Patrick Frank 25 January 2015
Propagation of Error and the Reliability of Global Air Temperature Projections
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Author Response to Reviewer 1.

Summary

The reviewer:

- does not realize the PWM precedes the step-model of Good, et al. by five years (item 2).
- mistakenly supposes the published CMIP5 ±4 Wm^{-2} LCF theory bias error is an author assumption (item 3).
- finds a "fundamental flaw" where none actually exists (items 3, 6, and 7.1).
- misunderstands the meaning and impact of model mean theory-bias error (item 4).
- is unaware of the magnitude of CMIP5 cloud forcing error (items 4, 5, and 6.4).
- confuses a metrical uncertainty with a theory-bias error (items 5 and 6).
- applies an incorrect method of error reduction (items 6.1 and 6.2).
- misconstrues the impact of systematic error (item 6.3).
- makes object-free criticisms (item 7.2).
- finishes with a gratuitous supposition (item 7.3).

The reviewer is quoted in full in italics, followed by the author response.

Detailed Response:

1. *The author concludes that the uncertainty in projections from climate models is at least an order of magnitude larger than seen in standard climate models.*

   1. Because physical error had never been propagated through a climate model projection prior to the author's study, the author would conclude that there could be no standard of physical uncertainty for climate models.

      It should have been clear from paragraphs 2 and 3 of the Introduction, that model projection variance about a model mean provides no indication of physical uncertainty.

2. *Central to the analysis is the simple model defined in equation 6. This, I believe, is a variant of the step-response model of Good et al. (2011), which is not cited (it is hard to follow the derivation).*

2. The author first published the passive warming model (PWM) in 2008, three years prior to Good, et al. [Frank, P, 2008], which was referenced in the text. The 2008 study received international attention. Therefore, if precedence is to be assigned, the model of [Good, P *et al.*, 2011] is a variant of the PWM, but which was not cited.

   The reviewer will want to know that the 2008 study was thoroughly peer-reviewed; first by the scientists listed in the acknowledgements, then by two climate scientists recruited by the publisher, Mr. Michael Shermer. One of the latter reviewers later revealed himself to be Tapio Schneider of CalTech.

The PWM was first publicly discussed in 2006, in a post at Mr. Steven McIntyre's Climate Audit blog: http://climateaudit.org/2006/12/22/pat-frank-forcing-assumptions-in-gcms/.

3. *Using this model, the forcing error term of magnitude 4 Wm-2 is assumed. This is where the fundamental error of the paper lies.*

3. The ±4 Wm^{-2} cloud forcing error was not assumed. It was obtained from [Lauer, A and Hamilton, K, 2013], who evaluated the errors of CMIP3 and CMIP5 models. That value represents the mean annual longwave cloud forcing error for 26 CMIP5 GCMs, averaged across 20 years of climate hindcast. The ±4 Wm^{-2} is a published thoroughly established error metric.

   If assuming this metric is the "fundamental error" within the analysis, then there is no fundamental error.

4. *Although there may be a model spread in estimates of the mean radiative balance of the atmosphere, this is irrelevant when estimating the incremental (year-to-year) potential error in forcing. This will be much less.*

4. The reviewer is recommended to [Lauer, A and Hamilton, K, 2013]. From p. 3833:

   "*The rmse of the multimodel mean for SCF [short wave cloud forcing] is 8 $W m^{-2}$ in both CMIP3 and CMIP5. ... For CMIP5, the correlation of the multimodel mean LCF [long wave cloud forcing] is 0.93 (rmse = 4 $W m^{-2}$) and ranges between 0.70 and 0.92 (rmse = 4–11 $W m^{-2}$) for the individual models.*

   Thus, the magnitude of the mean annual CMIP5 longwave cloud forcing error is ±4 Wm^{-2} as presented in the manuscript.

   Cloud forcing is calculated at every stage of a climate projection. A theory-bias error in cloud forcing will negatively impact the accuracy of every stage of a climate projection. The growth of uncertainty in a step-wise futures prediction becomes thereby unavoidable.

Lauer and Hamilton go on:

> *In both CMIP3 and CMIP5, the large intermodal spread and biases in CA [cloud amount] and LWP [liquid water path] contrast strikingly with a much smaller spread and better agreement of global average SCF and LCF with observations. The SCF and LCF directly affect the global mean radiative balance of the earth, so it is reasonable to suppose that modelers have focused on ‘‘tuning’’ their results to reproduce aspects of SCF and LCF as the global energy balance is of crucial importance for long climate*

integrations."

This interesting comment implies that CMIP5 longwave cloud forcing error, of interest here, may be unrealistically minimized by tuning.

5. *Based on IPCC AR5 Chapter 12 fig 12.4, the total error in forcing at the end of the 20th century is of the order of +/- 1 Wm^{-2}.*

5. Figure 12.4 in AR5 WG1 Chapter 12, "*Global mean radiative forcing (RF, W m^{-2}) between 1980 and 2100 estimated by alternative methods,*" shows the, "*1-σ range (68% confidence interval) of anthropogenic composition forcing...*," which is about ±1 Wm^{-2}.

The uncertainty in anthropogenic forcing, a metrical uncertainty, is not the same thing at all as a theory-bias error. The CMIP5 longwave cloud forcing error reflects an imperfect theory, and is relative to observations. Cloud forcing error is a product of GCM theory-bias. Theory-bias error arises independently of uncertainties in the radiative forcing of GHGs.

The reviewer is not comparing apples and oranges here, but rather apples and aardvarks.

