

communities directly or indirectly respond to increased temperatures by attacking their neighbours, competitors or the state, deterministic studies neglect the complex political calculus of governance, the agency of communities, and the multiple ways that people actually cope with challenging environmental conditions.

The present direction of the climate–conflict debate resembles that which emerged to explain high famine rates across Africa in the 1970s and 1980s. At that time, famine scholars asserted that these events were simply natural disasters, caused by a confluence of poor weather and bad land stewardship. The evidence seemed to be a simple and strong correlation between stressed environments and the practices of the poor. Yet, when scholars considered the contexts of famine occurrence, they identified interactions between natural triggers and political strategies and conditions, including poor governance, autocracy, ongoing conflict and widespread poverty⁹. These interactions offer more insightful perspectives on famine incidence.

Perhaps most troubling is the tendency in environmental security studies to presume that individuals and communities cannot (or choose not to) engage in positive coping behaviour to attenuate climate risks. On the ground in developing countries, climate change and ecological stress is treated as a problem to be solved, not a harbinger of apocalyptic violence as it is viewed by many analysts. Indeed,

during periods of hardship, higher levels of cooperation are found between erstwhile competitors. During disasters and periods of ecological stress, cooperation and aid, not violence, is the dominant response. Yet cooperation is far less likely to make headline news. Alternative livelihoods, migration, and changing agricultural patterns are all examples of how individuals and communities adapt to new and volatile circumstances. Anthropologists and human ecologists have documented these across continents in the scholarly literature for decades^{10–14}. Studies that assume maladaptive conflict responses to climate stress and conflate types of conflict and scales of analysis cannot capture the realities of the contemporary developing world.

In terms of predicting and interpreting future insecurity in developing states, it is probably more critical to understand ‘the nature of the state’ than the ‘state of nature’. There is a range of likely conflict causes in poor and weakly governed states, and variable rates of violence correspond more closely to strategic explanations than they do to physical neo-Malthusian explanations such as resource scarcity, biological claims about anger and aggression, or demographic stresses. People in poor countries do not respond to bad weather by attacking each other. Misconstruing the true nature and correlates of violence across developing states can lead to inferior policy suggestions and frame climate change as a military/security issue rather than a needs-based question¹⁵. □

Clionadh Raleigh is in the Department of Geography, School of Global Studies, University of Sussex, Falmer, Sussex BN1 9RH, UK. Andrew Linke and John O’Loughlin are in the Department of Geography, University of Colorado, Boulder, Colorado 80309–0260, USA.*

*e-mail: C.Raleigh@sussex.ac.uk

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COMMENTARY:

Making the most of climate impacts ensembles

Andy Challinor, Pierre Martre, Senthold Asseng, Philip Thornton and Frank Ewert

Increasing use of regionally and globally oriented impacts studies, coordinated across international modelling groups, promises to bring about a new era in climate impacts research. Coordinated cycles of model improvement and projection are needed to make the most of this potential.

Climate impacts ensembles, usually comprising multiple impact models, are a promising tool for projecting future crop productivity¹ and increasing coordination between international modelling groups, evident in model intercomparison programmes (MIPs),

is producing high-profile multi-model studies². An increasing number of these studies are global in extent, whereas model accuracy and data quality are often better at local to regional scales. Here, we explore the implications of this trend for the design and coordination of future

studies. We develop recommendations based on the assertion that a single-model intercomparison study, if it is to avoid being unwieldy, can focus on either projecting impacts, or on model evaluation and model intercomparison, but not both. Further, we assess the suitability of global

