Reconciling observations of global temperature change

Richard S. Lindzen and Constantine Giannitsis
Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

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[1] It is suggested that the much publicized discrepancy between observed surface global mean temperature and global mean atmospheric temperature from 1979 to the present may be due to the fact that the atmosphere underwent a jump in temperature in 1976 (before the satellite temperature series began), and that the surface response was delayed for about a decade due to the ocean heat capacity. The ocean delay depends on both climate sensitivity and vertical heat transport within the ocean. It is shown that the observed delay is best simulated when sensitivity to doubling of CO_2 is less than about 1C. *INDEX TERMS:* 1620 Global Change: Climate dynamics (3309); 1610 Global Change: Atmosphere (0315, 0325); 1635 Global Change: Oceans (4203); 1694 Global Change: Instruments and techniques

1. Introduction

[2] Over the last 9 years or so, there has been much public attention devoted to the claimed discrepancy between global mean temperature trends obtained from satellite microwave retrievals from the troposphere and surface temperature measurements. The period considered is from 1979 (when satellite measurements used began) to the present. The surface data suggests a warming of about 0.25C, while the satellite data shows no significant increase (more precisely, the trend in the satellite data through 2001 is 0.035 ± 0.06C/decade). A detailed description of the satellite data is given by [*Christy et al.*, 2000]. This difference provoked often acrimonious debate, and a panel was assembled by the US National Research Council to assess the situation. Its report [*NRC*, 2000], issued with considerable publicity, concluded that the surface change was probably real, as was the relative absence of a net change in the tropospheric temperature; i.e., temperature changed differently in the atmosphere and at the surface. In support of the satellite temperature series, was the fact that satellite temperatures were in substantial agreement with radiosonde data for tropospheric temperature. The three temperature series are reproduced in Figure 1. On the whole, the agreement is quite good. However, fluctuations are on the order of any net changes claimed. The NRC attempted to relate the fluctuations to specific events. However, such identifications are qualitative at best. What seems likely is that, as has been frequently noted, the period is too short to infer trends from any of the series since the trends estimated depend greatly on the subintervals chosen. The effective agreement of the satellite and radiosonde data, however, permits us to consider longer periods. Before turning to the longer records, however, it should be stressed that there is no rigorous reason to suppose that atmospheric and surface temperatures need track each other arbitrarily closely especially over short periods, and changes in each can represent a variety of mechanisms. Changes in oceanic upwelling and downwelling, for example, can directly impact surface temperature without directly impacting mid tropospheric temperatures. Greenhouse warming, on the other hand, impacts emission levels (ca 5 km) first, with the warming communicated to the surface through a variety of mechanisms, and with the surface temperature subject to ocean delay [*Lindzen and Emanuel*, 2001]. The absence of mid-tropospheric warming would, therefore, tend to rule out greenhouse warming.

2. Surface V. Radiosonde Record

[3] As noted by [*Angell*, 2000], the globally averaged radiosonde record is adequately represented with a well selected subset of radiosonde stations. Figure 2 shows both the surface temperature record and the radiosonde record of temperature over the interval 850–300 mb since 1964 compiled by [*Angell*, 2000]. Almost identical results were obtained with the full set of radiosonde data (A. Oort, 1991, personal communication, [*Sterin*, 1999]). Now there appears to be little difference in the trends of both records over the whole period. However, the tropospheric record seems to be characterized by an 0.25C jump around 1976, while the surface record rises somewhat more gradually, taking something less than 10 years to completely catch up

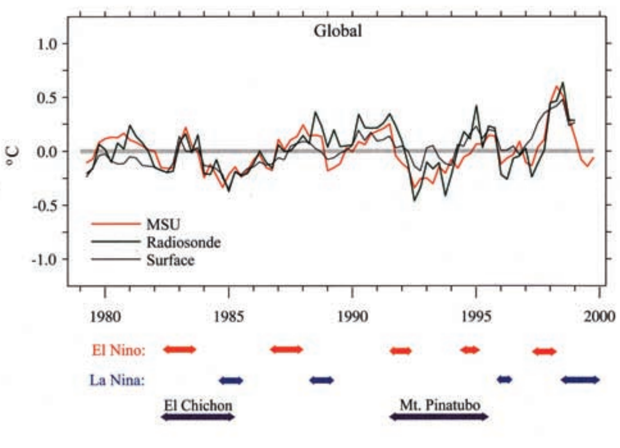

Figure 1. Time series (since 1979) for temperature for surface, troposphere from MSU2, and troposphere from radiosondes.

