

Regional projections of climate change using an Earth system model of intermediate complexity

Stephen R. Sobie, Trevor Q. Murdock
Pacific Climate Impacts Consortium (PCIC), Victoria, BC

Introduction

Earth System Models of Intermediate Complexity (EMICs) comprise a variety of climate models that can offer an alternative to more sophisticated, but computationally expensive, Global Climate Models (GCMs) in simulating the response of climate system to increasing concentrations of CO₂. The EMIC-Intercomparison Project (Petoukhov et al., 2005) has shown that the University of Victoria Earth System Climate Model (Weaver et al., 2001), in addition to other EMICs, performs similarly to more complex GCMs in zonally-averaged transient and equilibrium responses of temperature and precipitation to increasing levels of CO₂. Additionally, the range of EMIC responses tends to be as large as that of GCMs over most latitudes (Randall et al., 2007). In bridging the gap between fully-fledged GCMs and simple climate models, EMICs may offer a balance of complexity and resources in representing the climate system (Claussen et al., 2002).

Simulations of committed climate change, mitigation scenarios or higher than expected emissions can be completed quickly with EMICs that have already been shown to capture effectively the global response of the climate system to increasing CO₂. This study attempts to determine whether the UVIC Earth System Model can be used in lieu of the AR4 ensemble when examining temperature and precipitation response in sub-global regions to a variety of scenarios of increasing emissions of CO₂.

Model Evaluation

Version 2.9 of the UVIC model represents the Earth at 1.8° x 3.6° horizontal resolution with interacting land, vegetation, carbon cycle components, an energy-moisture balance atmospheric model and a fully dynamic ocean components model (Weaver et al., 2001). The ensemble of GCMs was composed of models simulations from 14 different modelling centres, obtained for the 20th century and future projections under each of the three SRES emissions scenarios (A1B, A2, B1).

Comparisons of temperature and precipitation between the UVIC model and the AR4 ensemble were done both on a global scale and on a regional scale for ten different sub-global regions covering a range of sizes and locations. In each region spatial averages were taken, with the time series converted to anomalies relative to a 1961-1990 baseline. Anomalies were then calculated in multiple time intervals as well as trends using Sen's nonparametric estimator of slope employing the Yue-Pilon pre-whitening technique (Yue et al., 2002). Values for the UVIC model and AR4 ensemble were compared at the 5% significance level.