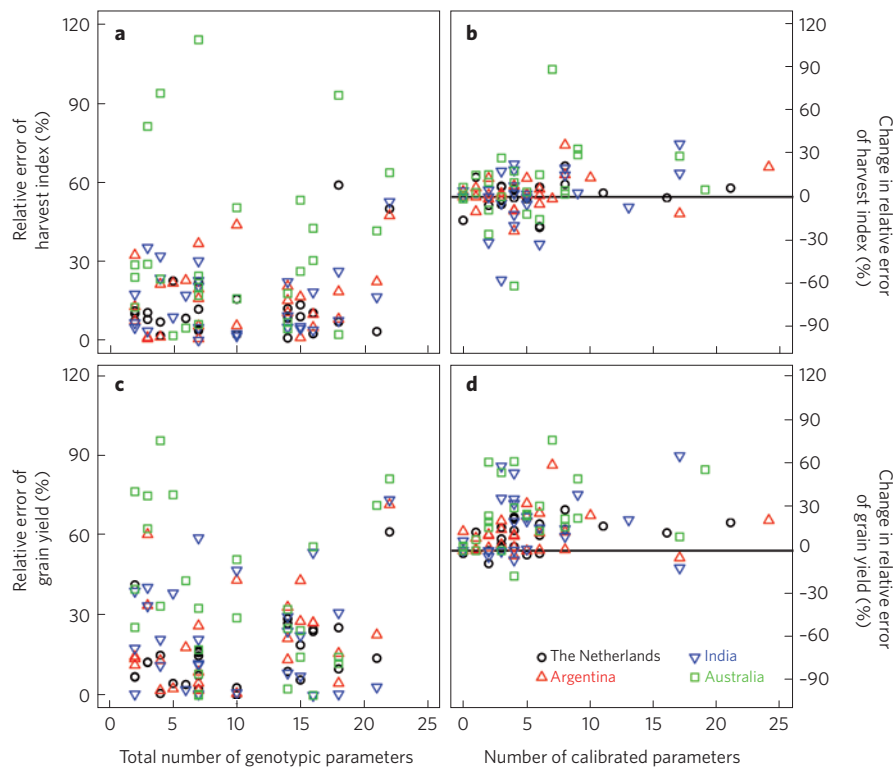


Figure 1 | Relationship between models' relative errors and the number of genotypic and calibrated parameters for 27 wheat crop simulation models in The Netherlands, Argentina, India and Australia. Left panels: Relative error of harvest index and grain yield, versus the total number of genotypic parameters. Also shown, in the right-hand panels, are the respective changes in relative error, due to model calibration versus the number of calibrated parameters. The experiments and the simulation protocols were developed by AgMIP and are described in ref. 2.

versus regional studies for achieving each of these aims. Although our analysis is presented for agriculture, it applies to a range of climate impacts. We define global studies as those with full global coverage, and regional studies as those with limited geographic extent, such as a country or province. We also include in the latter the modelling of specific fields (that is, local studies), because the ultimate aim of local-scale studies is often to draw conclusions for the region. The models used for the different studies may be the same, although in practice they often differ in complexity.

The value of multi-model impacts assessments in quantifying uncertainty is increasingly well documented³. However, we cannot simply take our cue from the larger body of work on climate ensembles, because impacts ensembles are different: they involve calibration towards a small subset of variables that may depend on the output variable of interest (for example, crop yield), as opposed to seeking to reproduce a broad set of properties of a closed system. For example, crop models are usually used primarily to simulate yield, which is only one of the many

aspects of crop growth and development. Climate models, in contrast, are assessed on their representation of rainfall, temperature, wind (jet streams, monsoon circulations), ocean properties and a host of other physical properties. Assessment of multiple properties of impact models is less advanced. This is not least due to differences in model structure constraining the identification of comparable properties, and difficulties in obtaining adequate data, particularly at regional scales. Although these problems are not insurmountable, the relative lack of progress means that crop models are prone to often unknown compensation of errors, making on-going assessment of causal relationships in our impacts models particularly important. The same issue arises in other impacts models, for example modelling hydrology⁴ and tree distribution⁵. Unpicking this compensation of errors is intractable in practice, because it involves separating calibration from tuning, and we do not often have the data to do this adequately. Thus a model can never be truly 'validated' for future use, only continually evaluated in the light of the most recent data. Thankfully, model

evaluation is becoming increasingly coordinated amongst model groups, and increasingly sophisticated. Progress has been facilitated by greater international coordination, for example, through the Agricultural Model Intercomparison and Improvement Project (AgMIP)⁶.

