Ecological Modelling 297 (2015) 20–25

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

On a minimal model for estimating climate sensitivity

Gavin C. Cawley[a,*], Kevin Cowtan[b], Robert G. Way[c], Peter Jacobs[d], Ari Jokimäki[e]

[a] School of Computing Sciences, University of East Anglia, Norwich, UK
[b] Department of Chemistry, University of York, York, UK
[c] Department of Geography, University of Ottawa, Ottawa, Canada
[d] Department of Environmental Science and Policy, George Mason University, Fairfax, VA, USA
[e] Skeptical Science, Brisbane, Australia

ARTICLE INFO

Article history:
Received 8 July 2014
Accepted 13 October 2014
Available online 14 November 2014

Keywords:
Greenhouse effect
Forcing
CO_2
Climate change

ABSTRACT

In a recent issue of this journal, Loehle (2014) presents a "minimal model" for estimating climate sensitivity, identical to that previously published by Loehle and Scafetta (2011). The novelty in the more recent paper lies in the straightforward calculation of an estimate of transient climate response based on the model and an estimate of equilibrium climate sensitivity derived therefrom, via a flawed methodology. We demonstrate that the Loehle and Scafetta model systematically underestimates the transient climate response, due to a number of unsupportable assumptions regarding the climate system. Once the flaws in Loehle and Scafetta's model are addressed, the estimates of transient climate response and equilibrium climate sensitivity derived from the model are entirely consistent with those obtained from general circulation models, and indeed exclude the possibility of low climate sensitivity, directly contradicting the principal conclusion drawn by Loehle. Further, we present an even more parsimonious model for estimating climate sensitivity. Our model is based on observed changes in radiative forcings, and is therefore constrained by physics, unlike the Loehle model, which is little more than a curve-fitting exercise.

1. The model of Loehle and Scafetta (2011)

Loehle and Scafetta (2011) (hereafter LS11) model variations in the HadCRUT3-gl annual global mean surface temperature anomaly dataset using a model comprised of a linear trend, and two cyclic components with periodicities of 20 and 60 years,

$$f(t) = \theta_0 + \theta_1 t + \theta_2 \cos\left\{\frac{2\pi(t-\theta_3)}{20}\right\} + \theta_4 \cos\left\{\frac{2\pi(t-\theta_5)}{60}\right\}, \quad (1)$$

where t is time, measured in years, and $\boldsymbol{\theta} = (\theta_0, \ldots, \theta_5)$ is a vector of model parameters. The model is then fitted to the HadCRUT3-gl annual GMST anomalies over a calibration period spanning the years 1850–1950. The linear component of the model, described by θ_1, is intended to capture a supposed "long term warming since the "Little Ice Age". The cyclic components, with periods of 20 and 60 years, model observed cyclical variations in climate data, tentatively associated with variations in ocean circulation, namely the Pacific decadal oscillation (PDO) and with variation in solar activity. The magnitude and phase of these cyclical components, *but not their periodicities*, are tunable parameters of the model. The model is shown (in blue) in Fig. 1(a), along with the HadCRUT3v-gl annual temperature anomalies (depicted in green), the corresponding model residuals are shown in Fig. 1(b). The model provides a subjectively reasonable fit to the observations during the calibration period, however the model does not explain the more rapid rise in temperature after 1950, and so this is modelled with an additional linear component, starting in 1942 and rising at a rate of $0.66 \pm 0.08\,^\circ$C per century, that is assumed to represent the anthropogenic influence on climate, as shown in Fig. 1(b). Loehle (2014) (hereafter LO14), uses this model to obtain estimates of the transient climate response and equilibrium climate sensitivity. Unfortunately, the LS11 model and hence the resulting estimates are fundamentally flawed, for reasons explored in the subsequent sections of this brief note.

1.1. *Understatement of the uncertainty in the estimates of climate sensitivity*

LO14 gives a 95% confidence interval for the value of transient climate response of 0.96–1.23 °C per doubling of CO_2, however this was derived from the slope of the linear "anthropogenic" component of the model, of $0.66 \pm 0.08\,^\circ$C per century, taken from LS11. The 95% confidence interval for this parameter in our MATLAB implementation of the Loehle–Scafetta model, using the `regress`

* Corresponding author. Tel.: +44 1603 593258.
E-mail address: g.cawley@uea.ac.uk (G.C. Cawley).