The Uvic ESCM: coupled components

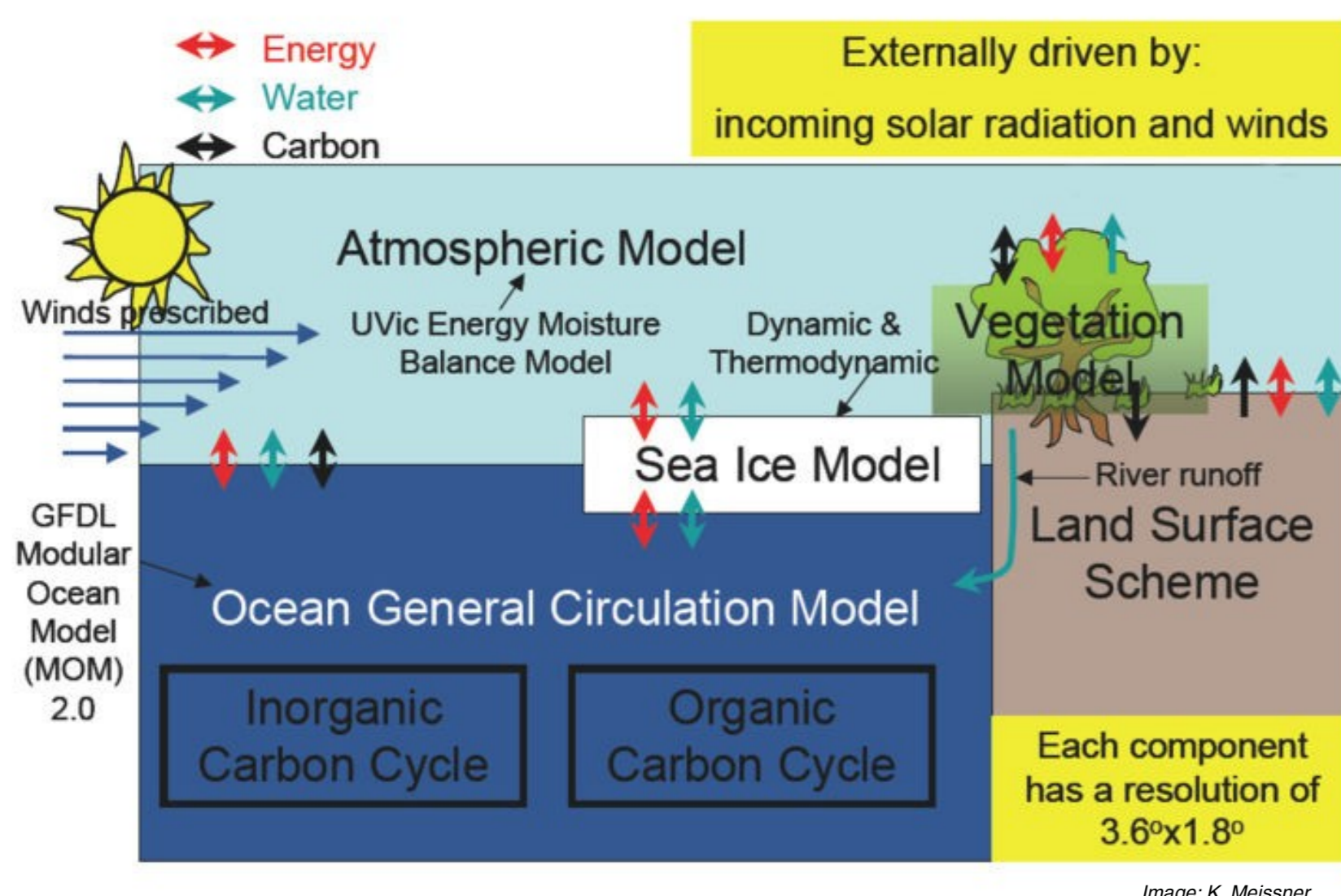


Figure 1. A schematic of the components of the UVIC Earth System Climate model, including energy, water and carbon exchanges between different model components.

Results

In the 21st century, temperature responses to increasing CO₂ in the UVIC model match trends and anomalies in the AR4 ensemble in 50% of comparisons, while there little agreement seen in the precipitation response between the model types. Sub-global regions with significant topography (such as Chile), and series within short time intervals show the fewest instances of agreement. In both temperature and precipitation, the UVIC model responds less rapidly to changing CO₂ forcing than the AR4 ensemble, but eventually achieves the same response trajectory as seen in the GCMs.

