TRENDANALYSIS OF SATELLITE GLOBAL TEMPERATURE DATA

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ABSTRACT

Global satellite data is analyzed for temperature trends for the period January 1979 through June 2009. Beginning and ending segments show a cooling trend, while the middle segment evinces a warming trend. The past 12 to 13 years show cooling using both satellite data sets, with lower confidence limits that do not exclude a negative trend until 16 years. It is shown that several published studies have predicted cooling in this time frame. One of these models is extrapolated from its 2000 calibration end date and shows a good match to the satellite data, with a projection of continued cooling for several more decades.

INTRODUCTION

Temperature trends provide critical evidence for evaluating claims regarding anthropogenic climate change. On the one hand, models project continued warming (e.g., Hansen et al., 2006). On the other, it has been argued that Earth's weather should be expected to exhibit long-term persistence (LTP) at some scale (Cohn and Lins, 2005; Easterling and Wehner, 2009; Wood, 2008). LTP could at any given time give a false impression of the strength of anthropogenic effects by adding a warming trend to an existing anthropogenic signal, or it could act to counter such signal for some period of years or decades. Thus it is critical to examine climate history data at multiple scales to evaluate these effects. Typical trend studies, however, have not evaluated the most recent decades per se. For example, periods evaluated include sea surface temperatures over 1960-1990 (Casey and Cornillon, 2001), lower troposphere RSS data over 1979-2001 (Fu et al., 2004), the global surface record for 1950-2004, 1979-2004, 1950-1980 (Vose et al., 2005), 1988-2005 (Hansen et al., 2006), and 1977-2001 (Jones and Moberg, 2003), the NCEP reanalysis Northern Hemisphere surface record for 1960-2000 (Lucarini and Russell, 2002), 1969-2000 for Southern Hemisphere data (Thompson and Solomon, 2002), and the satellite and balloon data for 1979-2004 (Christy et al., 2007). The most recent Intergovernmental Panel on Climate Change report (IPCC, 2007) shows 100 and 140 year trends. In all cases, the period of rapid warming in the late 1970s through 1990s was included in these analyses. All of these studies looked only at long-term trends.

Given that satellite data are now available for more than 30 years and that recent years do not show a visible upward trend, it seems appropriate to re-examine temperature trends. The purpose here is not to obtain the 30 year trend, which has been done previously, but rather to parse the data to evaluate evidence for LTP and recent trends. In spite of the importance of the satellite data for assessing trends, no analysis of trends for the most recent decades has been published using these data.

METHODS

The purpose of the analysis is to examine the data for linear trends. Looking backward from the most recent dates, the question is what is the temperature trend over recent years? If it is negative (cooling), how long can a cooling trend be said to have existed? Starting at the beginning of the record in 1979 and looking forward, how long a record is needed before a warming trend is detectable? Starting with intervals in the middle of the record, how does the trend in this middle interval compare to the starting and ending periods? Linear trends are the simplest way to assess climate change, and are used in the IPCC reports and most of the trend studies cited in the introduction, among many others. Linear trends also have the advantage that confidence intervals are well defined, which aids in interpretation. Calculating such linear trends overcomes issues due to subjective interpretation of noisy data and the arbitrariness of various methods of smoothing the data, especially at the end points (see Soon et al., 2004). By showing trends of data segments of multiple lengths, issues of the studied interval being unduly influential are avoided. Longer-term trends (or red noise) are graphically uncovered by the analysis, if they exist, and are not being estimated *per se*. Instead the questions are strictly empirical: how much has it warmed/cooled over various lengths of time, according to satellite data?

University of Alabama at Huntsville (UAH) and Remote Sensing Systems (RSS) Microwave Sounding Unit (MSU) data were obtained on July 20, 2009. UAH data were downloaded from http://vortex.nsstc.uah.edu/data/msu/t2lt/uahncdc.lt (Fig. 1a). RSS (http://www.ssmi.com/msu/msu_data_description.html) data were downloaded from ftp://ftp.ssmi.com/msu/monthly_time_series/rss_monthly_msu_amsu_channel_tlt_anomalies_land_and_ocean_v03_2.txt (Fig. 1b). Data from January 1979 through June 2009 (366 months) were available from both series.