The issue of compensation of errors is illustrated by a recent inter-comparison of 27 wheat simulation models, where parameter calibration led to a greater improvement in yield error than for any other variables, including leaf-area index, harvest index and cumulative evapotranspiration². Figure 1 presents further evaluation of the calibration procedure conducted for that study. There is no clear relationship between the total number of genotypic parameters — which can be taken as a proxy of model complexity — and the relative error of either harvest index or grain yield (Fig. 1a,c). This result suggests that the models have more degrees of freedom than can be constrained by experimental data. Subsequent calibration of the models using experimental data led to significant reduction of model error, although this improvement (y axis Fig. 1b,d) was generally greater for yield than for harvest index, suggesting some compensation of errors. However, there was no relationship between the number of calibrated parameters and the reduction of model error (Fig. 1b,d); that is, no evidence of model over-tuning. Detailed comparisons of a range of model variables are needed if we are to determine the nature of the compensation of errors — that is, the extent to which the models are getting the right answer for what is, in part at least, the wrong reason. Multi-variable impacts studies could facilitate assessments of crop sustainability (through, for example, nitrogen and water use) and crop quality (through, for example, grain protein or mycotoxin concentration).

The above analysis of compensation error and model tuning has an important implication: it illustrates the value of exploring differences — and in particular the reason for differences — between models. Thus, as has been argued for climate ensembles, a focus on narrowing uncertainty, that is, seeking consensus — is too limited^{7,8}. The differences matter. Good-quality observational data sets, for both agriculture and climate, are critical in determining and unpicking these differences⁹. Integrated analyses of model chains (for example, from climate to bio-physical impact to economic consequences) are also important if model differences are to be understood. Impacts

modellers should not be insular, but rather should recognize the benefit of engaging with the climate modelling community and with those who model other sectors (for example, the Inter-Sectoral Impact Model Intercomparison Project, ISI-MIP).

A second implication of model error and potential over-tuning is the need to be clear about how much can be achieved in any one study. In particular, how much of the globe can an ensemble study reliably assess? Global studies have the advantage of employing a consistent set of assumptions and therefore producing projections that are consistent and directly comparable, thus facilitating benchmarking across a range of environments. However, the datasets used to drive global models need to be both global in coverage and consistent, thus limiting the pool of available data. Consequently, there will certainly be areas over which more comprehensive and reliable data are available. Furthermore, specific impacts models developed and/or evaluated using such data typically perform better than a global assessment does over the same region. This can be due to calibration and/or the incorporation of key processes (for example, heat stress during anthesis) and interactions (for example, between canopy temperature and transpiration) relevant to that region but not yet incorporated into global assessments.

There is a question, then, of whether projections of climate change impacts are better made by ensembles that are global or regional in scope. The former can produce a single consistent and global evaluation — a significant advantage given the importance of quantifying uncertainty. However, we do not have data at the global scale to determine whether or not models are getting the right answer for the right reason (Fig. 1). Thus there is a danger that global simulations will seem robust, because of their consistency, whilst in fact lacking valuable regional specificity. The end result in this case is that both future research agendas and policy may be misinformed. Although there is currently no evidence of such misinformation, in-depth analyses have rarely been performed.

Clearly, global and regional studies each have advantages and disadvantages. This invites two questions: How can MIPs be designed in a way that makes the most of both types of study? And how can the need for projections — generating and synthesizing results based on impact scenarios — be balanced with the need for model intercomparison and improvement? Ensuring that detailed process research feeds through into improved projections

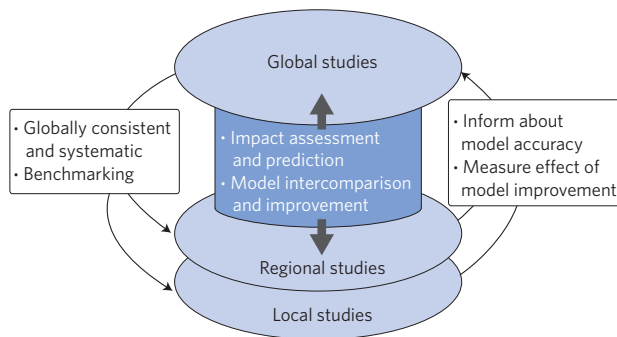
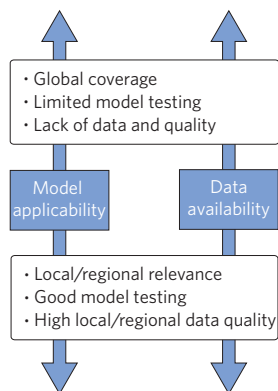


Figure 2 | Proposed coordinated cycle of model improvement and projection, based on recognition of the strengths and weaknesses of global, regional and local studies. Effective use of studies with different geographical domains is contingent on coordination within and across model intercomparison programmes.

requires strategic planning of MIPs that takes into account the different drivers of the component research. At the global level, policy makers are interested in the use of state-of-the-art models and methods to produce probabilistic projections of climate impacts. The ongoing increase in the use of land surface models for crop simulation¹⁰ is underpinning progress in this area. At the regional level, it is critical to ensure that improved projections enable adaptation and deliver improved livelihoods. This focus has led to an increase in outcome-orientated research for development, for example within the CGIAR (Consultative Group on International Agricultural Research).

