Supporting Online Material

for the paper

Global Warming Trend of Mean Tropospheric Temperature Observed by Satellites

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Results of bias and trend estimates for satellites connections shown in Figure 1

The basic estimates of climatic trends and instrumental biases discussed in the main paper are presented in Table S1. Estimates of the standard deviation of the trend, σ_{Trend}, were obtained by assuming that pentad averaged anomalies of global mean tropospheric temperature, $y'(t)$, are statistically independent in time.

Table S1. Bias and trend estimates. MSU data are for Ch.2. AMSU data are for Ch.5. $2\sigma_{Trend}$ is a measure of random error of the trend estimate. $\sigma_{Residuals}$ is an estimate of standard deviation of de-trended global temperature.

	Parameters in Eq. 1, *(17)*		
Diurnal cycle Seasonal cycle	*K=2, L=1* *N=2, M=2*	*K=2, L=1* *N=2, M=2*	*K=1, L=1* *N=2, M=2*
Instruments/ Satellites	9 MSU	9 MSU & 4 AMSU	9 MSU & 4 AMSU
Estimates of Biases, δ (K)			
TIROS-N	-0.31	-0.27	-0.03
NOAA-6	0.19	0.20	0.21
NOAA-7	-0.27	-0.23	-0.01
NOAA-8	0.18	0.18	0.18
NOAA-9	-0.14	-0.10	0.03
NOAA-10	0	0	0
NOAA-11	0.08	0.11	0.26
NOAA-12	-0.60	-0.60	-0.58
NOAA-14	-0.49	-0.44	-0.34
NOAA-15	-	-1.33	-1.40
NOAA-16	-	-1.55	-1.45
NOAA-17	-	-1.48	-1.70
AQUA	-	-1.78	-1.74
Trend Estimates (K/10yr)			
Trend, b_{00}	0.25	0.26	0.22
$2\sigma_{Trend}$	0.03	0.03	0.01
$\sigma_{Residuals}$ (K)	0.21	0.21	0.22

Dependence of Trend Estimate on Satellite Combinations

In the main body of the paper (see also Table S1), we showed that the global tropospheric warming trend estimate is a little larger if the asymmetry of the diurnal cycle is taken into account (*i.e.*, $K = 2$) compared to a version when this asymmetry is ignored so that $K = 1$. In this section we assume that the diurnal cycle is symmetric so that the ascending and descending orbits can be averaged together to obtain an unbiased estimate of daily averages. Under this assumption we can analyze the observations from different subsets of satellites without the necessity to maximize the number of observations per day. All that we need to estimate is the bias of one satellite with respect to another during the overlapping of their records. Table S2 shows the number of overlapping pentads of different satellites, while Table S3 lists the mean differences of the observed brightness temperatures between satellites during these overlapping periods. Earlier we used all available data and the longest overlapping periods to estimate the instrumental biases, mean tropospheric temperature, and climatic trend in addition to their diurnal variations. Here we neglect the diurnal variations so that we can use different subsets of satellites and connect them in different ways. Each of the subsets still covers the full period of observations 1978-2002.

Fig. 2 of the main paper shows that four of the satellites, TIROS-N, NOAA-6, NOAA-9 and NOAA-10, have to be included in every subset. Later satellites, NOAA-16, NOAA-17, and Aqua are not important here because we are not trying to evaluate the diurnal cycle and do not need many observations per day. Table S4 gives the bias and trend estimates for eight data subsets. Every satellite has to be connected to the conditionally unbiased satellite NOAA-10. We use arrows (> or <) to show the connections between the satellites and with NOAA-10.

Subset 1. TIROS-N<NOAA6<NOAA-9<NOAA-10>NOAA>11>NOAA-14;
NOAA-6>NOAA-7.
Subset 2. TIROS-N<NOAA-6<NOAA-7<NOAA-8<NOAA-9<NOAA-10>NOAA-11>NOAA-14.
Subset 3. TIROS-N<NOAA6<NOAA-9<NOAA-10>NOAA>12>NOAA-14;
NOAA-6>NOAA-7.
Subset 4. TIROS-N<NOAA-6<NOAA-7<NOAA-8<NOAA-9<NOAA-10>NOAA-12>NOAA-14.
Subset 5. TIROS-N<NOAA6<NOAA-9<NOAA-10>NOAA>12>NOAA-15;
NOAA-6>NOAA-7.
Subset 6. TIROS-N<NOAA-6<NOAA-7<NOAA-8<NOAA-9<NOAA-10>NOAA-12>NOAA-15.
Subset 7. TIROS-N<NOAA-6< NOAA-9<NOAA-10>NOAA-11>NOAA-12>NOAA-14>NOAA-15;
NOAA-14>NOAA-16;
NOAA-14>NOAA-17;
NOAA-14>AQUA;
NOAA-6>NOAA-7>NOAA-8.
Subset 8. TIROS-N<NOAA-6<NOAA-9<NOAA-10>NOAA-11>NOAA-12>NOAA-14;
NOAA-6>NOAA-7>NOAA-8.

