Probabilistic projections of climate change effects on sub-arctic palsa mires using the response surface method

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Introduction

Recent progress in estimating probabilities of future climate change from ensembles of model projections offers an opportunity to go beyond "what if" types of scenario analysis to a quantified assessment of risks to natural or human systems. However, the application of a potentially high number of ensemble climate projections as inputs to impact models may prove impractical. An alternative method, making use of the probabilistic representation of future climate in combination with impact response surfaces, is demonstrated here in a case study about sub-arctic palsa mires.

Palsa mires, which contain peat with permanently frozen ice, are located at the outer margin of the permafrost zone and are expected to undergo rapid changes under global warming. These changes are expected to have a significant influence on the biodiversity of sub-arctic mires and could also potentially affect the regional carbon budget.

The objectives of this study are:

1. To test alternative approaches of translating probabilistic projections of climate change to impacts,

2. To estimate the likelihood of different magnitudes of decline in area suitable for palsa mires in northern Fennoscandia as a consequence of climate change.

Methods

- A model describing the spatial distribution of palsa mires in Fennoscandia (Fig. 1) as a function of monthly temperature and annual precipitation was used to estimate the risk of palsa mire loss [1]. Impact model uncertainty was not accounted for.
- Joint distributions of projected changes in annual temperature (T) and precipitation (P) were derived from an ensemble of simulations with coupled atmosphere-ocean general circulation models (AOGCMs) using a re-sampling method [2] (Fig. 2).
- Impact response surfaces describing the change in area of palsa suitability were constructed from a sensitivity analysis of the impact model with respect to T and P. This required a simplification of the palsa mire model (that has more than two input variables) based on an analysis of the seasonal pattern of simulated monthly temperature changes.
- The joint distribution of projected changes in the two explanatory climatic variables, based on the re-sampled AOGCM outputs, was superimposed onto the impact response surface so that the frequency of a given impact response could be evaluated (Fig. 3).

Results and discussion

- It was estimated as very likely (>90% probability) that a loss of area suitable for palsa mires to less than half of the baseline distribution will occur by the 2030s and likely (>66%) that all suitable areas will disappear by the end of the 21st century under the A1B and A2 emissions scenarios (red and blue lines in Fig. 5). For the B1 scenario, it was more likely than not (>50%) that a small proportion of the current palsa mire distribution would remain until the end of the 21st century (top horizontal green bar in Fig. 4; green line in Fig. 5).
- The response surface method, though introducing additional uncertainty, gave reliable risk estimates of area loss for palsa mire suitability compared to multiple simulations with the original palsa model (compare grey lines to triangles in Fig. 5).
- Potentially the method could prove to be a useful tool in other impact modelling studies, as it can substantially reduce the number of simulations needed to conduct a quantified risk assessment.

