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I believe in climate change but how precautionary do we need to be in planning for the future?

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I believe in climate change. I am concerned, however, that the projections of the current generation of global climate models are not entirely credible. Comparisons of their predictions with the normal control period (1961–1990) show that they often exhibit strong bias, particularly with respect to precipitation estimates (Leith and Chandler, 2010). They are inadequate predictors of the control period in many parts of the world, even where there are ensemble predictions of regional-scale dynamic downscaling models, to the extent that many hydrological studies of the impacts of climate change are using bias corrections with respect to current conditions that are then assumed to hold in the future.

In the United Kingdom, the UKCP09 outputs at http://ukcp09.defra.gov.uk/ show many different aspects of the predicted changes at 25 km scale. They do not show any comparison of the predictions with the control period (despite having posted an official question asking for these to be made available. I am still awaiting a reply. Can I encourage others to log on and pose the same question!). Indeed, the UKCP09 weather generator (for which predicted realizations of weather at the 5 km scale can be obtained based on control period statistics), uses the regional future climate projections only by applying regional climate model (RCM)-derived change factors to the control period parameters in generating future realizations (Kilsby *et al*., 2007).

We expect, of course, that with more research money devoted to climate modelling, more computer power devoted to climate modelling at finer grid scales, better land surface parameterizations in the models (i.e. the hydrology and hydrologists should still *wince* at how it is being represented!) and improved understanding of other process representations in the models, the projections of the next generation of climate models might well be better. But in the meantime, there is an awful lot of research time, effort and money being devoted to impact studies based on the projections of the current generation of models (Wilby and Harris, 2006; Bell *et al*., 2007, and many others). The question is whether any of this work is fit for the purpose of adapting to, or managing for, the future?

Let us assume for the sake of argument (and to provoke a response) that it is *not*. We should not then consider the regional projections of climate models to be an adequate basis for impact studies (so that a lot of research time, effort and money is being wasted). This is not to deny that there might be an anthropogenic effect on climate. I believe in climate change. I am also worried about the possibility that the climate system, as a nonlinear dynamic system, might be subject to mode of behaviour shifts instigated by variability that is not being predicted by the current generation of general circulation models (GCMs) (Smith, 2000). We know that there have been rapid modal shifts in the past, before any significant anthropogenic greenhouse gas inputs to the atmosphere (Alley *et al*., 2003). This suggests that we should plan to adapt to the possibility

of change, despite the fact that we might have little faith in climate model projections. How should we then proceed?

The wrong reaction is to do nothing just because the climate projections have little credibility (or large uncertainty). It would be better to be precautionary by taking action. The question is *how far* to be precautionary and in what direction, given a lack of believable impact predictions? This depends on how risk averse or risk accepting we are prepared to be and that will often be a matter of how much we are prepared to spend on an adaptation strategy. Being risk averse will generally require more expensive measures than being risk accepting. But we can consider how expensive the required adaptation might be for different scenarios of future change, more or less extreme, quite independently of any climate model projections. Making such decisions does not require specifying the probabilities of potential outcomes; there are other decision frameworks for adapting to change (Beven, 2009, ch. 6). In that way it is possible to plan a response to different magnitudes of change in terms of costs (and benefits) that might be robust with respect to future change. This does not necessarily mean the over-design of hard infrastructure: other societal policies that permit the ability to adapt over time might well be more cost-effective.

A general principle commonly followed in policy formulation is that the response should be proportionate to the risk, so that ideally we would wish to evaluate the probability associated with each magnitude of change. UKCP09 is presented in this way, with quantiles of change factors for various model-predicted variables mapped across the country, conditional on assumed emissions scenarios. It is important to remember, however, that these projections are not a representation of the odds of climate actually turning out that way—they are rather the probabilities of the model projections within the ensemble sample itself (with some Gaussian interpolation to compensate for the limited number of ensemble members in a high-dimensional model space). This difference is important. Making use of these probabilities is to treat them as if the model was correct and the range of potential outcomes was complete. This is not the case (Hall, 2007). Indeed, such are the known scientific limitations of representing precipitation in climate models that these probabilities might have little or no relevance to the policy response.

