Review of the manuscript ”Propagation of Error and the Reliability of Global Air Temperature Projections” by Patrick Frank (Advances in Meteorology 3852317)

RECOMMENDATION: reject

In this manuscript, the author claims that errors of ±4 Wm^{-2} in the long-wave (LW) cloud radiative forcing (which are typical for current global climate models) imply an uncertainty of ±15 K in the simulated 21st century global mean temperature change. This claim is implausible and follows from a grave error in calculation.

To demonstrate his claim, the author uses a passive warming model (PWM) to emulate the behaviour of global climate models. The PWM itself is reasonable, but the way in which the author interprets its results is not.

1. The nature of the PWM

According to the PWM, the total warming due to well-mixed atmospheric greenhouse gases (GHG) relative to a hypothetical state in which these gases were absent is

$$\Delta T_t = 0.42 \times 33K \times \frac{F_0 + \sum_{i=1}^{t} \Delta F_i}{F_0} \qquad \text{(Eq. 6 in the manuscript)}$$

Here F_0 = is the year 1900 (i = 0) radiative forcing from well-mixed atmospheric GHGs (compared with negligible concentrations), and ΔF_i is the change in this forcing from year i-1 to i. Noting that

$$\sum_{i=1}^{t} \Delta F_i = (F_1 - F_0) + (F_2 - F_1) + \ldots + (F_{t-1} - F_{t-2}) + (F_t - F_{t-1}) = F_t - F_0 \qquad \text{(R1)}$$

and inserting the value F_0 = 33.30 Wm^{-2} quoted in the manuscript, one obtains the temperature change relative to a hypothetical GHG-free atmosphere as

$$\Delta T_t = 0.416 \times F_t \qquad \text{(R2)}$$

or the temperature change relative to the year 1900 as

$$\Delta T_t - \Delta T_0 = 0.416 \times (F_t - F_0) = 0.416 \times \Delta F \qquad \text{(R3)}$$

where $\Delta F = (F_t - F_0)$ is the change in radiative forcing (more commonly known just as radiative forcing) since the near-preindustrial baseline year 1900.

In essence, (R3) indicates that temperature depends linearly on radiative forcing. Global climate models give a similar result, although the coefficient of proportionality varies somewhat from model to model. This first-order linearity holds well for the hypothetical equilibrium warming resulting from a given stabilized radiative forcing, but it is also a good approximation for the transient temperature response under gradually increasing forcing as far the net heat flux to the ocean increases linearly with the global mean temperature change (e.g. Raper et al. 2002, Journal of Climate, 15, 124-130). Of course, the coefficient of proportionality is smaller in the transient case than in the equilibrium case.

2. Why the main argument of the paper fails

Suppose a climate model has a bias in its energy balance (e.g. due to an error in the long-wave cloud forcing as assumed in the paper). This energy balance bias (*B*) essentially acts like an additional forcing in (R3), leading to an error in the simulated warming:

$$ERR(\Delta T_t - \Delta T_0) = 0.416 \times ((F_t + B_t) - (F_0 + B_0)) = 0.416 \times (\Delta F + \Delta B) \quad \text{(R4)}$$

Thus, the error (or uncertainty) in the simulated warming only depends on the change ΔB n the bias between the beginning and the end of the simulation, not on the evolution in-between. For the coefficient 0.416 derived from the paper, a bias change $\Delta B = \pm 4$ Wm^{-2} would indicate an error of ±1.7 K in the simulated temperature change. This is substantial, but nowhere near the ±15 K claimed by the paper. For producing this magnitude of error in temperature change, ΔB should reach ±36 Wm^{-2} which is entirely implausible.

In deriving the ±15 K estimate, the author seemingly assumes that the uncertainty in the $\Delta F_{i:s}$ in equation (6) adds up quadratically from year to year (equation 8 in the manuscript). This would be correct if the $\Delta F_{i:s}$ were independent. However, as shown by (R1), they are not. Thus, their errors cancel out except for the difference between the last and the first time step.

Furthermore, in deriving his result, the author apparently assumes that climate models use a time step of one year (giving thus ~95 terms in the sum in Eq. (8), assuming that the calculation starts from the year 2005). However, in reality climate models typically have a time step of about 30 minutes. Therefore, if the author's reasoning was correct, the summation in Eq. (8) should actually be done with 30-minute time step. This would increase the number of terms in the sum of Eq. (8) by the factor 17520, amplifying the resulting uncertainty to broadly ±2000 K (or ±200 K already for the first year). This is clearly implausible, but so is ±15 K as well.

A secondary point, to be discussed below, is whether it is reasonable to assume that the model biases in LW cloud forcing actually change by $\Delta B = \pm 4$ Wm^{-2}.