The data were not smoothed. Series of different length were considered, with 60 months being the shortest. Data were considered for intervals that began in January 1979, for intervals that ended in March 2009, and for intervals starting at the record midpoint. Linear regression was performed using the Regress function in Mathematica (www.Wolfram.com). Slopes were computed on a per decade basis. Adjusted slope confidence intervals were calculated to account for temporal autocorrelation. The single month-to-month correlation of regression residuals, r, was calculated as

$$r_1 = \sum_{t=1}^{n-1} \left(e_t e_{t+1}\right) / \left(n - k - 1\right) / \left(s^2\right) \tag{1}$$

where e are the regression residuals at t, n is the sample size, k is the number of parameters (1 here), and s^2 is the residuals' variance. The effective sample size n_e is (Bartlett 1935; Quenouille 1952; Santer et al. 2008)

$$n_e = n\frac{(1-r_1)}{(1+r_1)} \tag{2}$$

where $n_e < n$ after adjustment. This value for n_e is used to recompute the standard error of the slope to get new confidence intervals. Longer-period autocorrelation is accounted for by computing trends at multiple time scales.

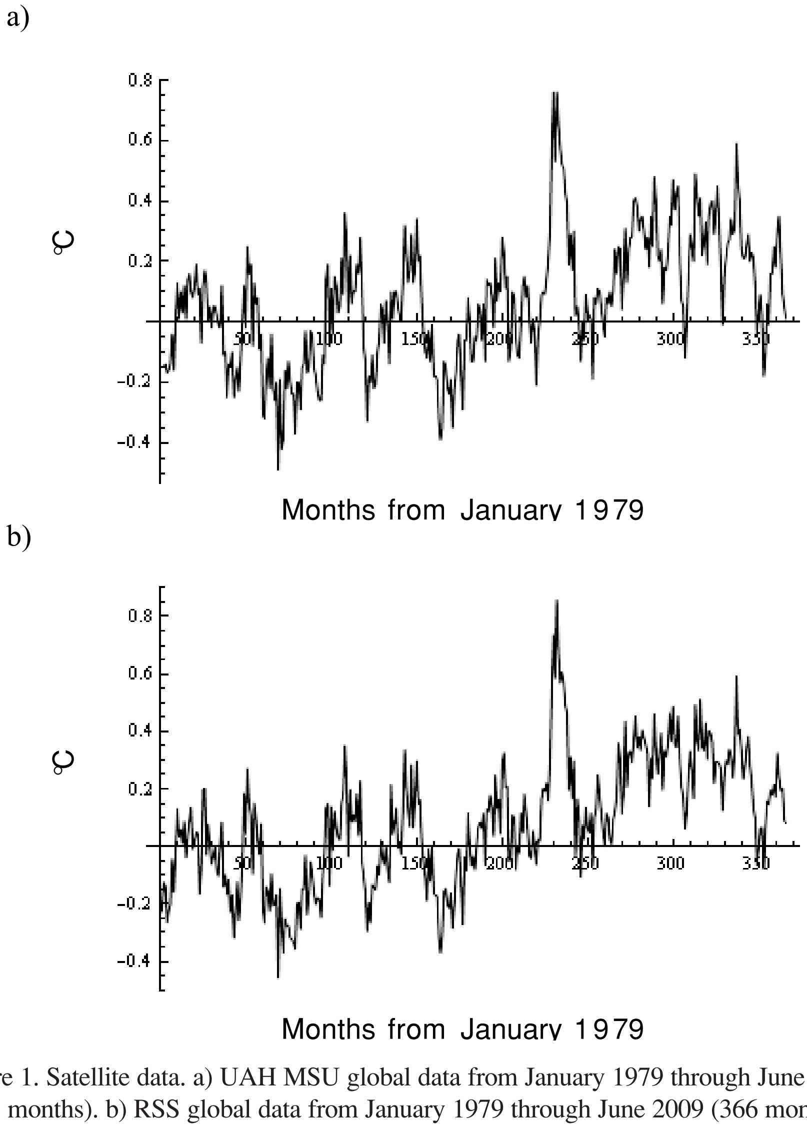

Figure 1. Satellite data. a) UAH MSU global data from January 1979 through June 2009 (367 months). b) RSS global data from January 1979 through June 2009 (366 months).