To ignore those probabilistic estimates and deal with the magnitudes of change factors directly (without the need for climate simulations) therefore precludes a complete risk-based strategy but places the focus directly on what is considered to be *affordable* in being precautionary.

A particular case in point is protection against flooding. If a changing climate is intensifying the hydrological cycle, we expect the frequency of floods of a given magnitude to be changing (even if, given the nature of extremes, this might be difficult to demonstrate from the available observations, e.g. Wolock and Hornberger, 1991; Robson, 2002; Kundzewicz *et al*., 2005; Wilby, 2006; Wilby *et al*., 2008). There have been a number of studies that have invoked the change factors produced by climate models to examine how flow frequencies might change. This is straightforward to do if it can be assumed that the parameters calibrated to represent catchment response might not change with changing inputs. It is much more difficult to do if it is thought that the change in inputs or land use and management might require that parameter sets be changed to represent new sets of conditions.

But it is known that climate models do rather poorly in representing some variables of hydrological interest, particularly rainfalls, under control period conditions. They get the wrong result, especially for extremes, and are known to get the wrong result (whether that be the result of scale effects, sub-grid rain, snow and cloud parameterizations, the simplicity of land surface parameterizations, inadequate representations of heat exchange with the oceans, anthropogenic forcings other than greenhouse gases etc., Pielke *et al*., 2009). What is clear, however, is that we should not be assuming stationarity in estimating flood characteristics (Milly *et al*., 2008) and we therefore need to plan for change.

A number of strategies are possible so as not to exacerbate the problem: avoiding new developments on flood plains, improving flood defences, flood proofing of existing buildings, breaching of existing defences to make more storage and building flood detention basins. In most cases, these solutions will be robust in the sense of not precluding future adaptive management strategies but they all have a greater or lesser cost. So what is the cost-benefit of protecting against different levels of change? How precautionary are we prepared to pay to be?

This is, essentially, a political decision. The science then comes in estimating costs and benefits of different policy options, which might be considered to be a far more realistic goal than the accurate prediction of future change. Even if some of the evident problems of the current generation of climate models will be (hopefully) less apparent in the next generation, the path towards having a realistic model still seems long and tortuous even if there were to be a major international coordinated effort in earth system modelling (Tim Palmer of European Center for Medium range Weather Forecasting (ECMWF) recently suggested that such an effort to achieve GCMs at much finer resolution and with more realistic process representations would cost less than a single major satellite programme. . .though, even if this could be agreed internationally, this will still take some significant time to implement).

So, given current model limitations, should we continue to do local bias corrections and use change factors in impact studies just because the funders of research and decision-makers are asking for 'evidence' of how great the impacts of change might be; or should we change the nature of the game into something more overtly political before the 'evidence' comes to be seen as based on insubstantial foundations. Future food and energy security might, for example, provide far more politically compelling arguments for climate mitigation policies than uncertain climate predictions.

In case you are worried about your current research funding, this need not lead to fewer impact studies. Indeed, a wider range of potential outcomes might need to be considered rather than just the latest grand ensemble of predicted change factors. It is just that the evidence does not now depend on climate models but rather on the range of potential future conditions that decision-makers want to consider in getting the greatest benefit for a given expenditure. The available science would still be an input to this process, and in the evaluation of the effectiveness of proposed measures, but this would not necessarily rely on GCM predictions.