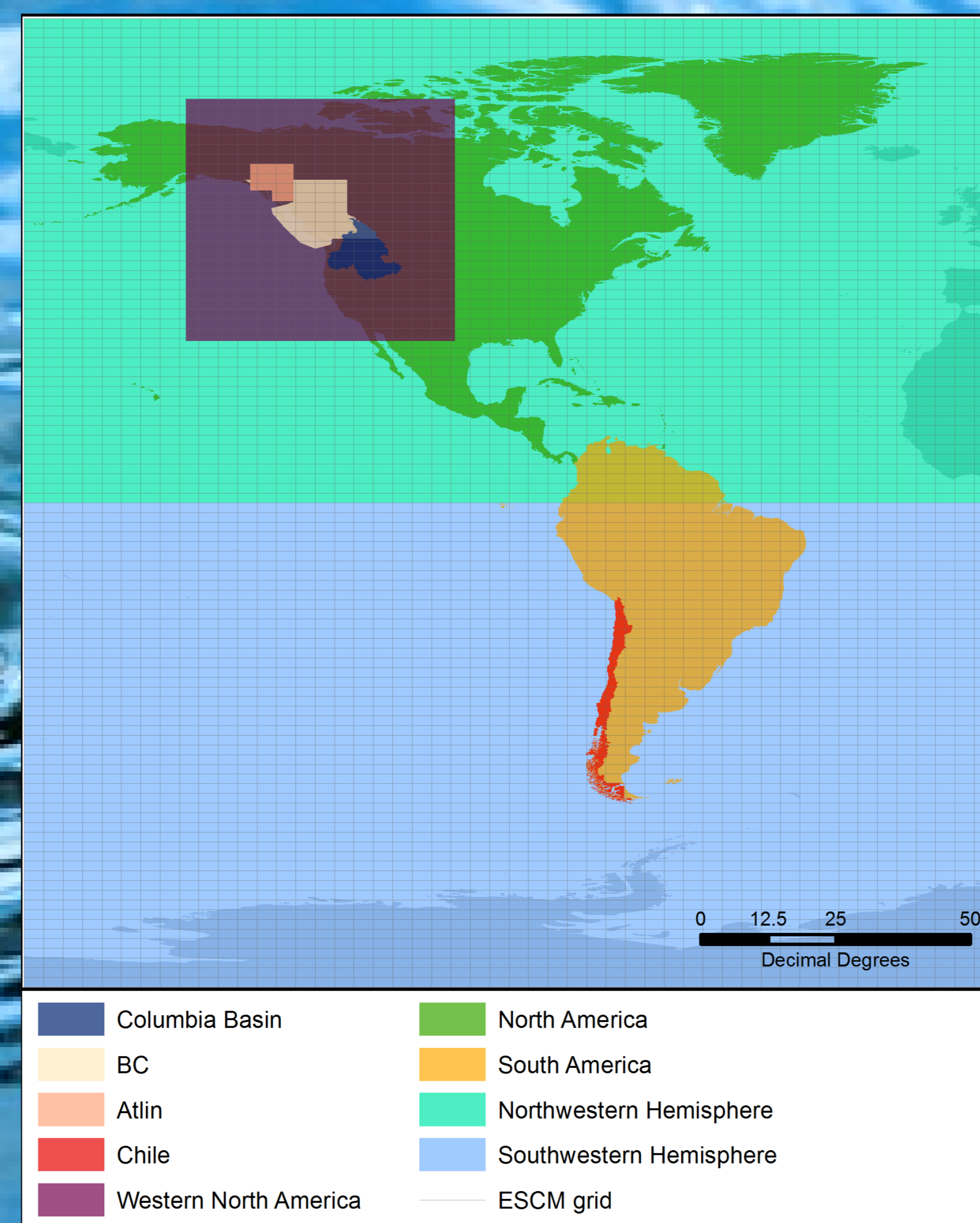


Figure 2. A map of the sub-global regions examined from both the UVIC model and the AR4 ensemble. The regions span a range of spatial areas and climates.

Table 1. Comparison of UVIC model and AR4 ensemble average temperature trends and anomalies. Percentages indicate the number of statistical matches at the 5% significance level for each region and over different time intervals. Values from the longest time series and smallest regions in the northern hemisphere agree most often with the AR4 ensemble.

Region	Interval Length (Years)		
	100	50	20
Atlin	100%	83%	83%
B.C.	67%	75%	67%
Columbia	83%	33%	33%
NW. America	83%	50%	33%
N. America	100%	33%	17%
NW. Hemisphere	83%	33%	17%
Global	83%	50%	33%
SW. Hemisphere	67%	67%	83%
S. America	83%	50%	0%
Chile	33%	42%	33%

Literature cited

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 Yue, S., P. Pilon, B. Phinney, and G. Cavadias, 2002: The influence of autocorrelation on the ability to detect trend in hydrological series. *Hydrol. Process.*, **16**, 1807-1829.