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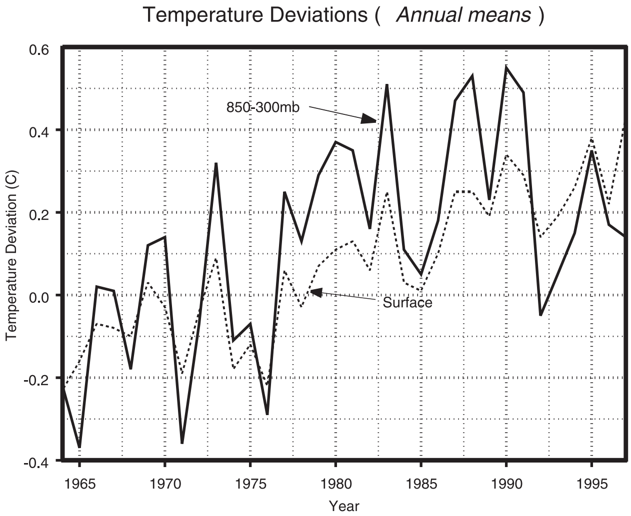

Figure 2. Time series (since 1964) for temperature for surface and troposphere from radiosondes.

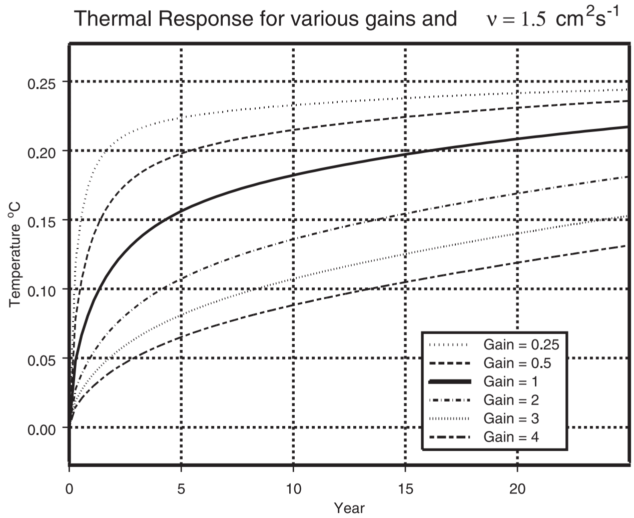

Figure 4. Surface response to impulsive 0.25C jump in tropospheric temperature for different climate sensitivities and ν = 1.5 10^4 $cm^2 sec^{-1}$.

with the atmosphere. The tropospheric jump is, of course, missed in the satellite record which began in 1979. The situation is more easily seen using 5-year running means. These are shown in Figure 3. The tropospheric jump around 1976 may well be associated with reasonably well documented atmospheric regime changes occurring at about the same time ([*Chang and Fu*, 2001; *Thompson and Wallace*, 1998]). The fact that the surface temperature takes about ten years to catch up with the atmosphere is plausibly consistent with the fact that the surface temperature change is delayed due to the heat capacity of the oceans. However, as has long been noted, the coupling of the atmosphere to the ocean is related to the overall climate sensitivity ([*Hansen et al.*, 1985; *Lindzen and Giannitsis*, 1998]). Finally, it should be noted that while the surface has to adjust to any jump in atmospheric temperature, it may, in addition manifest other sources of variability as discussed in the Introduction. Thus, the determination of how long the surface takes to catch up with the atmosphere is inevitably subject to some ambiguity.

3. Surface Response to the Atmosphere

[4] The way in which atmospheric temperature changes would force surface temperature changes is by no means trivial. If we assume that the coupling will eventually lead to temperature changes at the surface equaling those in the atmosphere, then the flux presented to the surface will have to diminish as climate sensitivity increases (i.e., by definition, the more sensitive a climate is, the less the flux needed to produce a given temperature change). This, in turn implies that the ocean delay increases with increased climate sensitivity. This effect is trivially calculated using a model described in [*Lindzen and Giannitsis*, 1998] wherein account is taken of land-sea coupling, and an ocean mixed

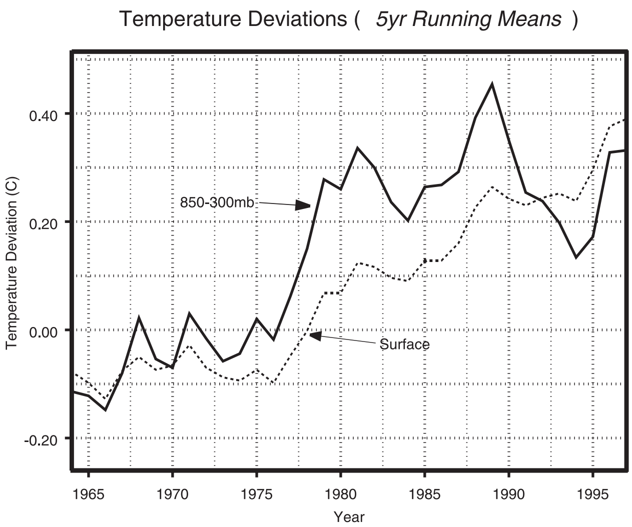

Figure 3. Same as Figure 2, but for 5 year running means.