RESULTS

As expected, as series length increases the confidence intervals narrow. For series ending in 2009, the shortest (60 months) show a strongly negative trend of -0.33ºC per decade for UAH and -0.38ºC per decade for RSS (Fig. 2). The trend does not stay positive until the period length is longer than 146 months (12.2 yr) for UAH or 149 months (12.4 yr) for RSS. There is a slightly more negative slope (faster cooling) at 130 months as the 1998 el Niño is included in the record. The lower confidence limit includes 0 until 196 months (16.3 yr) for UAH and 195 months (16.3 yr) for RSS. Thus for the past 16 years it is not possible to detect a warming trend with this data (lower confidence intervals include zero) and for the past 12+ years the data actually show a cooling trend. As the data length increases beyond month 200, the slope curve becomes stable (constant) and confidence intervals become narrow because a longer sequence is being analyzed and the addition of more months has little effect on the trend.

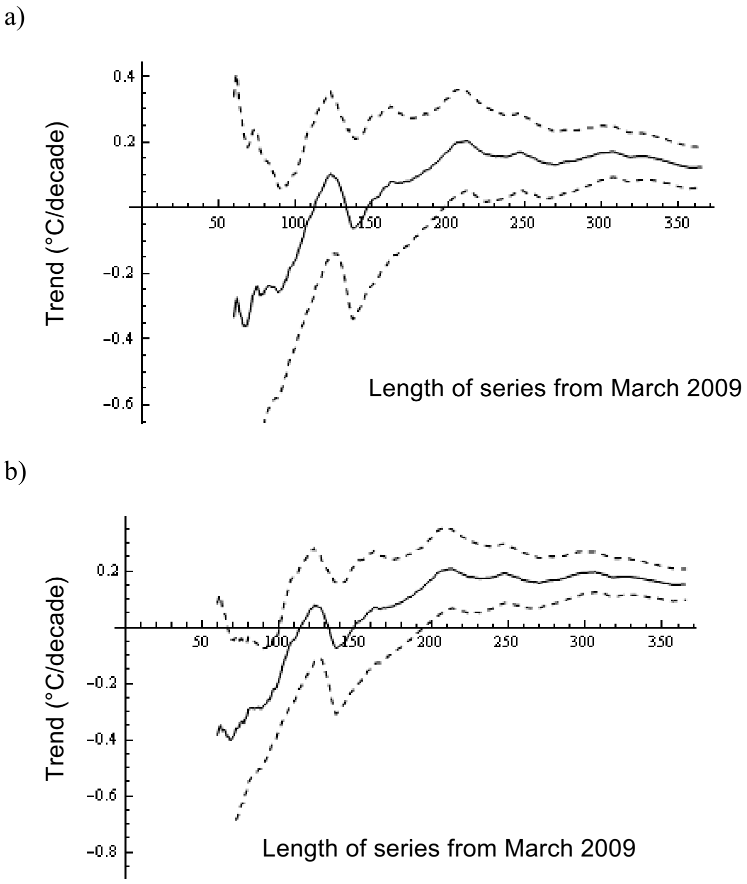

Figure 2. Trend analysis for records of different lengths (months) ending in March 2009 with autocorrelation corrected 95% confidence intervals. The first point on the left side is the slope for data from June 2004 to June 2009, with subsequent points being series beginning at earlier dates. a) UAH data. b) RSS data.

The same analysis was conducted for time series of different length that all originate in January 1979 (Fig. 3). Shorter series up to 193 months (16.1 yr) long for UAH and 129 months (10.8 yr) for RSS surprisingly show a negative slope. In fact, not until the record is 273 months (22.8 yr) long for UAH or 229 months (19.1 yr) long for RSS does the lower 95% confidence interval not include 0.

Next, series were constructed in the middle of the 366 month record. Beginning with a 60 month segment centered on the middle of the record, slopes were again calculated, but this time at each increment a month was added at the start and end of the record until the full series was captured (Fig. 4). With this approach, the records of various lengths all show positive slope (warming). However, for the short records (up to 200 months) the slope fluctuates considerably, and the confidence intervals are quite wide and include negative values. It is noticeable that at about 120 months the 1998 el Niño comes into play and creates a big apparent warming spike, which is quickly damped out for longer records.