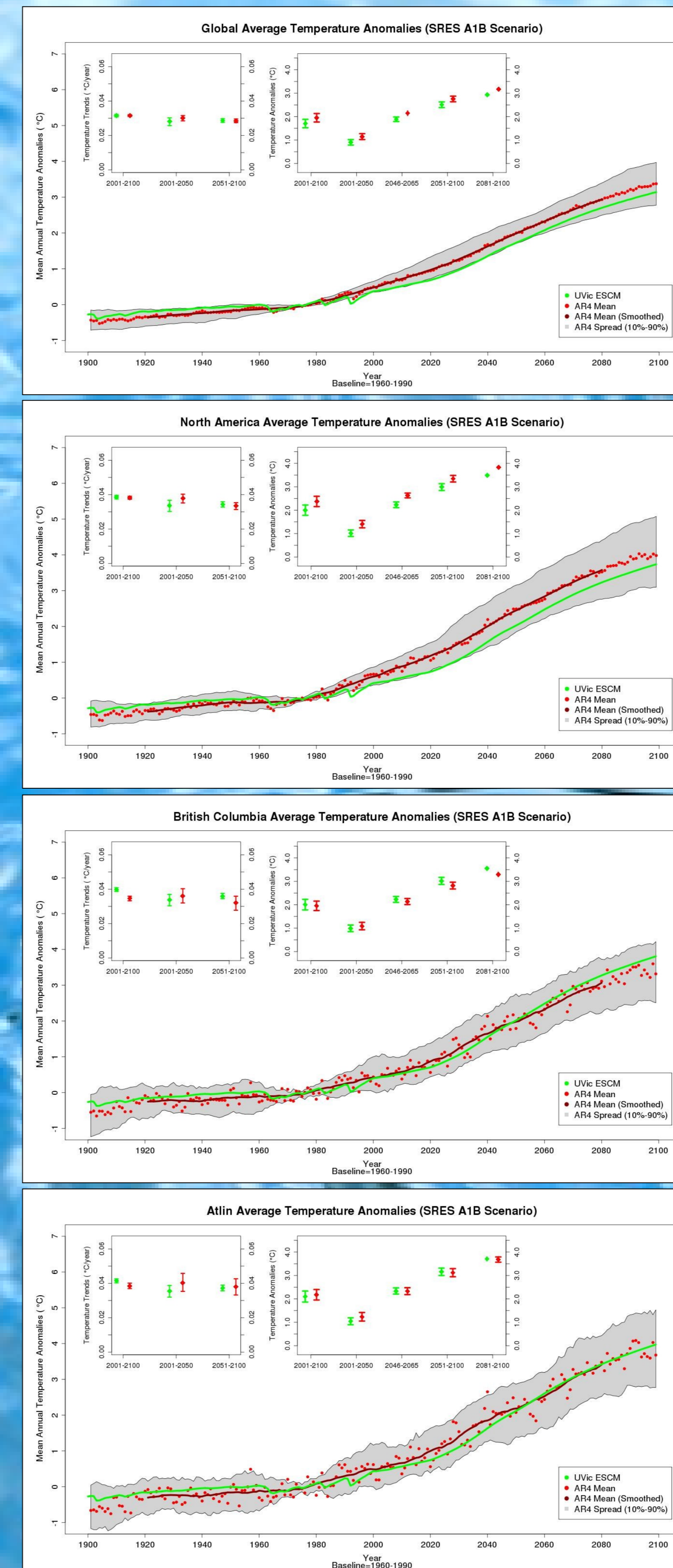


Figure 2. UVIC model and AR4 ensemble average temperature anomalies for four regions. Subplots display trend and anomaly values for selected intervals. The response of the UVIC model tends to be delayed compared to the AR4 ensemble. Long-term trends and anomalies agree best with the closest agreement within the Atlin-Taku plan area (bottom plot). The UVIC model shows similar results under the B1 scenario, but does not capture the rapid changes in the A2 scenario as effectively as the AR4 ensemble.