Are there difficulties with this approach? Yes, certainly. Climate models provide projections in space and time constrained by energy, momentum and mass balances. These projections are consistent insofar as the approximations of the numerical solutions allow. It could be argued, therefore, that any study of the potential impacts of change that only estimates the magnitude of change and consequent impacts will be inherently subjective, unscientific and providing inadequate evidence. This would be to totally misunderstand the arguments presented above. However, there is an associated problem of providing suitable scenarios for patterns of change factors in catchments that are complex in their patterns of precipitation and other characteristics [we might note that this is already an issue in current practice, since the need to make (often large) bias corrections in the local application of climate change projections is already inconsistent with the energy, mass and momentum balances of the original models. . .in fact, this is worse, since RCMs are already inconsistent with the GCMs within which they are nested, because their GCM-derived boundary conditions are based on different coarser grid land surface fluxes of the same domain].

So we could still accept that climate model projections (together with any necessary bias corrections) are just one way of producing plausible patterns of change factors into the future, but then modify the patterns of change factors in assessing costs and benefits for precautionary action. In doing so, we should also take into account any uncertainty in the impact modelling. Where the disbenefits are a nonlinear function of the projected change, this might make an important difference to the decision that might be made.

Do we reduce the strength of the arguments to induce a reaction in politicians to mitigate the effects of climate change by such a strategy? Perhaps—even if they might believe in climate change, the potential costs of adaptation might be considered politically unacceptable, particularly in a time of economic recession and increasing unemployment. Governments have made that argument in the past, most notably both Bush administrations in the United States. However, to do nothing is then to be risk accepting (or even irresponsible) to a possibly dangerous degree. In fact, it is possible to provide evidence that can be the basis of action to reduce emissions, as well as justifying adaptation strategies, using much simpler models (Jarvis *et al*. 2009; Li and Jarvis, 2009). It is also possible to use simple models in alternatives to purely risk-based decision strategies (Lempert and Collins, 2007). It is interesting, from the perspective of the sociology of science, that models that purport to be based on (approximate) physics are generally considered to provide more convincing evidence, *despite* their greater deficiencies in predicting historical observations.

In addition, there are other factors that might affect future hydrological responses (societal change, urbanization, agricultural intensification, energy security, deforestation/afforestation, river training and re-naturalization. . .) that might be far more important on the decadal time scales over which we might achieve some adaptive management strategy. There are certainly model-based predictions of the effects of potential changes in different factors, mostly deterministic in nature (Bronstert *et al*., 2007; Viney *et al*., 2009), even though we know that process representations of such factors are subject to considerable uncertainty. In this case, the sensitivity of response to assumed future change is generally evaluated (also, like the climate case, a form of scenario analysis) but mostly without an assessment of the cost of possible adaptation strategies. Such changes could also be evaluated in the form of the precautionary cost-benefit strategy suggested here.

People will not agree easily on how to assess appropriate costs and benefits for different types of impact and mitigation strategies, particularly in respect of future socioeconomic scenarios affecting future risk assessment and benefits that might be difficult to characterize. More science and understanding is

required to reduce the uncertainties in doing so as an input to an informed and open policy framing debate. That does not, however, preclude the use of such an approach. I believe in climate change (and the potential impacts of other catchment changes) but I would suggest that we need better ways of deciding how precautionary to be in planning for the future.

References

Alley RB, Martozke J, Nordhaus WD, Overpeck JT, Peteet DM, Pielke RA Jr, Pierrehumbert RT, Rhines PB, Stocker TF, Talleyt LD, Wallace JM. 2003. Abrupt climate change. *Science* 299: 2005–2010. DOI: 10.1126/science.1081056.

Bell VA, Kay AL, Jones RG, Moore RJ. 2007. Use of a grid-based hydrological model and regional climate model outputs to assess changing flood risk. *International Journal of Climatology* 27: 1657–1671.

Beven KJ. 2009. *Environmental Modelling—An Uncertain Future?* Routledge: London.