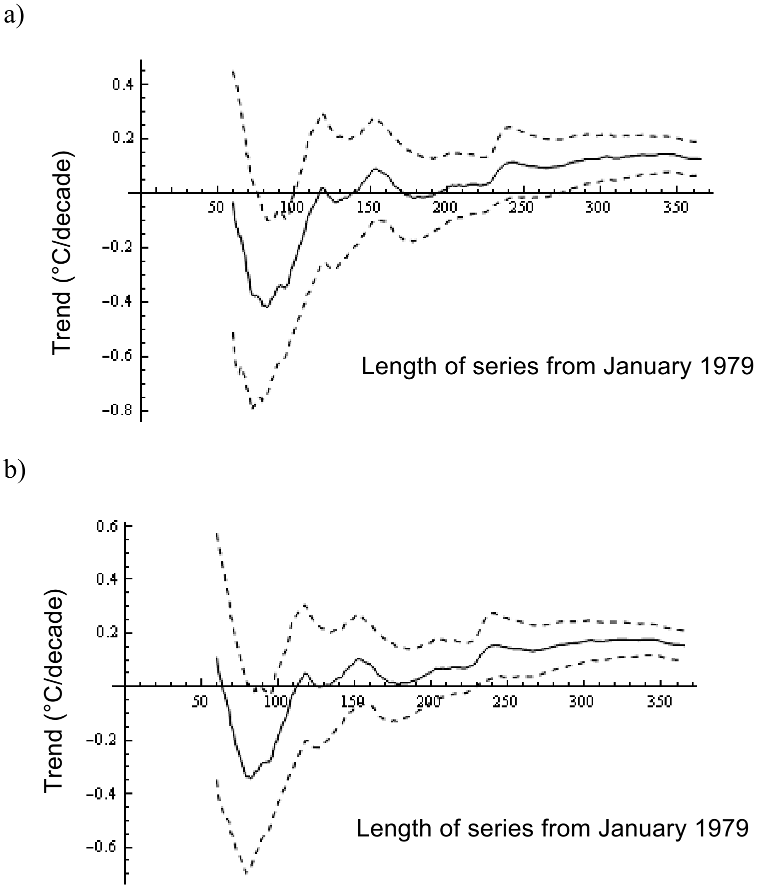

Figure 3. Trend analysis for records of different lengths (months) beginning in February 1979 with autocorrelation corrected 95% confidence intervals. The left-most point is the five year data from February 1979 to February 1984. a) UAH data. b) RSS data.

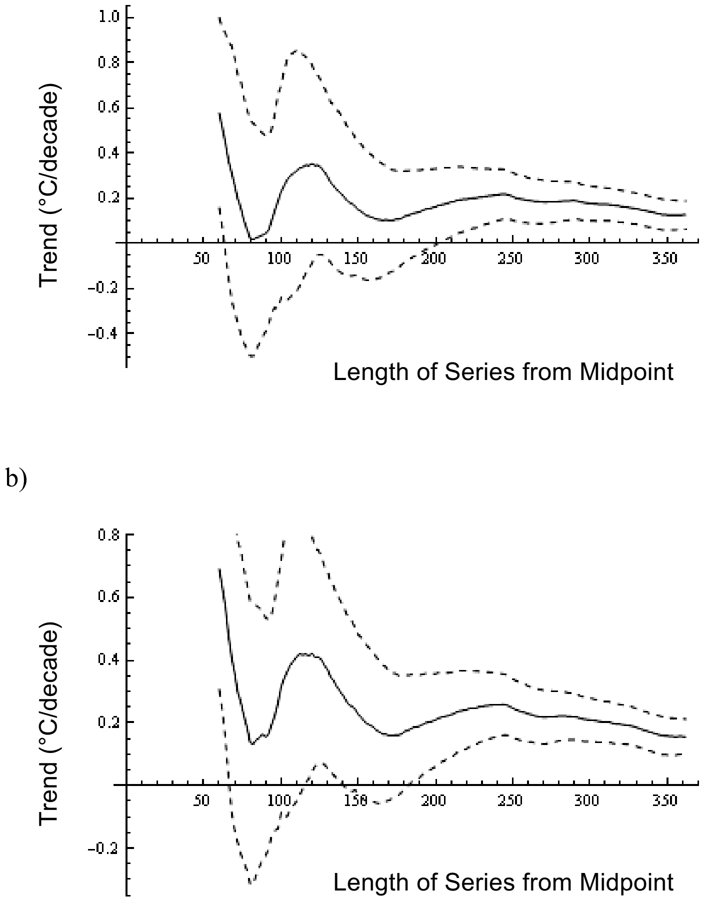

Figure 4. Trend analysis for records of different lengths (months) beginning at record midpoint with autocorrelation corrected confidence intervals. The left-most point is the five year interval centered on the series midpoint. a) UAH data. b) RSS data.