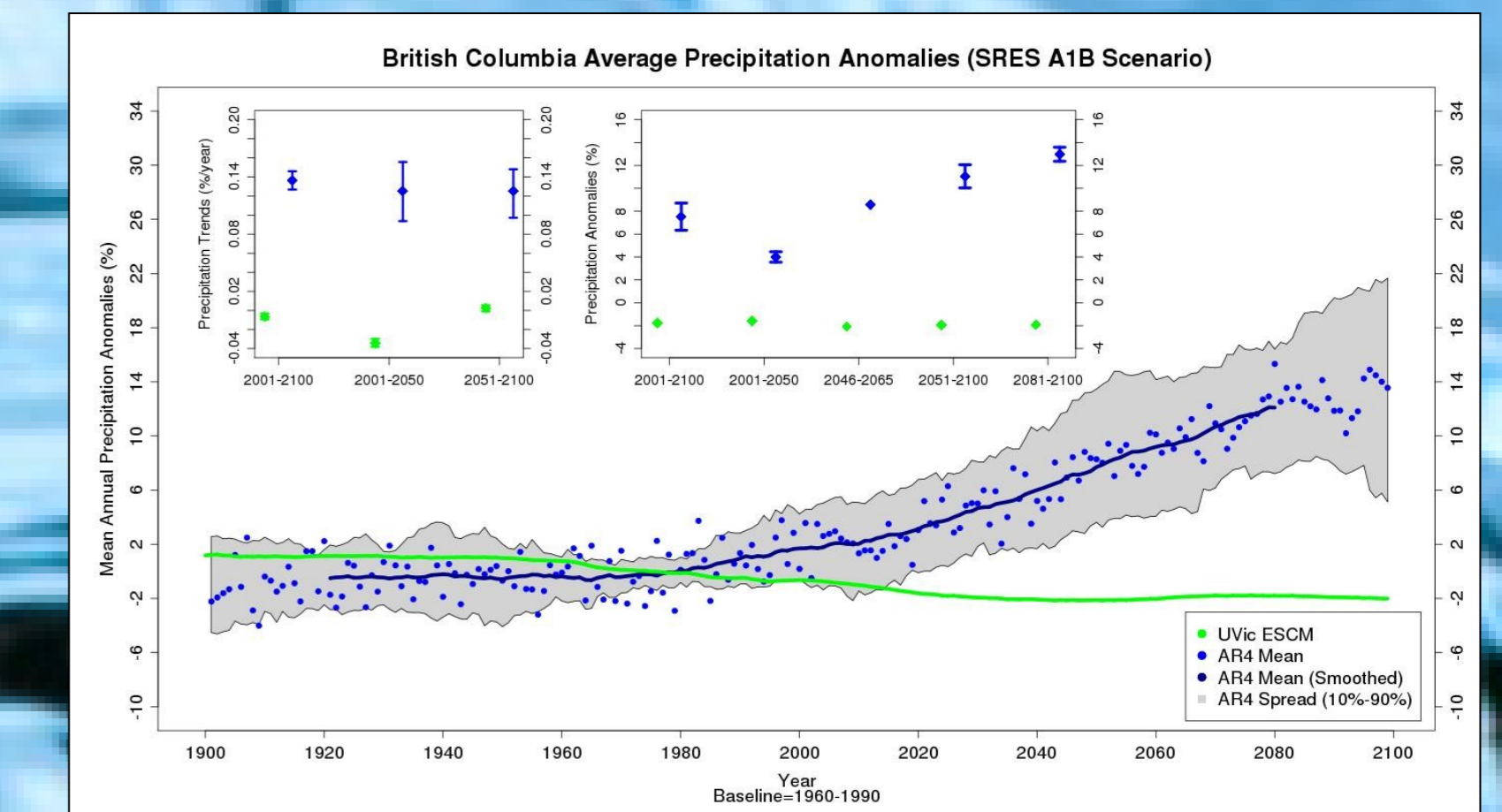


Figure 3. Precipitation anomalies for B.C. Future rainfall and snowfall projections cancel one another out in the UVIC model, leading to a significant underestimation in projected values relative to the AR4 ensemble.