Bronstert A, Bardossy A, Bismuth C, Buiteveld H, Disse M, Engel H, Fritsch U, Hundecha Y, Lammersen R, Niehoff D, Ritter N. (2007) and Viney, *et al*. (2009)., Bismuth C, *et al*. 2007. Multi-scale modelling of land-use change and river training effects on floods in the Rhine basin. *River Research and Applications* 23: 1102–1125.

Hall JW. 2007. Probabilistic climate scenarios may misrepresent uncertainty and lead to bad adaptation decisions. *Hydrological Processes* 21: 1127–1129.

Jarvis A, Leedal D, Taylor CJ, Young PC. 2009. Stabilizing global mean surface temperature: a feedback control perspective. *Environmental Modelling & Software* 24: 665–674.

Kilsby CG, Jones PD, Burton A, Ford AC, Fowler HJ, Harpham C, James P, Smith A, Wilby RL. 2007. A daily weather generator for use in climate change studies. *Environmental Modelling & Software* 22(12): 1705–1719.

Kundzewicz ZW, Graczyk D, Maurer T, Pinskwar I, Radziejewski M, Svensson C, Szwed M. 2005. Trend detection in river flow series: 1. Annual maximum flow. *Hydrological Science Journal* 50(5): 797–810.

Leith NA, Chandler RE. 2010. A framework for interpreting climate model outputs. *Journal of the Royal Statistical Society Series C-Applied Statistics* 59: 279–296.

Lempert RJ, Collins MT. 2007. Managing the risk of uncertain threshold responses: comparison of robust, optimum, and precautionary approaches. *Risk Analysis* 27((4)): DOI: 10.1111/j.1539–6924 .2007.00940.x.

Li S, Jarvis A. 2009. Long run surface temperature dynamics of an A-OGCM: the HadCM3 4xCO(2) forcing experiment revisited. *Climate Dynamics* 33: 817–825.

Milly PCD, Betancourt J, Falkenmark M, Hirsch RM, Kundzewicz ZW, Lettenmaier DP, Stouffer RJ. 2008. Stationarity is dead: whither water management? *Science* 319: 573–574.

Pielke R Sr, Beven KJ, Brasseur G, Calvert J, Chahine M, Dickerson R, Entekhabi D, Foufoula-Georgiou E, Gupta H, Gupta V, Krajewski W, Krider EP, Lau WKM, McDonnell JJ, Rossow W, Schaake J, Smith J, Soroosh S, Wood EF. 2009. Climate change: the need to consider human forcings other than greenhouse gases. *EOS Transactions-American Geophysical Union* 90(45): 413.

Robson A. 2002. Evidence for trends in UK flooding. *Philosophical Transactions of the Royal Society of London* 360: 1327–1343.

Smith LA. 2000. Disentangling uncertainty and error: on the predictability of nonlinear systems. In *Nonlinear Dynamics and Statistics*, Mees A (eds). Birkhauser: Basel; 31–64.

Viney NR, Bormann H, Breuer L, Bronstert A, Croke BFW, Frede H, Graeff T, Hubrechts L, Huisman JA, Jakeman AJ, Kite GW, Lanini J, Leavesley G, Lettenmaier DP, Lindström G, Seibert J, Sivapalan M, Willems P. 2009. Assessing the impact of land use change on hydrology by ensemble modelling (LUCHEM) II: ensemble combinations and predictions. *Advances in Water Resources* 32: 147–158.

Wilby RL. 2006. When and where might climate change be detectable in UK river flows? *Geophysical Research Letters* 33: L19407.

Wilby RL, Beven KJ, Reynard NS. 2008. Climate change and fluvial risk in the UK: more of the same? *Hydrological Processes* 22: 2511–2523.

Wilby RL, Harris I. 2006. A framework for assessing uncertainties in climate change impacts: low flow scenarios for the River Thames, UK. *Water Resources Research* 42: W02419.

Wolock DM, Hornberger GM. 1991. Hydrological effects of changes in levels of atmospheric carbon dioxide. *Journal of Forecasting* 10: 105–116.