6. *Assuming year-to-year errors to be uncorrelated in time, a simple calculation, dividing this number by 100 (years), yields a year-to-year error of +/- 0.01 Wm^{-2}. This would lead to an uncertainty in projected temperature that is much less than is claimed here and much closer to that seen in the CMIP5 models. Even if this calculation is over simplified, it is hard to see how a year-to-year error in radiative forcing could be anything like 4 Wm^{-2}.*

6.1 The ±4 Wm^{-2} mean annual LCF error reported by [Lauer, A and Hamilton, K, 2013] was obtained by averaging the error of 26 individual models across 20 years of hindcast, amounting to 520 model years.

Using the reviewer's calculational method and uncertainty, are we to suppose that individual models make 520×±1 Wm^{-2} = 520 Wm^{-2} annual error?

Apart from the mistake concerning magnitude, the reviewer's method of error reduction is incorrect. Please see item 6.2

6.2 Accepting the reviewer's assumption of uncorrelated annual ±1 Wm^{-2} errors, the reduction across 100 years would go as 1/sqrt(N), yielding a 10-fold reduction to ±0.1 Wm^{-2}, not ±0.01 Wm^{-2}.[Bevington, PR and Robinson, DK, 2003; ISO/IEC, 2008]

However, because the reviewer's choice of errors is incorrect (the correct choice is ±4 Wm^{-2} of LCF theory-bias error, not ±1 Wm^{-2} of uncertainty in GHG forcing) and as the reviewer's assumption of uncorrelated error is also incorrect, the corrected ±0.1 Wm^{-2} annual error has no bearing on the manuscript analysis.

6.3 The reviewer's assumption of uncorrelated annual error is incorrect because the LCF error is both multi-model and multi-year. This means the mean error has survived 520 model years of simulation. Any uncorrelated random error would have been reduced by 1/sqrt(520) = 1/22.8. That makes the remaining ±4 Wm^{-2} annual mean LCF error almost certainly systematic.

The systematic structure of CMIP5 LCF error is further demonstrated by the high correlation across independent CMIP5 TCF error residuals. Systematic error does not reduce by 1/sqrt(N). Instead, it accumulates across a calculation as the root-sum-square, i.e., $\pm\sigma_{sys} = \sqrt{\sum_{i=1}^{n}(\varepsilon_{sys})_n^2}$, where "sys" is systematic, ε_{sys} is the mean systematic error per simulation annual step, and n is the number of simulation years. See manuscript page 21, line 13ff, and especially Section 2.4.2 and Section 3, p. 28.

6.4 Finally, the reviewer is invited to look through AR5 Chapter 9, Section 9.4.1.2, where the average CMIP5 bias in short wave cloud radiative effect (CRE) is reported as 2±6 Wm^{-2} and the average CMIP5 longwave CRE bias is 6±9 Wm^{-2}.

The reviewer may also wish to contemplate AR5 Chapter 9, Figure 9.5d-f, and note the large multi-Wm^{-2} errors in CRE made by individual models.

The ±4 Wm^{-2} longwave cloud forcing error reported by [Lauer, A and Hamilton, K, 2013] is completely consistent with the IPCC error magnitudes.

The reviewer's assumption of a ±1 Wm^{-2} LCF error is unrealistic in light of the reported error magnitudes.

7. *In addition to this fundamental flaw, the paper is very poorly written, contains sections that seem irrelevant to the main conclusions and does not adopt the standard approach of working with anomalies. There may well be further fundamental flaws in the irrelevant sections.*

7.1 In light of items 3 and 6, the reviewer's conclusion of a "fundamental flaw" is incorrect and without foundation.

7.2 The reviewer gives no examples of poor writing style, not even a page or line number, does not mention which section might be irrelevant, and does not describe any standard of approach to anomalies that might have been violated.

The anomalies in Figure 2 are from [Covey, C *et al.*, 2001]. Figure 3 presents anomalies in the standard way (simulation minus the observational mean), Figure 5 is directly from the IPCC AR4 and Figure 6 is from [Hansen, J *et al.*, 1988]. Thus it is difficult to understand the reviewer's difficulties.

7.3 The reviewer's final sentence is gratuitous.

References:

Bevington PR, and Robinson, DK. 2003. *Data Reduction and Error Analysis for the Physical Sciences*, 3rd edn. McGraw-Hill: Boston.

Covey C*, et al.* 2001. Intercomparison of Present and Future Climates Simulated by Coupled Ocean-Atmosphere GCMs PCMDI Report No. 66 Lawrence Livermore National Laboratory. http://www-pcmdi.llnl.gov/publications/pdf/report66/ (last accessed 24 January 2015)

Frank P. 2008. A Climate of Belief. *Skeptic* **14**(1): 22-30.

Good P*, et al.* 2011. A step-response simple climate model to reconstruct and interpret AOGCM projections. *Geophysical Research Letters* **38**(1): L01703, doi:10.1029/2010GL045208.

Hansen J*, et al.* 1988. Global Climate Changes as Forecast by Goddard Institute for Space Studies Three ‐ Dimensional Model. *J. Geophys. Res.* **93**(D8): 9341-9364.

ISO/IEC. 2008. Guide 99-12:2007 International Vocabulary of Metrology - Basic and general concepts and associated terms (VIM)Rep., International Organization for Standardization, Geneva.

Lauer A, and Hamilton, K. 2013. Simulating Clouds with Global Climate Models: A Comparison of CMIP5 Results with CMIP3 and Satellite Data. *J. Climate* **26**(11): 3823-3845, doi:10.1175/jcli-d-12-00451.1.