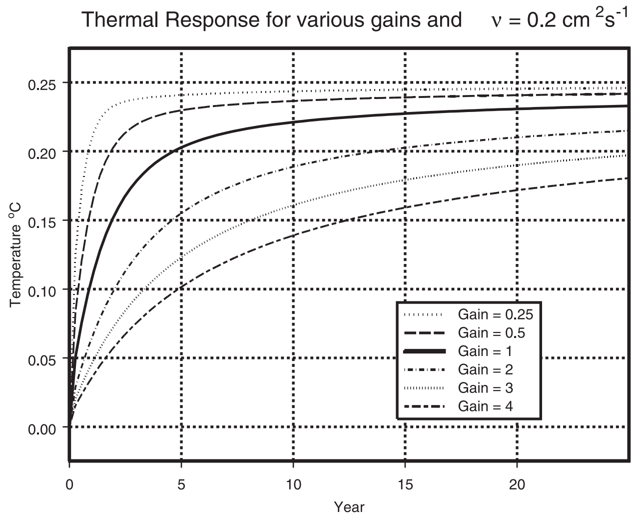

Figure 5. Surface response to impulsive 0.25C jump in tropospheric temperature for different climate sensitivities and ν = 0.2 10^4 $cm^2 sec^{-1}$.

layer above a finite thermocline. Parameters are tuned to replicate the annual cycle over both land and sea; this primarily determines the depth of the mixed layer and the land-sea coupling. A gain of unity is taken to correspond to a response of 0.3C for a flux of 1 Wm^{-2}.

[5] In such simple models, the vertical diffusion, ν, parameterizes *global* ocean heat uptake, rather than uptake in specific regions. There is substantial uncertainty in the choice of this parameter [*Forest et al.*, 2002]. Larger values such as $\nu = 1.5\ 10^4\ cm^2 sec^{-1}$ are based on tracer observations [*Hoffert et al.*, 1980]. Smaller values such as $0.2\ 10^4\ cm^2 sec^{-1}$ are based on specific mid ocean observations [*Danabasoglu et al.*, 1994], and probably underestimate globally averaged heat uptake which may involve significant exchanges in coastal shelf regions. Calculated results for the surface response to an instantaneous jump of 0.25C in atmospheric temperature using both the large and small choices for ν are shown respectively in Figures 4 and 5. Results are shown in both figures for various choices climate sensitivity (corresponding to an equilibrated response to doubled CO_2 of between 0.3 and 4.8C). Obviously, the use of the small value for ocean heat uptake leads to reduced ocean delay for larger choices of gain, and thus permits somewhat larger gains, the opposite being true for the choice of larger values for ocean heat uptake. While one wouldn't want to use such results for a precise determination of climate sensitivity, it is clear that for either choice of ν, best agreement with the observations is obtained for low values of gain (characteristically less than unity). This is consistent with the earlier results of [*Lindzen and Giannitsis*, 1998] based on the surface response to a sequence of volcanos. The low sensitivities suggested are consistent with the recent theoretical and observational analysis of tropical cloud/water vapor feedbacks [*Lindzen et al.*, 2001]. As noted in this last paper, current GCMs fail to replicate this potentially important negative feedback and thus may produce excessive climate sensitivity. Results consistent with these findings have recently been reported by [*Chen et al.*, 2002] and [*Wielicki et al.*, 2002].

4. Concluding Remarks

[6] Comparing radiosonde global averaged temperatures for the troposphere with surface temperatures over the period since 1964, shows that the gross trends are almost the same. This contrasts with similar comparisons since 1979 where trends for the troposphere from both radiosondes and microwave sounders are nearly zero in contrast to increases of about a couple of tenths of a degree C for surface data. The longer series suggests that the increase in tropospheric temperature occurred rather abruptly around 1976, three years before microwave observations began. The suddenness of the tropospheric temperature change seems distinctly unlike what one expects from greenhouse warming, while the relative rapidity with which the surface temperature caught up with the troposphere, less than about 10 years, suggests low climate sensitivity for a wide range of choices for thermocline diffusion.

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[8] The Editor would like to thank the reviewers of this manuscript.

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R. S. Lindzen and C. Giannitisis, Program in Atmospheres, Oceans, and Climate, Massachusetts Institute of Technology, Cambridge, MA 02139, USA. (rlindzen@mit.edu)