from the MSU data for each satellite, where $T_M = 0.5(T_{AM} + T_{PM})$. The running sum $\Sigma\Delta T$ of the adjustments inferred from consecutive satellites, as well as the adjusted MSU temperature $T_M^A (= T_M + \Sigma\Delta T)$ for each satellite, over land and ocean are also presented in this table. The last column of the table gives for each satellite the adjusted temperature over the globe, which has been weighted by land and ocean fractional areas. In Figure 2, the two or three year mean MSU temperatures over ocean, land, and the globe of each NOAA satellite are displayed. In addition, the adjusted monthly-mean temperature anomalies with respect to the 17 year mean annual cycle are shown for these regions in this figure.

The intersatellite instrument calibration differences and diurnal cycle biases (see Fig. 1) that exist together in the adjustment terms differ appreciably between land and ocean (Table 2). For this reason, independent analysis of the trend over land and ocean acts as a crude check of our method. From the resulting time series of temperature anomalies given in Figure 2, we deduce that the linear temperature trend over ocean from 1980 to 1996 is 0.114 K decade^{-1}. Similarly, the trend over land is estimated to be 0.101 K decade^{-1}. Finally, we infer that the global temperature trend, weighted by the land and ocean fractions over the region 75 N to 75 S in the period 1980 to 1996, is 0.109 K decade^{-1}. Although the trends of temperature do not necessarily have to be the same over land and ocean, the general similarity that we find increases the confidence in the validity of our analysis.

Our estimate of global temperature trend based on MSU data disagrees with that of Christy et al. (1998). There are three main differences in our methods. First, we have adopted the instrument calibration procedure developed by NOAA (1997). Second, in order to eliminate the effects of satellite altitude changes, only the MSU Ch 2 nadir observations are used. Third, we remove the annual cycle in one step in a simple and direct fashion. Christy et al. (1998) have a different instrument calibration procedure; they use data from multiple scan angles; and they remove the annual cycle indirectly in multiple steps.

In view of the fundamental differences in our analysis methods, we cannot pinpoint the reasons that our global trend differs from that of Christy et al. (1998). However, we emphasize that the method we have developed here is simple and explicit. Our result, a significant warming trend over the globe from 1980-1996 (0.109 K decade^{-1}), differs from that of Christy et al. (1998) by an amount outside of our estimated error, which is 0.06 K decade^{-1}. Also, the global temperature trend obtained in this study is in better agreement with that of surface data analyses (Jones, 1994; Hansen et al., 1995).

References

Christy, J.R., R.W. Spencer, E.S. Lobl, 1998: Analysis of the merging procedure for the MSU daily temperature time series. *J. of Climate*.

Hansen, J., H. Wilson, M. Sato, R. Ruedy, K. Shah, and E. Hansen, 1995: Satellite and surface temperature data at odds? *Clim. Change*, **30**, 103-117.

Jones, P. D., 1994: Recent warming in global temperature series. *Geophys. Res. Lett.*, **21**, 1149-1152.

NOAA, 1997: *NOAA Polar-Orbiter Data Users Guide*. (Available from NOAA / NEDIS / NCDC / CSD / SSB,FOB, Room G233, E/C C33, 4700 Suitland Road, Suitland, Maryland, 20746 or www2.ncdc.gov/POD/podug/cover.htm)

Prabhakara C., J. J. Nucciarone, and J.-M. Yoo, 1995: Examination of global atmospheric temperature monitoring with satellite microwave measurements 1) Theoretical consideration. *Climatic Change*, **30**, 349-366.

Shah, P.K. and D. Rind, 1995: Use of microwave brightness temperatures with a general circulation model. *J. Geophys. Res.*, **100**, 13841-13874.

Spencer, R. W. and J. R. Christy, 1990: Precise monitoring of global temperature trends from satellites. *Science*, **247**, 1558-1562.

C. Prabhakara, Code 913, NASA Goddard Space Flight Center, Greenbelt, MD, 20771. (e-mail: cuddapah@climate.gsfc.nasa.gov)

(Received November 20, 1997; accepted March 27, 1998.)