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Misdiagnosis of Earth climate sensitivity based on energy balance model results

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Abstract Monckton of Brenchley et al. (Sci Bull 60:122–135, 2015) (hereafter called M15) use a simple energy balance model to estimate climate response. They select parameters for this model based on semantic arguments, leading to different results from those obtained in physics-based studies. M15 did not validate their model against observations, but instead created synthetic test data based on subjective assumptions. We show that M15 systematically underestimate warming: since 1990, most years were warmer than their modelled upper limit. During 2000–2010, RMS error and bias are approximately 150 % and 350 % larger than for the CMIP5 median, using either the Berkeley Earth or Cowtan and Way surface temperature data. We show that this poor performance can be explained by a logical flaw in the parameter selection and that selected parameters contradict observational estimates. M15 also conclude that climate has a near-instantaneous response to forcing, implying no net energy imbalance for the Earth. This contributes to their low estimates of future warming and is falsified by Argo float measurements that show continued ocean heating and therefore a sustained energy imbalance. M15's estimates of climate response and future global warming are not consistent with measurements and so cannot be considered credible.

Keywords Climate sensitivity · Global warming · Climate change · Climate model · Climate feedback

1 Introduction

A recent paper, M15 [1], applies a simple energy balance model (EBM) in order to estimate climate response. Compared with other studies using a similar approach, M15 select parameters that lead to lower estimates of future global warming [2].

Many of M15's statements contradict the results of other research. We explain these contradictions in three steps: (1) M15 did not validate their model using direct observations, and we show that it performs poorly; (2) this poor performance is explained by M15 selecting parameters using a logically flawed semantic argument; and (3) M15's consideration of relevant studies is incomplete, and those studies that are considered are sometimes misinterpreted.

2 Model

The model in M15 is a form of the energy balance model (EBM) which has been used for almost 50 years [3]. Such

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models are not novel and have previously been used to estimate the transient climate response (TCR) and the equilibrium climate sensitivity (ECS) [4, 5]. M15 state that the anthropogenic temperature response $\Delta T_{t,a}$ at time t is given by

$$\Delta T_{t,a} = \frac{\Delta F_{t,a} \cdot r_t \cdot \lambda_\infty}{q_t}, \qquad (1)$$

where $\Delta F_{t,a}$ is the change in forcing due to a change in atmospheric CO_2, q_t is the fraction of the anthropogenic forcing due to CO_2, r_t is the transience fraction (i.e. the fraction of the equilibrium temperature change attained at time t), and λ_∞ is a climate sensitivity factor in K W^{-1} m^2.

Equation (1) is a form of a lumped-parameter model in which Earth's global temperature field is represented as a single value. This extreme simplification necessarily leaves out many physical processes and does not explicitly account for how parameters may change depending on the spatial pattern of warming or background state.

The M15 approach differs from the standard in that only anthropogenic components are considered. However as M15 implicitly assume that λ_∞ is independent of non-anthropogenic forcing, it follows that it is the same for total forcing, and if we assume sufficiently long timescales such that the average unforced contribution to temperature and radiative imbalance tends to zero, we have:

$$\Delta T_t = \Delta F_t \cdot r_t \cdot \lambda_\infty, \qquad (2)$$

where the temperature change ΔT_t responds to the total forcing ΔF_t. The standard approach of Eq. (2) is more useful than Eq. (1) because both ΔT_t and ΔF_t may be estimated from observations, and by combining these, the product $r_t \cdot \lambda_\infty$ may be inferred. A value of λ_∞ may therefore be estimated if the form of r_t is known. Due to Earth's thermal inertia and expected time variation in feedbacks, r_t is a time-dependent function which has been studied with a variety of models [6–14]. M15 claim to adopt values of r_t from the simple model of [6], which considered a step change in forcing. In reality, the history of radiative forcing is a more complex continuous function. This may be accounted for by a convolution of the forcing series with the temporal response function, although this requires clarity over assumptions regarding the state dependence of r_t and λ_∞, which is not discussed in M15.

3 Validation

Rather than compare model projections against observations, M15 develop synthetic data for 1990–2050, assuming that temperature changes will be between recent 17-year RSS and 63-year HadCRUT4 temperature trends. Both of these are likely to be underestimates. Statistical methods show that the 17-year RSS trend is strongly suppressed by recent El Niño variability [15] and by larger-scale, longer duration alterations in the Pacific Decadal Oscillation.

Meanwhile, the 63-year HadCRUT4 trend is in response to radiative forcing growth of approximately +0.027 W m^{-2} yr^{-1} rather than the +0.036 W m^{-2} yr^{-1} growth for 1990–2050 under transition to the RCP6.0 scenario adopted by M15 [16]. During the more analogous period 1970–2014 when forcing increased by +0.034 W m^{-2} yr^{-1}, observed temperature rise was $+0.17 \pm 0.03$ K $decade^{-1}$ [$\pm 2\sigma$, ARMA(1,1) noise assumed], significantly ($P < 0.002$) greater than the highest value assumed by M15.

Instead of using synthetic data, we use observations to assess the performance of both the M15 parameterization and the more complex models criticized in M15. We use the [4] forcing time series with the M15 parameter range for the M15 projection. The more complex models are sampled from the Coupled Model Intercomparison Project 5 (CMIP5), and we select the 5 %–95 % range of simulations available from KNMI [17], driven with RCP6.0 from 2006 and with continuous data for 1850–2100 ($N = 45$, although we note that results are similar when all KNMI runs are used). Finally, we also use Eq. (2) with the IPCC AR4 values from M15 Section 4.1, being $r_t = 0.50$ (assuming that $r_t \approx r_{100}$, as the majority of the forcing change took place over the past century) and λ_∞ falling on [0.59,1.25] K W^{-1} m^2 with a best estimate of $\lambda_\infty = 0.88$ K W^{-1} m^2.

Figure 1 shows the CMIP5 and M15 projection ranges in the upper panel, based on an 1850–1900 baseline and compared with HadCRUT4, Berkeley Earth (BEST) and Cowtan and Way (CW14) [18] global mean surface temperature (GMST) data. Observations fall within the CMIP5 range, but are mostly above the M15 projected maximum since 1990. The lower panel shows the substantial improvement in the M15 fit when AR4 values are used with the EBM instead.

If the M15 assumption of approximately constant r_t is used, then $r_t \cdot \lambda_\infty$ may be estimated by regressing ΔT_t onto ΔF_t. Using HadCRUT4, BEST and CW14 [18] temperature data with the forcing from [4], we obtain:

$$0.36 \le r_t \cdot \lambda_\infty \le 0.40. \qquad (3)$$

Although in reality r_t is not constant, $r_t \le 1$ always. It follows that λ_∞ must exceed 0.35 K W^{-1} m^2, and observations exclude the range assumed by M15, where $0.21 \le \lambda_\infty \le 0.35$ K W^{-1} m^2.

Performance is assessed for the periods 1900–2010, 1970–2010 and 2000–2010 using root-mean-square error (RMSE) and bias during each period. Results are reported in Table 1. Another forcing data set [16] results in substantially worse M15 model performance; RMSE is 7 %–