3. Do present-day biases give a good estimate of the future change in bias?

The author additionally assumes that energy balance biases in present day climate give a good order-of-magnitude estimate of the absolute change in bias when climate changes (ΔB in Eq. (R4)). He is formally correct in arguing that this cannot be rigorously disproved as far as observations from the distant past and the future are unavailable.

Nevertheless, most climate scientists would find this assumption very unlikely at least for small and moderate changes in forcing. This is because, in most cases, the changes in climate parameters vary (in absolute terms) much less between different models than their baseline values. As an illustration, Fig. 1 below shows the global mean LW cloud forcing (the quantity used by the author) for 16 CMIP5 models for the baseline climate and near a transient quadrupling of CO_2. There is a large variation between the models in both cases, but the baseline values and the values under quadrupled CO_2 are strongly correlated. Thus, the intermodel standard deviation for the change (4 x CO_2 minus baseline) in the LW cloud forcing is only 0.9 Wm^{-2}, although the standard deviation of the baseline values is 3.3 Wm^{-2}.

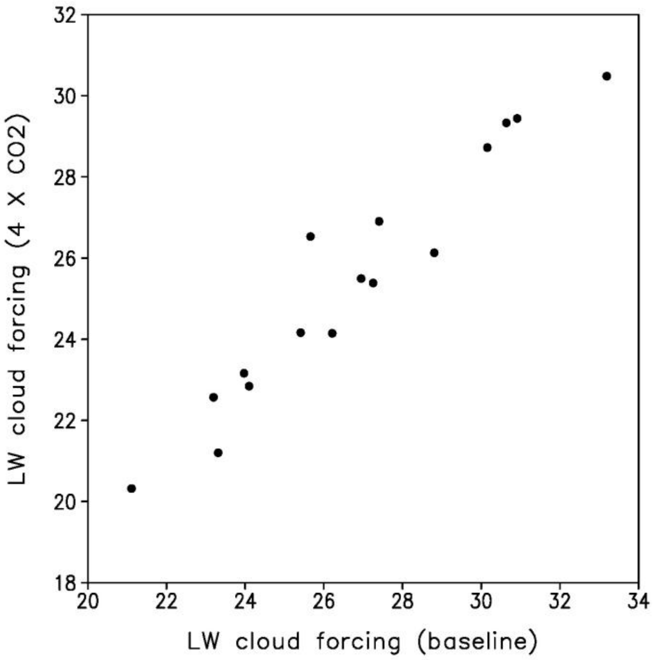

Figure 1. Global mean LW cloud forcing in 16 CMIP5 models in the baseline climate (horizontal axis) and just before the quadrupling of atmospheric CO_2 (years 131-140 in simulations in which CO_2 increases 1 % per year, vertical axis).

The quadrupling of CO_2 represents a very strong radiative forcing which is comparable with the highest RCP scenario, RCP8.5. As shown in Fig. 2, intermodel differences in the change of the LW cloud forcing are substantially smaller for smaller radiative forcing.

The author is formally correct in that these intermodel differences only quantify the precision of the model results, not their absolute accuracy. Nevertheless, Figs. 1 and 2 strongly suggest that the magnitude of present-day biases is not a meaningful measure for the uncertainty in the future change of the bias. This is most evident for the near term when the changes in radiative forcing remain relatively small.

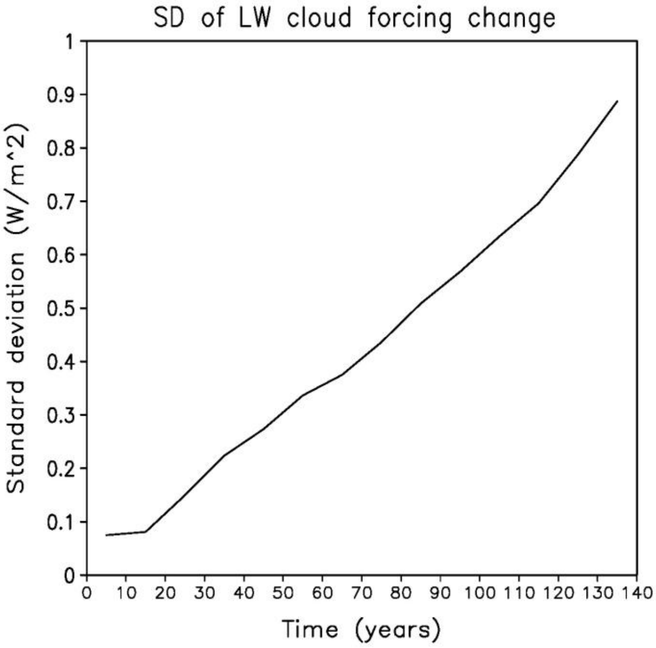

Figure 2. Intermodel standard deviation of the change in global mean LW cloud forcing in CMIP5 models, in experiments in which CO_2 is increased by 1 % per year until doubling in 140 years.