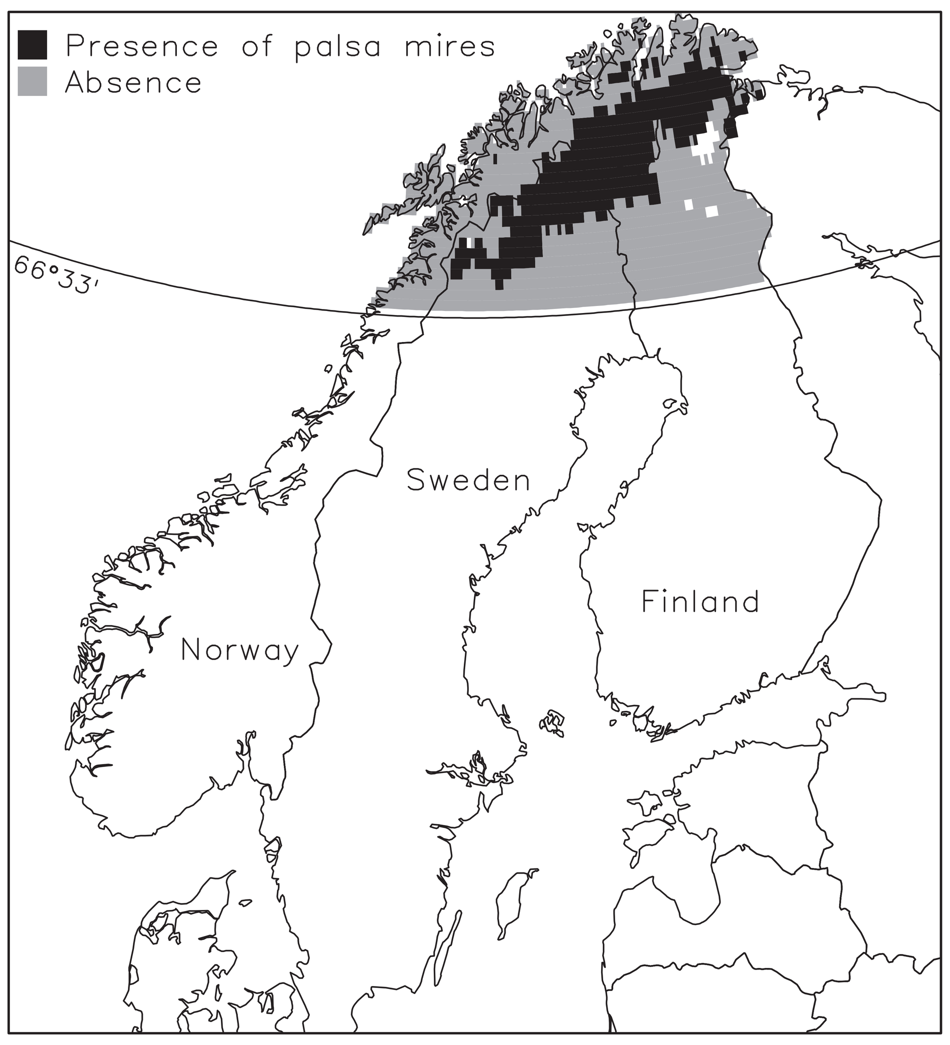

Figure 1. Map of the study area showing the palsa mire locations in Northern Fennoscandia.

