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Editorial

Beyond the downscaling comparison study

This Special Issue of the *International Journal of Climatology* draws upon papers given at the session convened by the guest editors at the European Geosciences Union meeting in Vienna in April 2006: 'Linking climate change modelling to impacts studies: downscaling techniques for hydrological impact studies'. The session explored some of the latest developments in 'downscaling' techniques, commonly used to address the scale mismatch between coarse resolution global climate model (GCM) output and the regional or local catchment scales required for climate change impact assessment and hydrological modelling. Presentations covered the development of new downscaling techniques, the inter-comparison of downscaling methods, the downscaling of extremes, and progress with quantifying uncertainties in the estimation of climate change impacts (such as the use of multi-model ensembles and probabilistic methods). The main questions addressed by the session were how can these innovations be used in hydrological impact studies, and what further steps are needed to embed downscaling in the adaptation process?

Although the last decade has witnessed a plethora of publications on downscaling from climate models, very few studies consider impacts *per se*, and even fewer (about one in six of all downscaling studies) examine hydrological impacts. Even when studies do have an applied element, consideration is seldom given to how results might enable stakeholders and managers to make more informed, robust decisions on adaptation in the face of deep uncertainty about the future. In fact, apart from a handful of often cited examples, downscaling studies are conspicuously absent in the recent reviews on climate change and water adaptation (e.g. EEA, 2007; Kundzewicz *et al*., 2007). Paradoxically, the rhetoric has become much more confident about projected changes in temperature and even precipitation at regional scales (Christensen *et al*., 2007). Somewhere along the line there has been a disconnection between the suppliers and users of regional climate change scenarios for adaptation and resource planning. It is hoped that this Special Issue will catalyse a debate about *applied* downscaling research and show the need to begin mainstreaming such work within adaptation frameworks. This will involve the identification of technical (and institutional) constraints, as well as options for improving access to, and use of, downscaled scenarios in climate change risk assessments.

Fowler *et al*. (this Special Issue) set the scene by comprehensively reviewing contemporary downscaling literature through a hydrological lens. Sections focus on the downscaling concept; new methods; comparative methodological studies; the modelling of extremes; and the application to hydrological impacts. The review then considers recent developments in the construction of climate scenarios which offer potential for methodological advances in the field. These include probabilistic modelling using multi-model ensembles, pattern-scaling and downscaling of multiple variables. An example is given to show how these techniques may be merged into a probabilistic climate change scenario framework for assessing uncertainties associated with climate change projections. Recommendations are made for future research priorities, including the provision of decision-making tools for planning and management that are robust to future uncertainties.

Salathé *et al*. (this Special Issue) then review the methods developed by the Climate Impacts Group (CIG) at the University of Washington to evaluate and downscale GCM simulations for the integrated assessment of climate impacts on hydrologic systems in the Pacific Northwest, U.S. The approach is intended to support regional water resource management and the different downscaling methods used by the group are described. Many of these are simple empirical corrections of global climate model data. However, the performance of statistical downscaling and a high-resolution (15 km) dynamical downscaling method are also evaluated. The regional climate model (RCM) shows important differences in the regional climate response from that captured by GCMs and statistical downscaling. For example, localised amplifications of warming unseen by GCMs are shown by the RCM to be due to changes in the local surface radiation budget caused by the loss of snow and increased cloudiness.

The next two papers use statistical methods to downscale information from multiple GCMs to examine hydrological impacts and the uncertainties introduced by the choice of GCM and emissions scenario. In Gachon and Dibike (this Special Issue) the downscaling tool SDSM (Wilby *et al*., 2002) is assessed with respect to simulated changes in mean and extreme temperatures for specific locations in northern Canada. The study uses outputs from two GCMs (CGCM2 and HadCM3) and two emissions scenarios (SRES A2 and B2) to explore temperature projections for 2070–2100. The statistical downscaling step provides additional information on temperature change not captured by the direct use of GCM outputs, including the effects of synoptic scale forcings, and is found to reduce inter-model differences in projections. However, SDSM is found to be conservative in the presence of non-stationarity in the climate system, so potentially underestimates warming in the downscaled signal.

