MAGICC uses differential land–ocean and North–South hemisphere forcings and incorporates different land and ocean feedback factors[6,7]. Thus, while Shindell has quantified this effect for some Coupled Model Intercomparison Project Phase 5 (CMIP5) models, knowledge of the effect *per se* is not new and it has always been accounted for in MAGICC.

The differential temperature response between the Northern and Southern hemispheres (TNH/TSH) is about 1.5 (median at CO_2 doubling) across all CMIP5 models for a 1% yr^{-1} CO_2 increase experiment (similar to the value reported by Shindell for a CMIP5 subset). The currently released versions of MAGICC (5.3 and 6), which are calibrated to an older generation of climate models, have a slightly smaller central response ratio of 1.3. MAGICC can easily be calibrated to emulate the newer atmosphere–ocean global circulation model results. Both MAGICC and the CMIP5 ensemble show a wide range of TNH/TSH.

As aerosol forcing is greater over land than ocean, MAGICC versions show a faster climate response to aerosol forcing than to greenhouse-gas forcing. MAGICC, therefore, also reproduces the higher hemispheric asymmetry due to aerosol forcing. An ensemble aerosol + ozone-only forcing experiment with MAGICC 6 (as in ref. 7) yields a mean TNH/TSH of 1.9 in 2000 (median 1.6), similar to the value (2.1) in Shindell's Fig. 2. If recalibrated to match the larger greenhouse-gas-only hemispheric asymmetry from the CMIP5 models, the aerosol response asymmetry in MAGICC will likely increase.

Explicit examination of the temporal evolution of the climate response to different types of aerosol forcing (for example, sulphate versus black carbon, direct versus indirect), preferably using single-forcing experiments, would be helpful both to characterize differences in this respect among Earth-system models, and to provide information that could inform improved parameterizations of simple models.

Shindell concludes that failing to account for spatially variable forcing will lead to ECS estimates that are biased low. This is a timely finding, as several recent studies inferred rather low ECS values from observations through the use of simple models that may be biased by not accounting for spatial variations in forcing and climate response. We wish to clarify that this bias is not present in models such as MAGICC. ❐

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Reply to 'Questions of bias in climate models'

Shindell reply — I appreciate that Smith *et al.*[1] support the primary conclusion of my paper[2] that accounting for the geographic distribution of radiative forcing is important in determining the climate response. They describe how the reduced-form model MAGICC represents the response to spatially inhomogeneous forcing via four boxes, one for land and one for ocean in each hemisphere, and I appreciate that clarification. My statement that there will be biases in simple models that do not account for the forcing distribution should have said that there will be biases in simple models that do not adequately account for the forcing distribution.

Smith *et al.*[1] report that the current versions of MAGICC underestimate the hemispheric asymmetry of the temperature response to well-mixed greenhouse gases by ~40% relative to the CMIP5 models. Although MAGICC can be recalibrated, this supports the conclusion that the highly simplified representation of forcing and response distributions in MAGICC contributes to the differences with respect to a CMIP5-generation model seen in a previous analysis of the response to predominantly Northern Hemisphere aerosol forcing, as discussed in my paper[2].

Smith *et al.*[1] also report that MAGICC captures the hemispheric asymmetry of the temperature response to inhomogeneous (predominantly aerosol) forcing seen in the CMIP5 models reasonably well. This agreement appears coincidental, however, as Smith *et al.*[1] state that their highly asymmetric response is driven by aerosol forcing being greater over land than ocean, whereas in the CMIP5 models I analysed, the historical aerosol + ozone forcing is actually greater over the oceans than land. The land responds more strongly in the CMIP5 models despite this, not only because of its inherently faster response time, but also because localized forcing influences climate well beyond the location of the forcing itself, especially in the zonal direction[3]. This process is absent in MAGICC. More generally, I presented the hemispheric temperature responses simply as an example to support my claim that the different response to inhomogeneous forcing relative to homogeneous forcing was largely due to the spatial pattern rather than differences in the effectiveness of those forcing agents, and not to imply that the Northern and Southern hemisphere responses told the whole story. In fact, my study[2] showed an even stronger response in the Northern Hemisphere extratropics than in the Northern Hemisphere as a whole, leading to an even larger asymmetry between the Northern and Southern hemisphere extratropics. This is consistent with the Northern Hemisphere extratropics having the greatest land fraction and fractional area in which powerful snow and ice albedo feedbacks operate, and is in agreement with previous results from multiple models[4–6]. Hence, climate sensitivity is not simply a function of the average Northern and Southern hemisphere forcing.

The CMIP5 models use thousands of boxes in the horizontal and do well at capturing the heterogeneity of the climate system. Although a four-box model might be calibrated to match the CMIP5 models' global mean response to aerosol forcing for certain particular cases, assessments of its skill in capturing the climate response to complex temporally and spatially evolving inhomogeneous forcings (for example, recent shifts in aerosols from more northerly developed to more equatorial developing nations) are surely required. Thus, the conclusions of my paper hold firm, namely that the geographic distribution of radiative forcing plays an important role in determining the transient climate response, and that calculations with simple models and those inferring transient climate response from historical surface temperature observations need to adequately account for this. ❐

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COMMENTARY:

Breaking the climate change communication deadlock

Adam Corner and Christopher Groves

Climate change communication is trapped between the norms that govern scientific practice and the need to engage the public. Overcoming this tension requires new societal institutions where the science and politics of climate change can co-exist.

Over more than two decades, a substantial body of social science research has generated a range of well-supported findings with clear, practical implications for public engagement on climate change[1]. It is now well understood that effective climate change communication involves more than simply presenting the facts of climate science in a clearer or more concise way. The idea that members of the public suffer from a 'deficit' of knowledge (which science outreach campaigns can address) is insufficient to explain the gap between the social and the scientific consensus on climate change that appears to have emerged over the past 10 years — particularly in the United States, the United Kingdom and Australia, despite extensive programmes of outreach and engagement in these countries[2]. Although the reasons for public scepticism about climate change are complex and multi-faceted[3], a consistent finding is that deeply held values and views about the organization of society and political ideology[4] are primary determinants. Strikingly, improved scientific literacy in an audience can actually amplify polarization between ideologically opposed groups[5], rather than lead to consensus between them.

In response to this increasingly troubling contrast between the urgency of the message conveyed by scientists and the lack of a political and public response proportionate to the scale of the climate change challenge, there have been multiple calls for climate science to put its communicative house in order. Scientists have been advised to develop simple, repetitive messages that can be honed for public consumption[6], to 'stand up for their science' and 'set the record straight'[7], to speak truth to power[8] and to get arrested if necessary[9]. But for the most part, the recommendations and rousing calls to arms have not translated into changed communicative practices or elevated levels of public engagement. We argue here that a 'deadlock' prevails because of a fundamental tension between the norms of scientific practice and those that govern the social

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