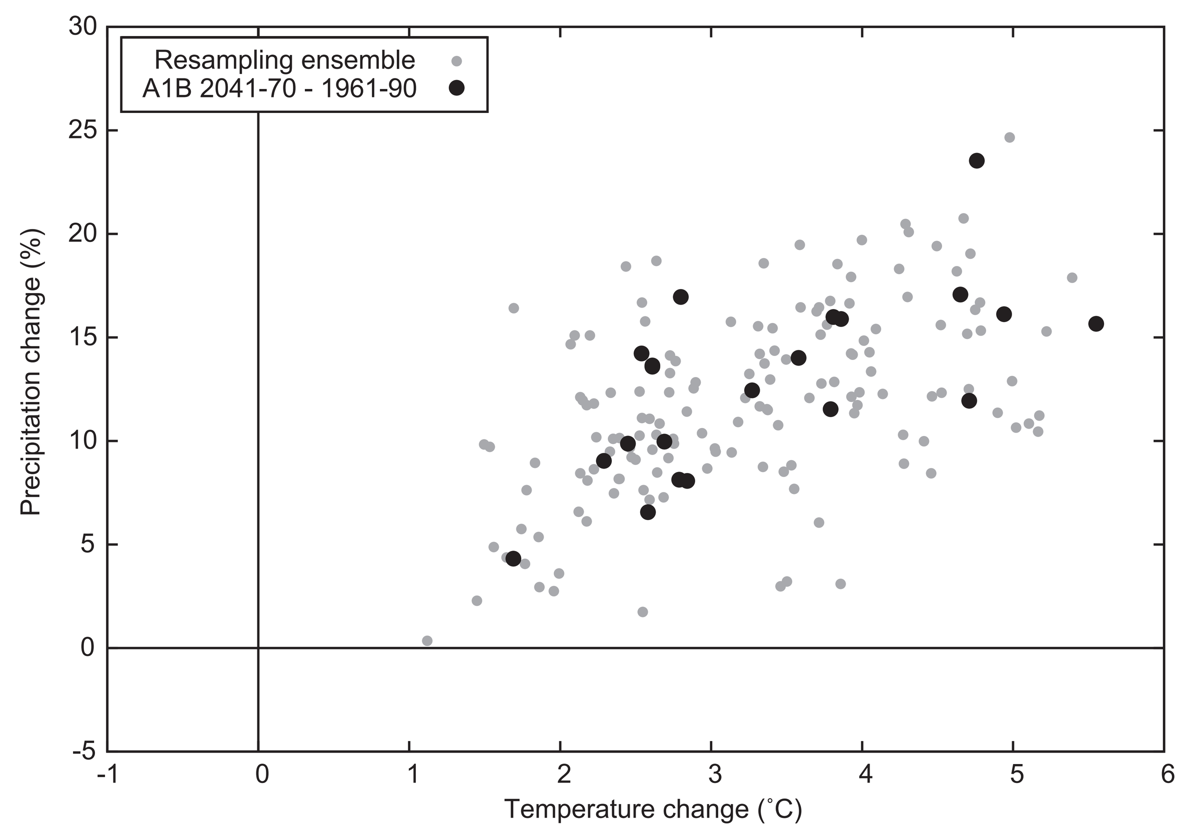

Figure 2. Changes from 1961–1990 to 2041–2070 in annual mean temperature (°C) and precipitation (%) in northern Fennoscandia. Black dots: as simulated by 21 AOGCMs (A1B emissions scenario). Grey dots: as inferred from the re-sampling ensemble. Source: reference [1]

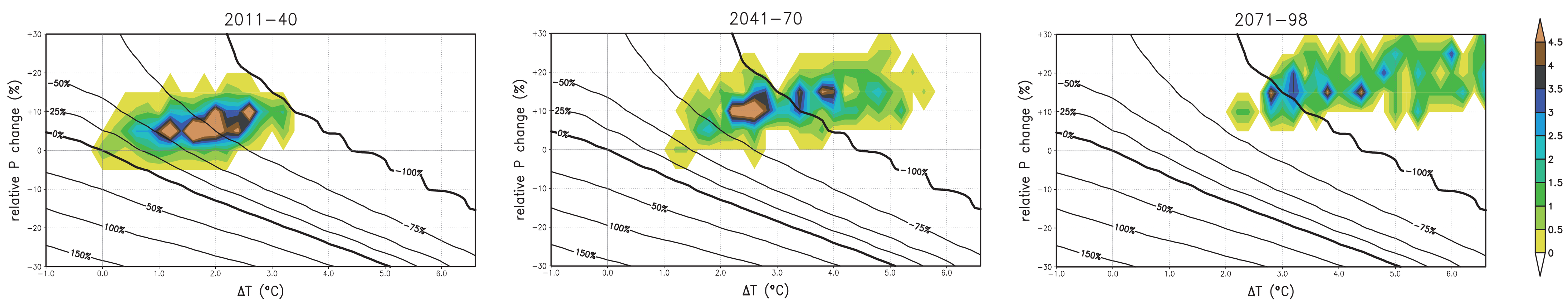

Figure 3. Impact response surface of change in area suitable for palsa mires (isolines, % change relative to the simulated 1961-1990 distribution) and relative frequency of annual temperature and precipitation changes by 2011-2040, 2041-2070 and 2071-2098 relative to 1961-1990 (coloured shading, %).