Charles *et al*. (this Special Issue) use a stochastic non-homogeneous hidden Markov model (NHMM) to downscale from four GCMs (CSIRO Mk3, CCAM, HadAM3P and ECHAM4) forced by the SRES A2 emissions scenario to quantify the impacts on multi-site, daily precipitation in southwest Western Australia. Hydrological impacts are then assessed using a catchment water balance model while keeping evapotranspiration and land use fixed at present-day conditions. Differences in projected decreases in runoff between the GCMs are found to be related to both the magnitude and timing of monthly precipitation biases despite similarities in downscaled mean annual precipitation. Thus, the authors suggest that studies that validate climate model predictors on a seasonal basis may mask within season compensating biases that unknowingly add uncertainty to projected impacts, particularly when simulating non-linear processes such as catchment runoff.

In the next three papers, dynamical downscaling methods are used to estimate climate change impacts on hydrological systems. Boé *et al*. (this Special Issue) compare the results of a multivariate statistical downscaling methodology based on weather typing and conditional re-sampling with a bias-correction technique for dynamical downscaling based on quantile–quantile mapping. They first evaluate the statistical method using the atmospheric forcing from the ERA-40 reanalysis data to drive a hydrological model and then use the same forcings from the ARPEGE variable resolution GCM (~60 km resolution) to compare the methods for the future climate. The statistical method is found to be better at reproducing the temporal and spatial properties of downscaled temperature and rainfall. However, runoff simulations are similar, with both methods successfully reproducing the seasonal cycle and daily distribution of streamflow.

Bell *et al*. (this Special Issue) use a grid-based hydrological model and 25 km resolution, hourly outputs from a Hadley Centre RCM to assess changing flood risk in catchments across the UK. The authors use a single ensemble member of current (1961–1990) and future (2070–2100) climate to show how natural variability in downscaled rainfall translates into uncertainty in flood risk assessments. In the absence of a formal ensemble of climate predictions, a re-sampling method is used to investigate the robustness of the modelled changes in flood frequency. Unsurprisingly, perhaps, estimates of change in higher return period flood events are found to be less robust than at lower return periods. However, this study shows that in some regions of the UK results from RCMs can be used as direct inputs to hydrological impact studies without the need for further bias-correction.

Blenkinsop and Fowler (this Special Issue) take the issue of robustness of estimates further by discussing preliminary results from the EU Framework VI AquaTerra project. This study is developing a framework for probabilistic climate change scenarios to assess impacts on European hydrological systems using probability density functions (pdfs) of future change. These will be produced by weighting projections from a multi-model ensemble according to their skill at reproducing observed climate statistics that are important for the impacts under consideration. Here, they examine the results from six RCMs from the EU Framework V PRUDENCE project, assessing their ability to downscale both mean precipitation and a precipitation-based drought index for six catchments of varying size across Europe. Considerable model uncertainty is demonstrated for both current and future projections, particularly for drought frequency, at the regional scales required for management. Increases in the frequency of long-duration droughts are identified for catchments in southern Europe, although the magnitude of this change is uncertain. Conversely, northern European catchments may show reductions in the frequency of long-duration droughts, but changes in short-duration drought are less certain. The projected changes and uncertainties could pose challenges for the management of water resources in each region. For the scientific community, the challenge is how to incorporate this uncertainty in climate change projections to allow informed decision-making based on model projections, although it is argued that probabilistic methods may offer considerable potential in this respect.

The last two papers of this Special Issue explore such ideas in further detail. Bronstert *et al*. (this Special Issue) present a scheme for the evaluation of regional climate change scenarios specifically for hydrological impact studies based on expert judgement. The first step of this procedure evaluates the capability of the climate scenarios to represent regional climate and the plausibility of the future climate conditions thus depicted ('climate adequateness'). The second step then evaluates the hydrologically relevant information given by the climate scenarios ('hydrological usefulness'). The approach is demonstrated by a climate change impact assessment for Southern Germany in which the authors compare three downscaling methods against the use of direct results from the host GCM, ECHAM4, for 2021–2050 under the SRES B2 emissions scenario. The downscaling methods include a dynamical method using the REMO RCM, a statistical weather-type based regionalisation method, and a statistical re-sampling method. It is clear that downscaling provides improved estimates of hydrological change over use of raw GCM output, but none of the methods is evaluated as 'good'. However, processes governed by temperature (such as evaporation and snow melt) are better reproduced than processes governed by precipitation (such as runoff generation and flooding). The authors recommend that for hydrological impact studies, regional scale temperature and spatio-temporal variability of precipitation are of the highest relevance and that evaluation of climate models should focus on these hydrologically relevant variables.

