Appraising Marvel et al.: Implications of forcing efficacies for climate sensitivity estimates

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Summary

Different agents may have effects on global temperature (GMST) different to those which would be expected simply by reference to the radiative forcing they exert. This difference is encapsulated in the term "forcing efficacy". In their recent paper, Marvel et al. estimate efficacies for various forcings from climate simulations of the GISS-E2-model over the period from 1850 to 2005 (the historical period). They then use data pertaining to three recent observational climate sensitivity studies, incorporating the efficacy figures and calculating new estimates for the transient climate response (TCR) and effective climate sensitivity (a proxy for equilibrium climate sensitivity: both are designated ECS). Taking the average for the three studies, these new estimates imply an increase in TCR from 1.3°C to 1.8°C and in ECS from 1.9°C to 3.0°C. The increases are due to the efficacy-adjusted sum of forcings over the historical period being substantially less than the unadjusted sum of forcings.

Marvel et al. conclude that "GISS ModelE2 is more sensitive to CO_2 alone than it is to the sum of the forcings that were important over the past century" and that "Climate sensitivities estimated from recent observations will therefore be biased low in comparison with CO_2-only simulations owing to an accident of history: when the efficacies of the forcings in the recent historical record are properly taken into account, estimates of TCR and ECS must be revised upwards." The second statement would not be scientifically valid even if Marvel et al.'s findings were correct. Results from any single-model model study reflect the characteristics of the particular model involved, which may well behave differently from the real climate system – and from other models. Moreover, due to multiple methodological, data and computational errors and deficiencies in their study, Marvel et al. fail to establish that their first assertion is true either. When these problems are corrected, GISS ModelE2 does not appear to be materially, if at all, more sensitive to CO_2 alone than it is to the sum of the forcings acting over the historical period.

Marvel et al.'s revised observationally-based TCR and ECS figures substantially exceed the GISS-E2-R model's TCR of 1.4°C and effective climate sensitivity of 1.9–2.0°C.[1] However, GISS-E2-R already exhibits warming that is greater than in the real climate system: the simulated GMST increase and ocean heat uptake rate are both higher than observations at the end of the historical period, which implies that its TCR and effective climate sensitivity are probably excessive. That their new estimates of TCR and ECS are higher still is therefore paradoxical and suggests that there is something seriously wrong with their work.

The transient efficacy estimates in the paper disagree with estimates from more detailed work by James Hansen using the earlier GISS Model E, and with other work using different models. The equilibrium efficacy estimates use the same GISS-E2-R forcing data as do the transient estimates, and are therefore also very questionable. Moreover, Marvel et al.'s use of ocean heat uptake values rather than radiative imbalance data, which is what should have been used, biases down its estimates of equilibrium efficacies and of ECS.

[1] The ECS estimate also substantially exceeds the GISS-E2-R model's *equilibrium* climate sensitivity figure of 2.3°C.

Marvel et al. estimate forcing efficacies from simulations in which the climate is forced by just a single forcing at a time. Efficacies that are derived in this way may be different to those that apply when all forcings are applied simultaneously in the same model. The forcing produced by a forcing agent may vary substantially with climate state. Previous studies show that to be the case in GISS-E2-R for both aerosol and ozone forcing. Moreover, efficacies estimated from a climate simulation may be substantially different to those that apply in the real climate system.

The efficacy estimates Marvel et al. made using instantaneous radiative forcing (iRF) are largely irrelevant, since few if any observational studies use that measure of forcing. IPCC AR5 does not provide estimates of iRF either, preferring the effective radiative forcing (ERF) measure. Moreover, Marvel et al.'s iRF efficacy estimates use a regression model under which a zero forcing may, unphysically, have a materially non-zero effect on temperature. In some cases, requiring zero forcing to have no effect on GMST radically changes the estimated efficacies.

The efficacy estimates scale with the forcing arising from a doubling of CO_2 concentration (F_{2xCO2}). Marvel et al. use the RF value of F_{2xCO2}, 4.1 W/m^2, as its iRF value and hence in calculating iRF efficacies, and they imply that they use the same value for the ERF F_{2xCO2} and for ERF efficacies. No value appears to have been published for either iRF or ERF F_{2xCO2} in GISS-E2. In GISS-E, iRF F_{2xCO2} was 10% higher than the RF F_{2xCO2} value. Were the same true in GISS-E2, all the iRF efficacy, TCR and ECS estimates calculated from Marvel et al.'s data would need to be increased pro rata. Likewise, there are grounds for thinking that the true ERF F_{2xCO2} value is ~10% higher than the one they used. Without accurately established iRF and ERF values for F_{2xCO2}, efficacy estimates can have little credibility.

On the basis of the indicated ERF F_{2xCO2} of 4.1 W/m^2, all ERF efficacy estimates given in the Marvel et al. paper disagree with those I calculate using their data. Moreover, the climate sensitivity (TCR and ECS) estimates that they give using ERF appear to be inconsistent with both their data and their ERF efficacy estimates.

Using better justified estimation methods, and the GISS-E2-R effective rather than equilibrium climate sensitivity, the Historical iRF and ERF data are both found to produce efficacies within 10% or so of unity, both when using Marvel et al.'s estimates of the forcing from a doubling of CO_2 and with them adjusted up by 10%. This indicates no material bias in climate sensitivity estimation as a result of forcings that were important over the last 100–150 years having differing efficacies from CO_2.

Marvel et al.'s calculations of TCR and ECS estimates for the three observational studies cited contain multiple errors. They are also conceptually wrong in the case of Otto et al. 2013, since the underlying forcing estimates used in that study already reflect efficacies.

The methodological deficiencies in and multiple errors made by Marvel et al., the disagreements of some of its forcing estimates with those given elsewhere for the same model, and the conflicts between the Marvel et al. findings and those by others – most notably by James Hansen using the previous GISS model, mean that its conclusions have no credibility.

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