Performance of current GCMs in high latitudes – in the context of global climate change and variability studies

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1. Introduction

According to estimates obtained using current coupled atmosphere ocean general circulation models (AOGCMs), polar regions play a crucial role in projected global warming. Usually this is explained by positive feedbacks in the polar climate system, sea ice being a prime consideration. Meanwhile, representation of high-latitude physical processes and feedbacks is one of weak spots of current GCMs. This results in significant biases demonstrated by GCMs in simulations of current polar climate, as well as in the high-latitude enhancement of across-model scatter in future climate projections. In this paper, the state of the art and tendencies of high-latitude climate modelling are considered in the context of global climate natural variability and anthropogenic change studies.

2. Problems of polar region representation in current GCMs

Polar regions are sites of specific phenomena, such as the very stable stratification in the lower troposphere; the low water vapour content; peculiarities of cloudiness; the unique stratification and fresh water budget of the Arctic Ocean; the World Ocean deep and bottom water formation in the sub-Arctic seas and the Sothern Ocean; complexities of the marine and terrestrial cryosphere; sharp orographic gradients (Greenland and Antarctica); small values of Rossby radius; etc. Additionally, sparse and inconsistent observational data available for the Arctic region prevent GCMs from proper validation.

In GCMs, the polar regions are marked with specific "high-latitude" numerical problems. Converging meridians in spherical coordinates calls for certain measures (near-pole filtering; employing rotated (for the Arctic Ocean), reduced or other special grids; etc.) to avoid computational instability when a reasonable time step is used. Poor representation of water vapour in the dry polar atmosphere by spectral models requires applying alternative approaches (e.g., semi-Lagrangian schemes). These and other features make the polar regions one of major challenges in general circulation modelling.

A comprehensive review of the polar region modelling problems can be found in the paper by Randall et al. (1998).

3. GCM performance in high latitudes

The three sources of the simulation data were 17 AMIP-II AGCMs (Gates, 1992), 19 CMIP2 AOGCMs (Meehl et al., 2000), and 8 IPCC DDC AOGCMs (IPCC-TGCIA, 1999). The AMIP-II simulations span the period 1979-1996 for which the SST and sea ice are prescribed from observations. The CMIP2 provides pairs of 80-year simulations (a control run with the constant atmospheric CO_2 concentration, and that with CO_2 increasing 1% per year), averaged over 4 consecutive 20-year periods. In the IPCC DDC simulations, usually spanning the period 1900-2100, the greenhouse gas (GHG) and sulphate aerosol concentrations were prescribed through the 20th century in accordance with observations and through the 21st century in accordance with GHG and aerosol scenarios IS92a (a 1% per year increase of CO_2). Another set of IPCC DDC simulations was carried out with GHG-only forcing (IS92a).

The set of plots below is illustrating some important biases in current GCM simulations of current polar climate and its future projections.