The final paper by García-Morales and Dubus (this Special Issue) describes the use of probabilistic seasonal

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forecasts for optimising the hydroelectric power production system of the EDF Group, the largest French electric power producer. A statistical downscaling method based on Singular Value Decomposition and Multiple Linear Regression is developed using 45 years of precipitation observations and geopotential fields from ERA-40 reanalysis data to provide seasonal forecasts of precipitation for 48 catchments in southern France. The downscaling model is then applied to seasonal hindcasts provided by the EU Framework V DEMETER project. The study shows that it is possible to obtain valuable information for management at the local scale from seasonally averaged information. Importantly, however, useful information for management is only provided by a probabilistic multimodel ensemble forecast approach; the ensemble mean was not a useful forecasting tool.

Some common themes run through the collection of papers. Several are concerned with the value-added (if any) by the downscaling procedures, compared with the more straightforward use of raw GCM products. This is an important test and should be much more commonplace in downscaling studies, if only to demonstrate that the time and effort is justified. Other papers evaluate the relative significance of different sources of uncertainty affecting downscaled scenarios within the cascade of emissions scenario(s), choice of GCM(s), characterisation of natural variability, downscaling technique(s), and hydrological impacts model(s). What remains less clear is how decision-makers should react to such information. One way forward may involve the 'blending' of uncertainties in probabilistic frameworks – an approach that is already yielding commercial benefits under present climate conditions (see, for example, García-Morales and Dubus, this Special Issue). However, to be effective, this 'top-down' perspective needs to be supported by data on climate-sensitive operational thresholds or on tipping points between different planning pathways.

This Special Issue provides a snapshot of downscaling research activity that is broadly representative of themes in the wider research literature. In particular, the 'comparison study' has become the template for much (of our) thinking. What is still lacking is practical guidance on how to incorporate all of the uncertainties demonstrated in downscaling analyses into robust adaptation planning. The downscaling community also needs to recognise that decision-makers are more interested in short-term impacts that will happen by the 2020s rather than by the 2080s (the preferred time horizon for most climate change modelling studies and thus downscaling research). This immediately shifts the onus to better capturing seasonal- to inter-decadal variability in downscaled temperature and precipitation scenarios. Nowhere is this more critical than for the Tropics and the developing world in general, where economic growth is already severely hampered by climate variability and change. Although the situation is improving, these regions have been largely neglected by the downscaling community, yet this is where climate risk information is most urgently needed for development and adaptation planning. Even in data- and resource-rich Europe and North America there is still a paucity of guidance on what to do when the downscaling shows no skill or wide-ranging outcomes. To move beyond the downscaling comparison study we will need to work harder at translating our science into practical measures that can be taken up and used at the point of delivery of adaptation. This will mean improving the dialogue between the suppliers and users of climate scenarios, identifying knowledge gaps and obstacles to uptake, and the better showcasing of the benefits of downscaling.

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References

Christensen JH, Hewitson B, Busuioc A, Chen A, Gao X, Held I, Jones R, Kolli RK, Kwon W-T, Laprise R, Magaña Rueda V, Means L, Menéndez CG, Räisänen J, Rinke A, Sarr A, Whetton P. 2007. Regional climate projections. In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Solomon S, Quin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds). Cambridge University Press: Cambridge.

European Environment Agency (EEA). 2007. *Climate Change and Water Adaptation Issues*, EEA Technical Report No. 2/2007, Copenhagen, 110.

Kundzewicz ZW, Mata LJ, Arnell NW, Döll P, Kabat P, Jiménez B, Miller KA, Oki T, Sen Z, Shiklomanov IA. 2007. Freshwater resources and their management. In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Parry ML, Canziani OF, Palutikof JP, Hansen CE, van der Linden PJ (eds). Cambridge University Press: Cambridge.

Wilby RL, Dawson CW, Barrow EM. 2002. SDSM–a decision support tool for the assessment of regional climate change impacts. *Environmental and Modelling Software* **17**: 145–157.

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