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A minimal model for estimating climate sensitivity

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ABSTRACT

Climate sensitivity summarizes the net effect of a change in forcing on Earth's surface temperature. Estimates based on energy balance calculations give generally lower values for sensitivity (<2 °C per doubling of forcing) than those based on general circulation models, but utilize uncertain historical data and make various assumptions about forcings. A minimal model was used that has the fewest possible assumptions and the least data uncertainty. Using only the historical surface temperature record, the periodic temperature oscillations often associated with the Pacific Decadal Oscillation and Atlantic Multidecadal Oscillation were estimated and subtracted from the surface temperature data, leaving a linear warming trend identified as an anthropogenic signal. This estimated rate of warming was related to the fraction of a log CO_2 doubling from 1959 to 2013 to give an estimated transient sensitivity of 1.093 °C (0.96–1.23 °C 95% confidence limits) and equilibrium climate sensitivity of 1.99 °C (1.75–2.23 °C). It is argued that higher estimates derived from climate models are incorrect because they disagree with empirical estimates.

1. Introduction

Climate sensitivity is a measure of the net temperature response of the Earth to a change in radiative (primarily CO_2) forcing. It summarizes the end result of the complex processes of the Earth's dynamic atmosphere and oceans. It can only be calculated from first principles for a theoretical Earth. Many early estimates of sensitivity, defined in terms of response to a doubled forcing, were based on climate models. Sensitivity effectively summarizes what the models say in a single metric and is estimated as 3.0 °C (3.4 °C in AR5) (IPCC, 2007). However, the recent 16+ year halt in global warming, which is not predicted by the models, suggests that the models might have sensitivity set too high. Thus estimates of climate sensitivity that are not based on general circulation models (GCMs) would provide a check on model outputs.

Interestingly, estimates of sensitivity based on energy balance considerations and historical data (Aldrin et al., 2012; Annan and Hargreaves, 2011; Bengtsson and Schwartz, 2013; Hargreaves et al., 2012; Lewis, 2013; Masters, 2013; Michaels et al., 2002; Otto et al., 2013; Ring et al., 2012) consistently estimate equilibrium sensitivity near 2 °C per doubling. That is, they all give much lower sensitivity to a change in forcing than studies based on GCM response. These studies use various methods but generally depend on certain overlapping types of data, including estimates of solar forcing, greenhouse forcing, ocean heat content, historical temperature data, and Earth radiation balance estimates. Unfortunately, the assumption that solar forcing operates only via direct total solar irradiance (TSI) is unproven, and even estimates of TSI are uncertain (Scafetta, 2013). Likewise, the effects of clouds (at multiple levels, e.g., Chen et al., 2013), black carbon, and aerosols, both in terms of strength of forcing and historical data accuracy, are poorly known according to the IPCC (2007) and others (e.g., Scafetta, 2013), as are ocean heat content changes, making estimation of sensitivity uncertain. The net result, as Lindzen and Choi have shown, is that data only weakly constrain estimates of sensitivity. This lack of constraint yields the long upper tails of the sensitivity probability density functions (pdfs) (Lewis, 2013), which are made even longer through use of inappropriate statistical methods, according to Lewis (2013), as well as wide confidence intervals on the best estimate.

One of the factors that complicates attempts to compute climate sensitivity is that there appear to be complex natural fluctuations in Earth's climate (Lüdecke et al., 2013), whether internally or externally forced is unknown. While empirical sensitivity studies attempt to account for known forcings and energy balances, they are unable to fully account for internal climate oscillations or forcings whose mechanisms are not well-understood. An alternate approach is to statistically account for natural climate oscillations even if their cause cannot be determined. After subtracting these oscillations, the remaining signal should be the anthropogenic signal plus noise. This residual can then be used to estimate sensitivity. This is the approach used in this study.

2. Methods

The approach taken is based on Loehle and Scafetta (2011), who used a signal decomposition method to factor out natural

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climate fluctuations and estimate the anthropogenic temperature signal. This approach greatly reduces the problem of data uncertainty. Because it has recently become more likely that natural multi-decadal cycles due to solar activity and/or endogenous ocean current patterns have not been properly taken into account in GCMs (de Freitas and McLean, 2013; Fyfe et al., 2013), this attribution study estimated these cycles (60 and 20 years) and subtracted them from the temperature record to obtain a residual signal due to human activity. Loehle and Scafetta (2011) noted that an approximate 60 year cycle in climate can be identified in many geologic records spanning the past several hundred years or more and is roughly identifiable with the Pacific Decadal Oscillation (e.g., Agnihotri and Dutta, 2003; Black et al., 1999; Camuffo et al., 2010; Klyashtorin et al., 2009; MacDonald and Case, 2005; Mazzarella and Scafetta, 2012; Parker et al., 2007; Wiles et al., 2004). It is not necessary for the purpose of attribution that this cycle is a permanent feature of the Earth system, but only that it has been observed recently to be approximately regular, as documented in Loehle and Scafetta (2011). It was also documented in this earlier work that solar activity exhibits a variety of periodic behaviors, including 60- and 20-year cycles. Loehle and Scafetta (2011) used these two cycles as a hypothesis to detrend the historical temperature record in order to remove the decadal scale natural variations so that the human impact signal could be detected. Recent work (de Freitas and McLean, 2013) suggests a mechanism whereby these periodic signals might operate.