DISCUSSION

The data clearly show a cooling phase over the past 12 to 13 years, with lower confidence intervals including negative trend over the past 16 to nearly 23 years, depending on dataset. The recent cooling trend is also evident in the Hadley and the Goddard Institute for Space Studies (GISS) data, though with some lag, and in ocean heat content data (Loehle, 2009).

Satellite data since 1978 are clearly nonstationary. The early and late periods show modest cooling trends, while the middle portion shows a strong warming trend. This could be an indication of the combination of a linear or other warming trend with one or more periodic climate cycles, as suggested by Chylek et al. (2009), Loehle (2004), Klyashtorin and Lyubushin (2003), Schlesinger and Ramankutty (1994), Soon (2005), and Zhen-Shan and Xian (2007), among others. Zhen-Shan and Xian (2007) and Klyashtorin and Lyubushin (2003) noted that the result of this combination of forcings could be to exaggerate the apparent warming (and therefore the apparent greenhouse forcing effect) of the last third of the 20th Century. Empirical identification of periodic or semi-periodic climate signals has a precedent in the identification of sunspot cycles and is thus worthy of consideration for longer periods, which is considered next in the context of forecasting future climates.

Several papers have forecast a cooling episode for the coming decades, each using different methods. Keenlyside et al. (2008), for example, suggested that a decade of cooling could be in store. They based this on climate models forced with more detailed historical ocean data. Based on a dynamical analysis of coupling between regional modes of climate variability (Tsonis et al., 2007; Wang et al., 2009), it has been argued that the Earth's climate system in 2001/02 underwent a dynamic shift to a new state that is predicted to show a flat to cooling trend for several decades (Swanson and Tsonis, 2009). The timing of this prediction closely matches the trends in satellite data analyzed herein. De Jager and Duhau (2009) argue that the solar dynamo is currently undergoing a transition, which began in 2000, from the recent Grand Maximum to a different regime that will be marked by lower solar activity. Based on analysis of solar cycles, Landscheidt (2003) shows that the peak in the geomagnetic aa index in 1990 would lead to a prediction, due to an eight year lag, of a peak temperature in 1998, which is clearly visible in Fig. 7. He further posits that this peak will be followed by a cooling period expected to last until the next Gleissberg minimum around 2030. Schlesinger and Ramankutty (1994) used singular spectrum analysis on 1858-1992 surface temperature data to show the effect of a 65-70 year periodic signal, which they interpreted to be due to oscillations in the North Atlantic currents and thereby on the weather of nearby land masses. The last peak in their analysis is in 1941, giving a following expected peak between 2006 and 2011. This expectation nicely coincides with the downturn observed in this study. Bratcher and Giese (2002) showed that tropical Pacific temperatures lead global air temperatures by 4 years for sea surface temperature and 11 years for subsurface temperatures. On the basis of a tropical Pacific cooling for 8 years from the early 1990s, they forecast a shift in the PDO similar to the 1976 shift, but with opposite sign, leading to cooling over coming decades. This forecast seems particularly prescient since NASA identified a shift in the PDO to its cool phase over the past two years. Klyashtorin and Lyubushin (2003) demonstrated that a 50-60 year period temperature signal is dominant from about 1650 (the end of the Little Ice Age) in Greenland ice core records, in several very long tree ring records, and in sardine and anchovy records in marine sediment cores (Klyashtorin et al. 2009), a result also reported by Biondi et al. (2001). They then modeled 1861-2000 global temperature data with a linear trend plus a 64.13 year cycle (estimated from global temperature records). They extrapolated this model, obtaining a peak in 2005 followed by cooling for the next 32 years, since the periodic component is dominant over the linear warming trend over the scale of several decades. Loehle (2004, but written in 2001) used two 3000 year paleo-timeseries to estimate periodic models of varying complexity. Most of the models predicted cooling in the early 21st Century, with cooling initiation generally near the year 2000. Zhen-Shan and Xian

(2007) used Empirical Mode Decomposition on data over 1881-2002. They found a strong 60 year cycle and a 20 year cycle plus linear trend. Their model peak was in 2001 for China (which slightly leads world values in their analysis). After this time both cycles are in negative mode. Thus they forecast about 20 more years of cooling. Except for Keenlyside et al. (2008) the studies agree on the influence of the multidecadal quasicycle generally associated with the Gleissberg solar cycle (e.g., Yousef, 2006), although they disagree on the precise cycle length. Furthermore, the studies agree on the timing of the transition or peak as being between 1998 and 2005. This is in spite of being based on very different models and data.