The different drivers of global and regional research lead to different — if somewhat overlapping — communities. Modelling and international coordination strategies need to be carefully thought through if we are to make the most of the full range of models and researchers, rather than deepen the existing divide. Figure 2 draws on the reasoning above to conceptualize effective coordination of MIPs. This conceptualization recognizes that different MIPs might — indeed probably should — have different aims. Effective coordination involves the exploration of synergies between different MIPs and associated international programmes. For example, work that is focused on livelihoods could make use of the broader global research base. Such multi-level analyses, at least at the regional-to-local scale, have been shown to support development outcomes that are consistent across different types of production system¹¹.

The conceptualization in Fig. 2 also emphasises model improvement, underpinned by inter-comparison, as an

important aim for MIPs. Thus studies should contain explicit statements on the assumptions made in the modelling, and they should report discrepancies in addition to agreement. Detailed modelling studies and experimental data are needed to understand response mechanisms and ensure they are included in models¹². Studies should also assess multiple variables, for example, nitrogen, water use, crop quality and yield. This not only provides stronger constraints on models, it also facilitates assessments of crop sustainability and crop quality.

At the heart of Fig. 2 is the concept of coordinated cycles of model improvement and multi-model projection. Quantifying the effect of model improvement on predictive skill will help to focus research efforts. For example, globally oriented

Box 1 | Recommendations.

- Recognition of the separate but linked strategies of different model intercomparison and improvement programmes.
- Increased assessment of multiple variables within single impacts studies, for example, nitrogen, water use, crop quality and yield.
- Design and implementation of coordinated cycles of model improvement and multi-model projection (Fig. 2).
- Use of systematic intercomparison of impacts studies to synthesize knowledge.
- Full treatments of uncertainty, which go beyond impacts models and include relationships between climate and its impacts.

studies can incorporate key processes that have been identified by regional studies. Coordination efforts need to be underpinned by international data and modelling strategies, such as those being developed by Future Earth¹³. The projection phase of an MIP should be inclusive, by using systematic inter-comparison of impacts studies to synthesize knowledge and use new insights. For example, multi-model impacts studies¹⁴ or meta-analyses¹⁵ can be used to develop response functions, and associated uncertainties. These response functions quantify change in crop yield as a function of the changes in local temperature resulting from climate change.

Finally, a critical component of coordinated MIPs is a full treatment of uncertainty, which goes beyond impacts models. Integrated treatments of climate and impacts model chains not only provide more accurate assessments of uncertainty; they can also lead to improved ways of presenting

uncertain information^{16,17}. Such methods contrast with the scenario-driven approaches that are still prevalent in impact MIPs. The recommendations we have outlined above are summarized in Box 1. □

Andy Challinor^{1,2*}, Pierre Martre³, Senthil Asseng⁴, Philip Thornton⁵ and Frank Ewert⁶ are at ¹University of Leeds, School of Earth and Environment, Institute for Climate and Atmospheric Science, Leeds LS2 9JT, UK. ²International Centre for Tropical Agriculture (CIAT), A.A. 6713, Cali, Colombia. ³INRA UMR1095 GDEC, 5 Chemin de Beaulieu, Clermont-Ferrand, F-63039 France. ⁴University of Florida, Institute of Food and Agricultural Sciences, Agricultural & Biological Engineering Department, 221 Frazier Rogers Hall, Gainesville, Florida 32611-0570, US. ⁵International Livestock Research Institution, CCAFS 16 Mentone Terrace, Edinburgh EH9 2DF, UK. ⁶University of Bonn, Institute of Crop Science and Resource Conservation, Katzenburgweg 5, Bonn, D-53115 Germany.

*e-mail: a.j.challinor@leeds.ac.uk

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Correction

In the Commentary 'Making the most of climate impacts ensembles' (*Nature Climate Change* **4**, 77–80; 2014) the contact details for Philip Thornton and Frank Ewert were exchanged. This has now been corrected in the HTML and PDF versions after print 4 February 2014.