http://dx.doi.org/10.1016/j.ecolmodel.2014.10.018
0304-3800/

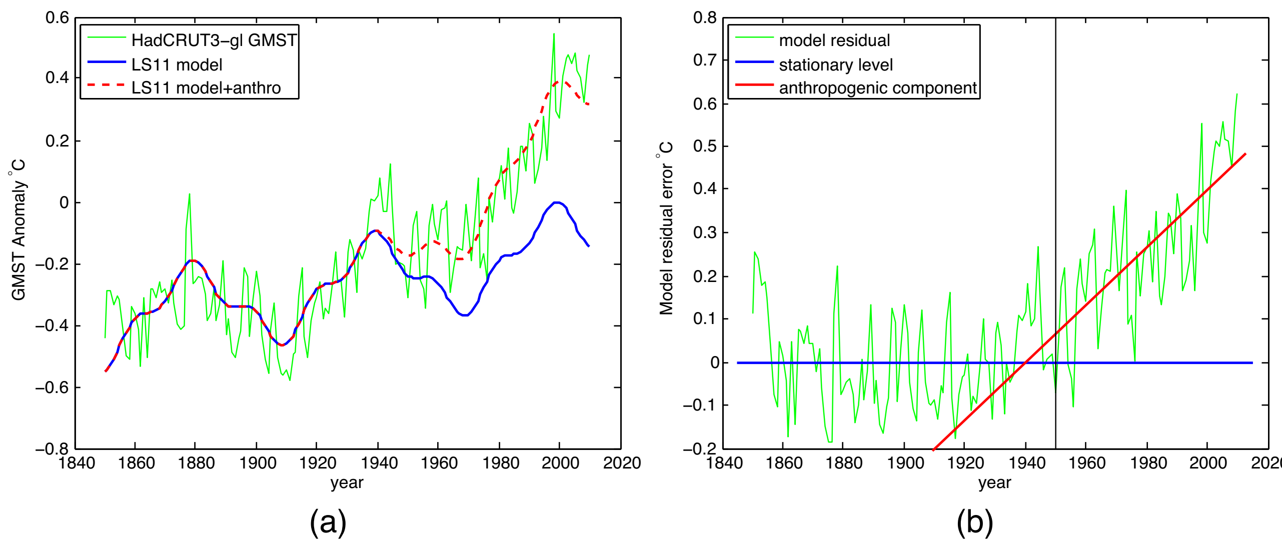

Fig. 1. LS11 model fitted to HadCRUT3v-gl GMST anomalies from 1850 to 1950 and projection to 2013 (a) and model residual errors (b). (For interpretation of the references to color in the text, the reader is referred to the web version of this article.)

routine of the statistics toolbox, is $0.664 \pm 0.165\,^{\circ}$C per century. The width of this interval is, to within the accuracy of rounding, twice that reported by LS11, so it seems likely that the interval reported in LS11 is a one standard deviation interval, rather than a 95% confidence interval. This (according to our MATLAB reimplementation) implies that the 95% confidence interval for the LO14 estimate of transient climate response should be $1.100 \pm 0.274\,^{\circ}$C for each doubling of atmospheric CO_2 (implying an equilibrium climate sensitivity of $2.000 \pm 0.498\,^{\circ}$C per doubling, using the method employed by LO14, see Section 2). More importantly, this interval represents only the uncertainty in inferring the slope of the linear "anthropogenic" component from the residuals of the cyclic model. In reality, there is also considerable uncertainty in inferring the other parameters of the model, $(\theta_1, \ldots, \theta_5)$ from the calibration period, which also substantially broaden the confidence interval of the estimate of transient climate response. A Bayesian analysis of the model of LS11, described in Appendix A, gives a highest posterior density (HPD) credible interval for the transient climate response of 0.753–1.434 °C per doubling of CO_2 with a corresponding estimate for equilibrium climate sensitivity of 1.369–2.607 °C per doubling (using the method employed by LO14). These intervals are considerably broader than the corresponding intervals given in LO14.

1.2. The existence of 60 and 20-year cyclic components is not well supported by the calibration period

Inspection of the residuals of the standard LS11 model, shown in Fig. 1(b), suggest that the model is clearly deficient as large-scale structure is evident in the residuals for the calibration period (1850–1950), with the residuals exhibiting a downward trend from 1850 to around 1890 and an increasing trend from then onward. An extended model, where the periodicities of the cyclic components were also tunable parameters, fitted to the calibration data, was also evaluated, where

$$f(t) = \theta_0 + \theta_1 t + \theta_2 \cos\left\{\frac{2\pi(t-\theta_3)}{\theta_4}\right\} + \theta_5 \cos\left\{\frac{2\pi(t-\theta_6)}{\theta_7}\right\}. \qquad (2)$$

The results for this model are shown in Fig. 2(a) and (b), instead of the periodicities of 20 and 60 years used in the standard LS11 model, the extended model gives optimised periodicities of 21.76 and 69.65 years. In addition to improving the subjective fit of the model to the calibration period, the extended model clearly addresses the deficiency identified in the standard LS11 model as the residuals, shown in Fig. 2(b), no longer exhibit any clear structure during the calibration period. The model, however, now gives substantially higher estimates of transient climate response and equilibrium climate sensitivity (respectively 1.191 ± 0.262 and $2.164 \pm 0.476\,^{\circ}$C per doubling of atmospheric CO_2).

A Bayesian analysis of the extended model, described in Appendix A, was then conducted to determine the plausible periodicities of cycles within the calibration period and to obtain a credible interval on the estimates of climate sensitivity that reflect the uncertainties due to the estimation of all of the tunable parameters of the model from a finite calibration period. The 95% HPD credible interval on the periodicity of the shorter cycle, θ_4, extends from 20.67 to 22.89 years, providing very little support for a periodicity as short as 20 years in the calibration period. The credible interval for the periodicity of the longer cycle, θ_7, extends from 63.44 to 79.32 years, thus we conclude that the existence of a 60 year cycle in the calibration period is implausible. This result demonstrates that the standard LS11 model is inappropriate for use in attribution as a key modelling assumption is clearly invalid. The 95% HPD credible intervals on transient climate response and equilibrium climate sensitivity are 0.800–2.000 and 1.454–3.635 respectively.

LO14 states that "*... the recent 17 year pause in warming was predicted based on data ending in 1950 (i.e. it performs a successful 60 year forecast)*". This claim is clearly incorrect as the modelling of the hiatus is entirely predicated on the existence of 20 and 60 year cycles, which were not based on data ending in 1950, but were chosen *"a-priori"*, and indeed, as we have shown, are effectively *ruled out* by the observations comprising the calibration period. If the periodicities are based on the observations up to 1950, the model no longer correctly predicts the 17 year pause in warming (see Fig. 2).

1.3. The extension of the linear component representing natural warming is not justified

LO14 states that *"The long term warming since the Little Ice Age is captured by the slow warming (linear) component, which we*