The trend was estimated using the same model (Eq. 2) but with $K = L = 0$, $N = M = 2$. Biases have been estimated using data from Table S3 for the corresponding satellite overlaps. Looking at the trend estimates in Table S4 for the subsets 1-6 we find that all are in the range of 0.15 to 0.34 K/10 yr. Subset 7 uses all MSU and AMSU observations and has the longest sequence of satellite overlaps. The trend in this case is the same 0.22 K/10 yr as in Table 1 for $K = L = 1$. The same trend is seen in subset 8, which has the same satellite connections as in version 7, but only includes MSU observations. We do not see a reason to ignore the observations of any of these satellites. We expect that the trend estimate of 0.22 K/10 yr is the best one based on the assumption that four observations per day is sufficient to estimate unbiased diurnal averages of globally averaged tropospheric temperature. As shown in the main body of the paper, taking into account the diurnal cycle of tropospheric temperature, we obtained a trend estimate equal to 0.26 K/10 yr, which is only a little larger than 0.22 K/10 yr.

Table S2. Number of overlapping pentads of observation of different satellites. T-is TIROS, N- is NOAA satellites.

	T-N	N-6	N-7	N-8	N-9	N-10	N-11	N-12	N-14	N-15	N-16	N-17	Aqua
T-N	89	41	0	0	0	0	0	0	0	0	0	0	0
N-6	41	315	109	0	73	0	0	0	0	0	0	0	0
N-7	0	109	261	79	6	0	0	0	0	0	0	0	0
N-8	0	0	79	92	13	0	0	0	0	0	0	0	0
N-9	0	73	6	13	158	18	0	0	0	0	0	0	0
N-10	0	0	0	0	18	347	213	19	0	0	0	0	0
N-11	0	0	0	0	0	213	510	316	55	0	0	0	0
N-12	0	0	0	0	0	19	316	547	280	31	0	0	0
N-14	0	0	0	0	0	0	55	280	576	325	153	31	24
N-15	0	0	0	0	0	0	0	31	325	327	154	31	24
N-16	0	0	0	0	0	0	0	0	153	154	155	31	24
N-17	0	0	0	0	0	0	0	0	31	31	31	31	24
Aqua	0	0	0	0	0	0	0	0	24	24	24	24	24

Table S3. Mean differences in brightness temperature, K (Satellite row – Satellite column) for the overlapping periods. T- is TIROS, N- is NOAA satellites.

	T-N	N-6	N-7	N-8	N-9	N-10	N-11	N-12	N-14	N-15	N-16	N-17	Aqua
T-N	0	0.23	-	-	-	-	-	-	-	-	-	-	-
N-6	-0.23	0	-0.22	-	-0.18	-	-	-	-	-	-	-	-
N-7	-	0.22	0	0.20	0.15	-	-	-	-	-	-	-	-
N-8	-	-	-0.20	0	-0.05	-	-	-	-	-	-	-	-
N-9	-	0.18	-0.15	0.05	0	-0.03	-	-	-	-	-	-	-
N-10	-	-	-	-	0.03	0	0.26	-0.59	-	-	-	-	-
N-11	-	-	-	-	-	-0.26	0	-0.84	-0.46	-	-	-	-
N-12	-	-	-	-	-	0.59	0.84	0	0.24	-0.97	-	-	-
N-14	-	-	-	-	-	-	0.46	-0.24	0	-1.06	-1.11	-1.35	-1.41
N-15	-	-	-	-	-	-	-	0.97	1.06	0	-0.03	-0.19	-0.17
N-16	-	-	-	-	-	-	-	-	1.11	0.03	0	-0.17	-0.14
N-17	-	-	-	-	-	-	-	-	1.35	0.19	0.17	0	0.03
Aqua	-	-	-	-	-	-	-	-	1.41	0.17	0.14	-0.03	0

Table S4. Biases and trend estimates for different combinations of satellites. T- is TIROS, N- is NOAA satellites.

Subset:	1	2	3	4	5	6	7	8
BIASES TO BE ADDED (K)								
T-N	-0.03	-0.13	-0.03	-0.13	-0.03	-0.13	-0.03	-0.03
N-6	0.21	0.11	0.21	0.11	0.21	0.11	0.21	0.21
N-7	-0.01	-0.11	-0.01	-0.11	-0.01	-0.11	-0.01	-0.01
N-8	-	0.08	-	0.08	-	0.08	0.18	0.18
N-9	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
N-10	0	0	0	0	0	0	0	0
N-11	0.26	0.26	-	-	-	-	0.26	0.26
N-12	-	-	-0.60	-0.59	-0.59	-0.59	-0.58	-0.58
N-14	-0.20	-0.20	-0.35	-0.35	-	-	-0.34	-0.34
N-15	-	-	-	-	-1.56	-1.56	-1.40	-
N-16	-	-	-	-	-	-	-1.45	-
N-17	-	-	-	-	-	-	-1.70	-
Aqua	-	-	-	-	-	-	-1.75	-
TREND ESTIMATES (K/10 yr)								
Trend	0.29	0.34	0.20	0.26	0.15	0.20	0.22	0.22