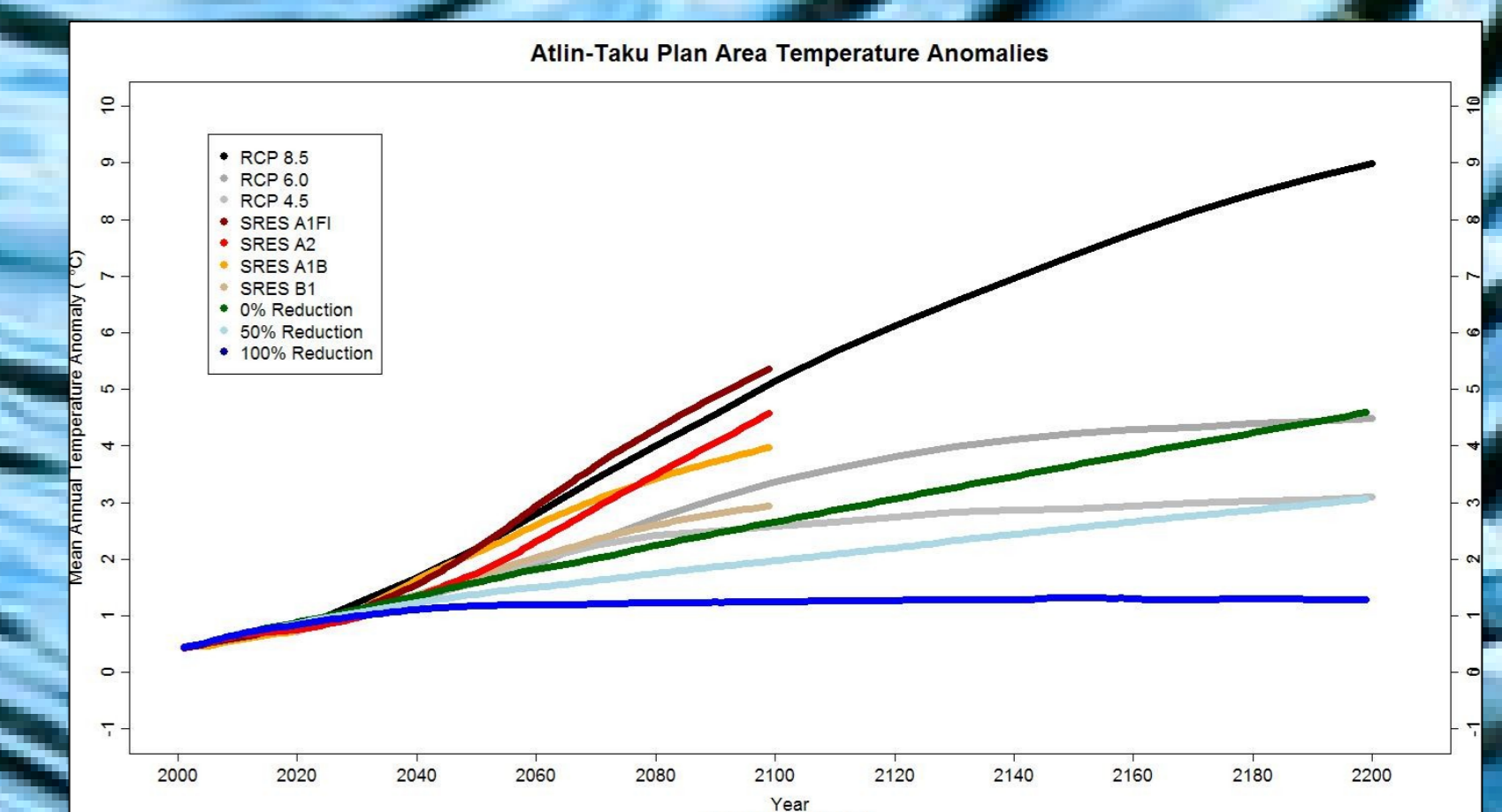


Figure 4. Projected temperature anomalies for the Atlin-Taku plan area from the UVIC model supplied with a range of future emissions scenarios to address local stakeholder information needs. Reduced computational requirements of the UVIC model means that each scenario can be completed in a few days.

Conclusions

The results suggest that the UVIC model could be used effectively to study surface temperature response in sub-global regions to changes in radiative forcing under certain conditions. In all sub-global regions, the UVIC model performs closest to the AR4 ensemble in temperature anomalies (29 out of 30 statistical matches), and trends (19 out of 30 statistical matches) over the full 2001-2100 period. Short-term analyses of temperature in sub-global regions are not as well replicated (24 out of 60 statistical matches) and are best left for other means such as global or regional climate models with fully dynamic atmospheres. Small sub-regions (e.g. Atlin, British Columbia) in the mid-latitudes with greater inter-annual variability can also be effectively represented by the UVIC model. In simulating precipitation, the UVIC model is less capable in smaller regions, underestimating changes in rainfall and overestimating snowfall decreases compared to the AR4 ensemble. As a result, precipitation in the UVIC model does not respond as strongly as in the AR4 suite of models, a result that could be corrected with an improved moisture-balance in the atmospheric model. The reduced computational requirements of the UVIC model allows modifications to the model to be evaluated quickly and enables rapid investigation of alternative emissions pathways not possible using complex GCMs.

Acknowledgments

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