It is worth examining the model of Klyashtorin and Lyubushin (2003) in more detail. The equation of their fitted curve is:

$$Z(t) = a + b \cdot (t - t_0) + A \cdot \cos\left(\frac{2\pi \cdot (t - t_0}{T} - \phi \right)$$

where: t_0 = 1861; t is calendar year; a = –0.332632; b = 0.0038827; A = 0.131125; T = 64.1453; and j = 1.43346. Their model for the period 1861-2000 AD has a linear component slope of 0.0388°C/decade, a cycle amplitude (peak-to-trough) of 0.262°C, and a cycle period of 64.15 years (Fig. 5a). The IPCC Third Assessment gives a linear trend over this same period of 0.044°C/decade (Folland et al., 2002), but this higher value results from the series ending on an upturn in the 64 year cycle. Residuals (Fig. 5b) indicate that the model fits equally well over the entire 140 year span. This model suggests that a constant rate of warming (the linear term in the model) has been ongoing since before human influence was significant (i.e., prior to 1950), with no acceleration in recent decades. This is evident from the residuals plot (Fig. 5b). The oscillations in the model are persistent features of the climate over the past 350 years, possibly related to solar activity and/or ocean oscillations such as the Pacific Decadal Oscillation. We can extend this model from 2000 through 2020 and compare it to the UAH data on a common anomaly basis (Fig. 6). The extrapolated model almost perfectly captures the temperature turning point in the UAH data. Continued cooling is forecast by this model until 2037.

Easterling and Wehner (2009) argued that periods of no warming or even cooling of a decade or two are possible even in the presence of a greenhouse warming trend. They assume that variability in trends is due to internal oscillations rather than forcings (i.e., to LTP). This means that detection of a cooling trend, as in the present study, is not an automatic refutation of greenhouse theory (although the same argument can be used to suggest that the most rapid warming interval in the 1990s was itself merely LTP). However, even in their study such periods were unusual and here we have shown that the present cooling is correlated with solar activity indices (such as the aa index) and was predicted by multiple studies dating to 1994. Furthermore, simple LTP can not produce a periodic signal over 350 years (since the Little Ice Age) nor would it be so consistently predicted by the various methods discussed here, including those based on patterns of solar activity and ocean mode indices. Thus suggests that the cooling is not merely a random fluctuation, but definitive evidence will take more time.