A three-component model was fit to the Hadley global land and ocean data for the period 1850–1950 (101 years) because IPCC has stated that human effects on climate are only evident (detectable) after 1950. The fit over the period was good (Fig. 1a). When the model was projected forward, the actual data post-1950 rise faster than the model, indicating that something is missing from the model. We assumed that this missing component is anthropogenic forcing. We fit a linear model to the post-1950 data minus model residuals. The linear anthropogenic signal starts in 1942 and rises $0.66 \pm 0.08\,^{\circ}$C/century (Fig. 1b). Note that not only is the overall

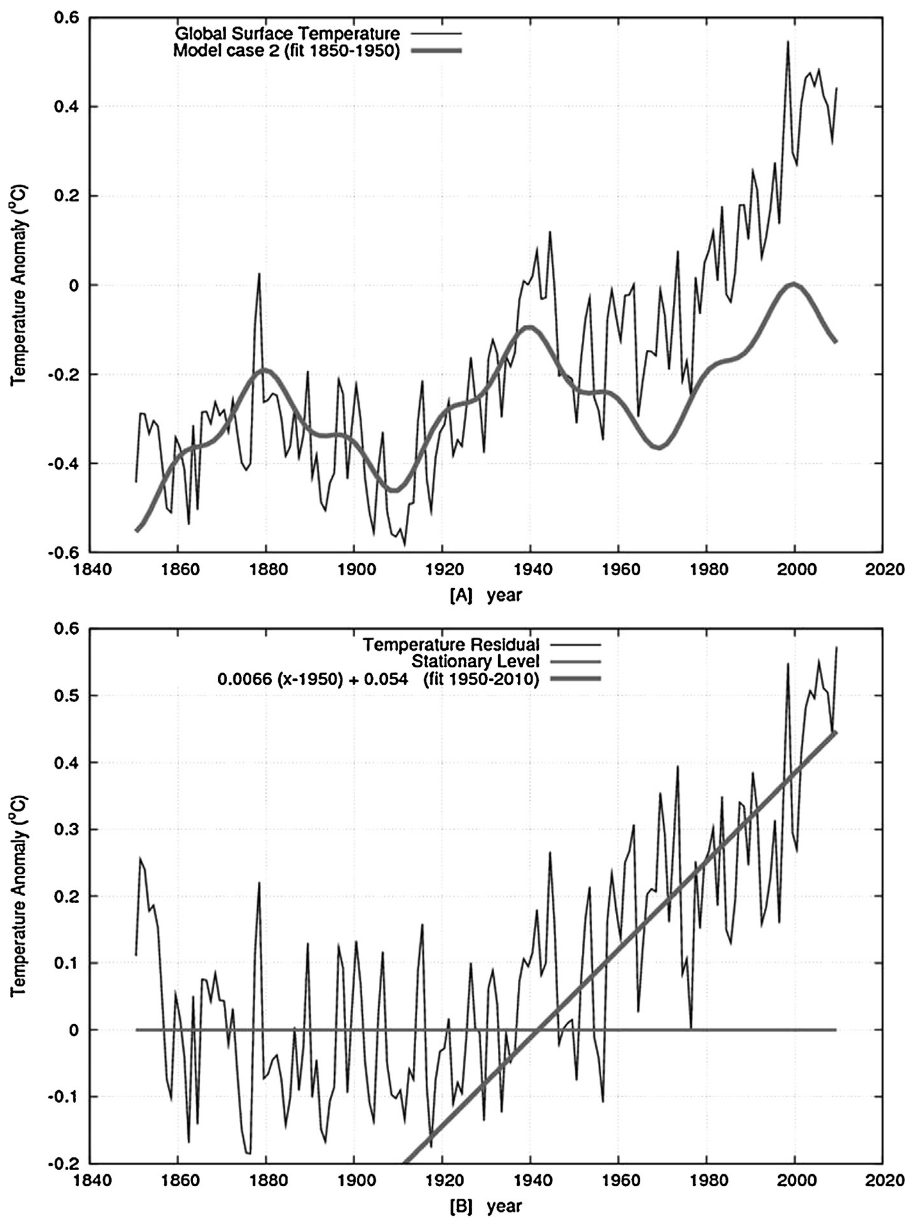

Fig. 1. (a) Model estimation process, based on natural modulation of climate (Loehle and Scafetta, 2011) fit using global temperature data only from 1850 to 1950 with extrapolation after 1950. (b) Residuals (data – model) showing unexplained warming after 1950 assumed to be due to human activity.