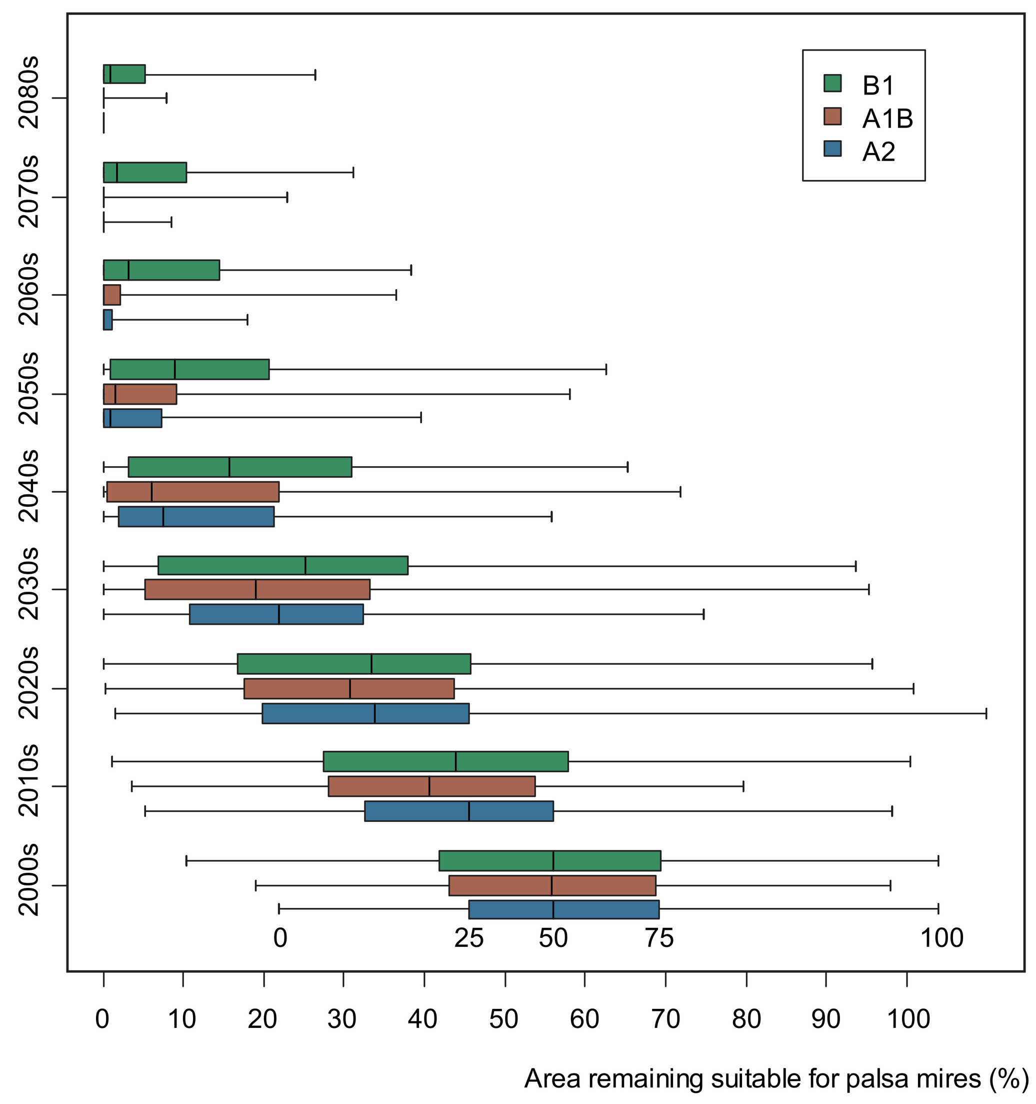

Figure 4. Projected distribution of area suitable for palsa mires (relative to 1961-1990) for 3 SRES scenarios and 30-year periods during the 21st century using re-sampled ensembles based on 15 AOGCM projections.