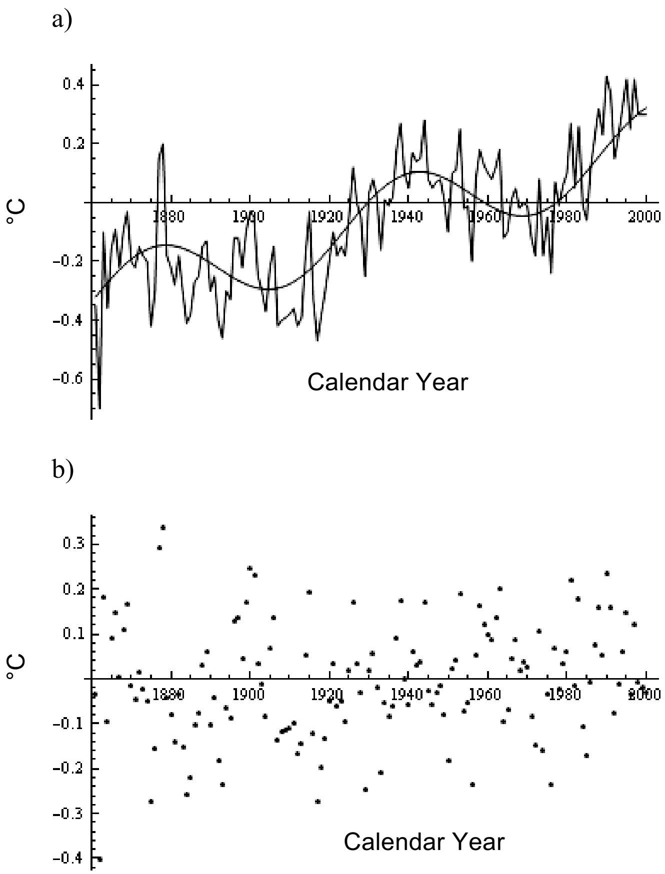

Figure 5. Best fit linear plus periodic model from Klyashtorin and Lyubushin (2003). a) Model overlaid over global temperature anomaly. Linear trend is 0.0388° C/decade for the entire period. b) Residuals, showing constant good fit over the record and no evidence of nonlinearity or recent acceleration of warming.

CONCLUSIONS

Analysis of the satellite data shows a statistically significant cooling trend for the past 12 to 13 years, with it not being possible to reject a flat trend (0 slope) for 16 years. This is a length of time at which disagreement with climate models can no longer be attributed to simple LTP. On the other hand, studies cited herein have documented a 50-70 year cycle of climate oscillations overlaid on a simple linear warming trend since the mid-1800s and have used this model to forecast cooling beginning between 2001 and 2010, a prediction that seems to be upheld by the satellite and ocean heat content data. Other studies made this same prediction of transition to cooling based on solar activity indices or from ocean circulation regime changes. In contrast, the climate models predict the recent flat to cooling trend only as a rare stochastic event. The linear warming trend in these models that is obtained by subtracting the 60-70 yr cycle, while unexplained at present, is clearly inconsistent with climate model predictions because it begins too soon (before greenhouse gases were elevated) and does not accelerate as greenhouse gases continue to accumulate. This model and the empirical evidence for recent cooling thus provide a challenge to climate model accuracy.

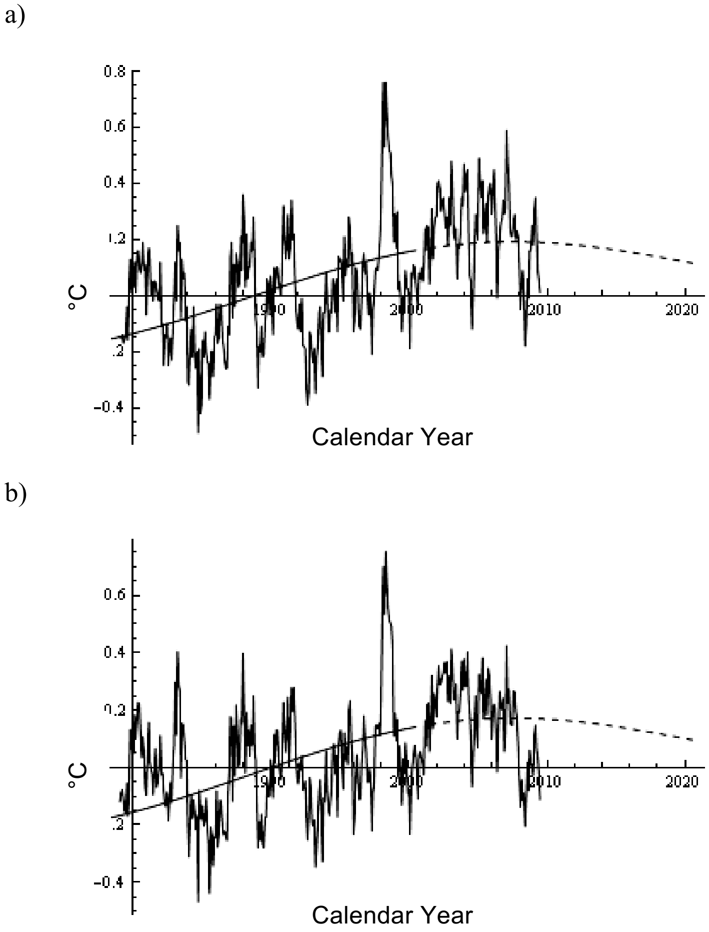

Figure 6. Linear plus period model from Klyashtorin and Lyubushin (2003) overlaid on satellite data after intercept shift. Dotted line is model extrapolation post-2000 calibration period end. a) UAH. b) RSS.

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