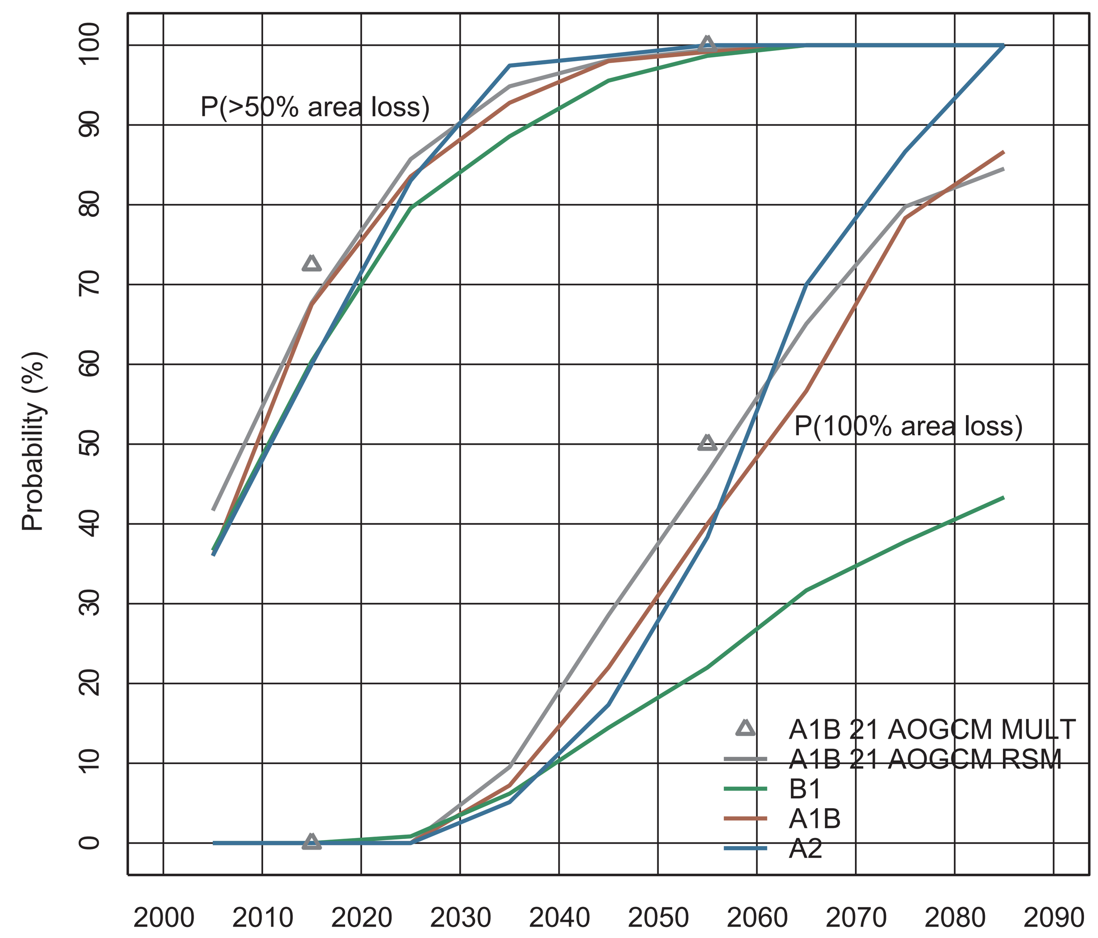

Figure 5. Projected distribution of area suitable for palsa mires during the 21st century relative to 1961-1990 estimated with multiple scenario simulations (MULT, triangles) and the response surface method (RSM) for a re-sampled ensemble of 21 AOGCMs (grey line) with A1B forcing and for a re-sampled ensemble of 15 AOGCMs with B1, A1B and A2 forcing (coloured lines).

References and acknowledgements

[1] Fronzek, S., Luoto, M. and Carter, T.R.: 2006, 'Potential effect of climate change on the distribution of palsa mires in subarctic Fennoscandia', Climate Research 32, 1-12.

[2] Räisänen, J. and Ruokolainen, L.: 2006, 'Probabilistic forecasts of near-term climate change based on a resampling ensemble technique', Tellus 58A, 461-472.

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