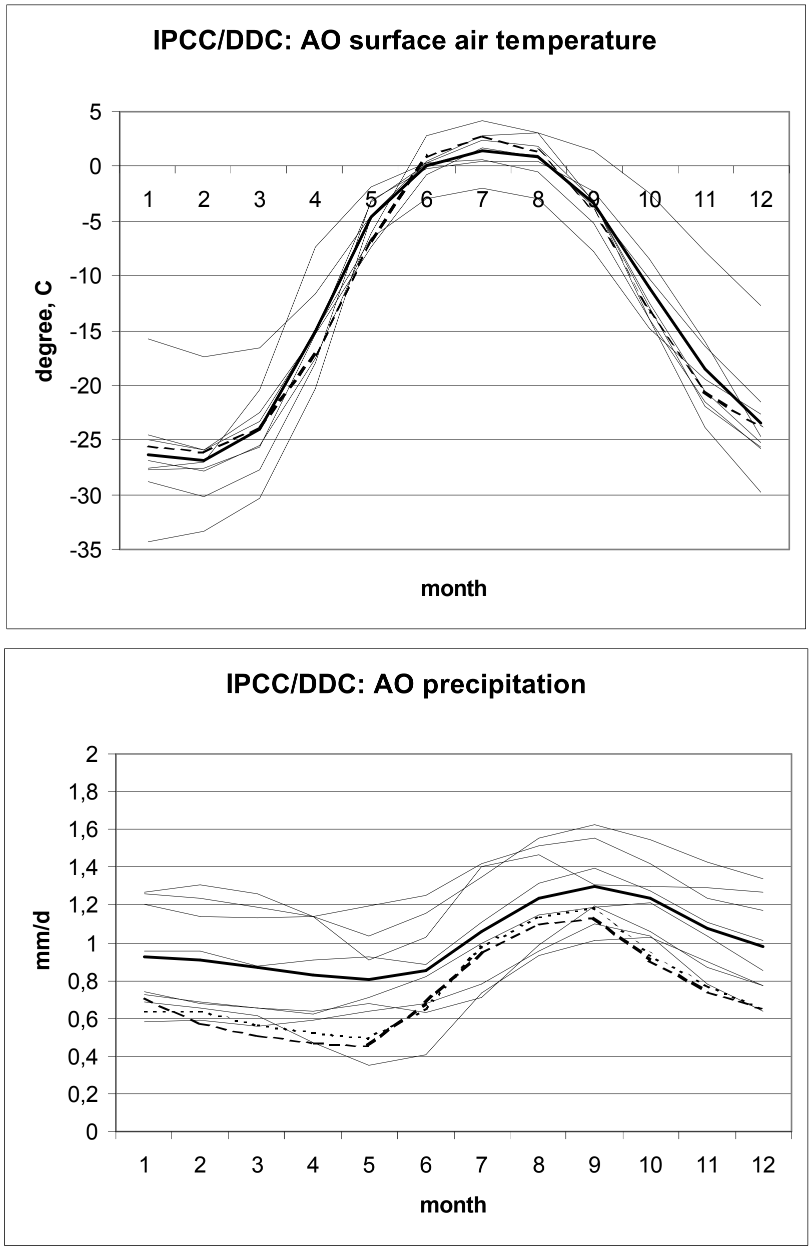


Figure 1. IPCC DDC AOGCM mean seasonal cycles of surface air temperature (^{0}C, upper panel) and precipitation (mm/day, lower panel) over the Arctic Ocean region within 70^{0}N (ocean only) averaged over the period 1961-90. The solid thin lines are for individual models, the solid thick lines are for the 8-model mean, the dashed lines are for the NCEP reanalysis (upper panel) and observational climatologies (lower panel).

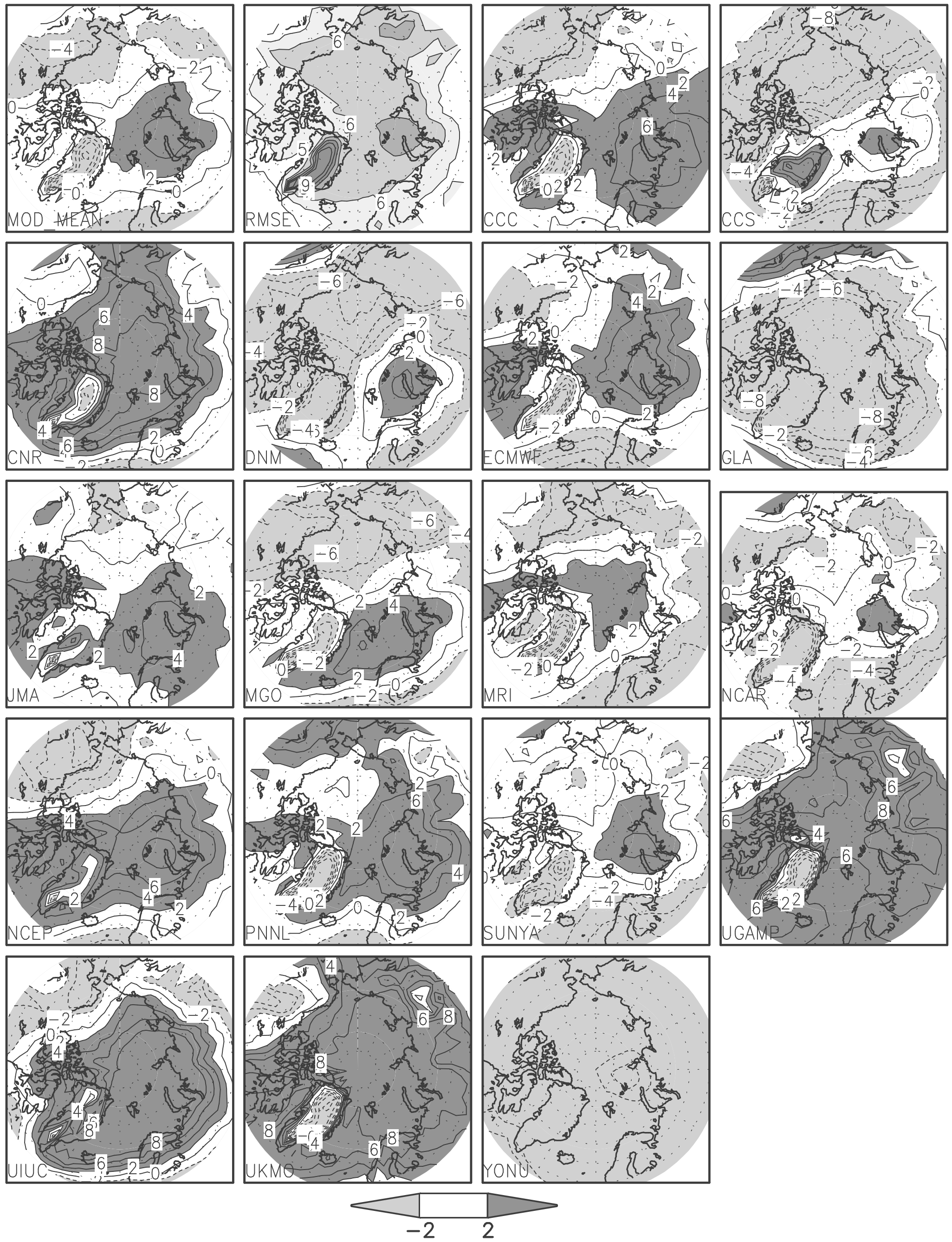


Figure 2. AMIP-II AGCM annual mean sea level pressure biases (with respect to the NCEP reanalysis) in the Northern Polar region. The two top left plots are, correspondingly, the model composite mean bias and across-model standard deviations. The rest of the plots are for the individual models. The shift of the Arctic polar air mass is apparently a common feature of the most AGCMs and AOGCMs (Walsh et al., 2001). The bias leads to systematic errors in the wind field, which makes clear, why, in spite of rather mature current status of modelling sea-ice alone (or coupled to the ocean), introducing comprehensive dynamics into AOGCMs is somewhat slow (McAvaney et al., 2001). The shading scale is for bias plots only, not for the standard deviation plot.

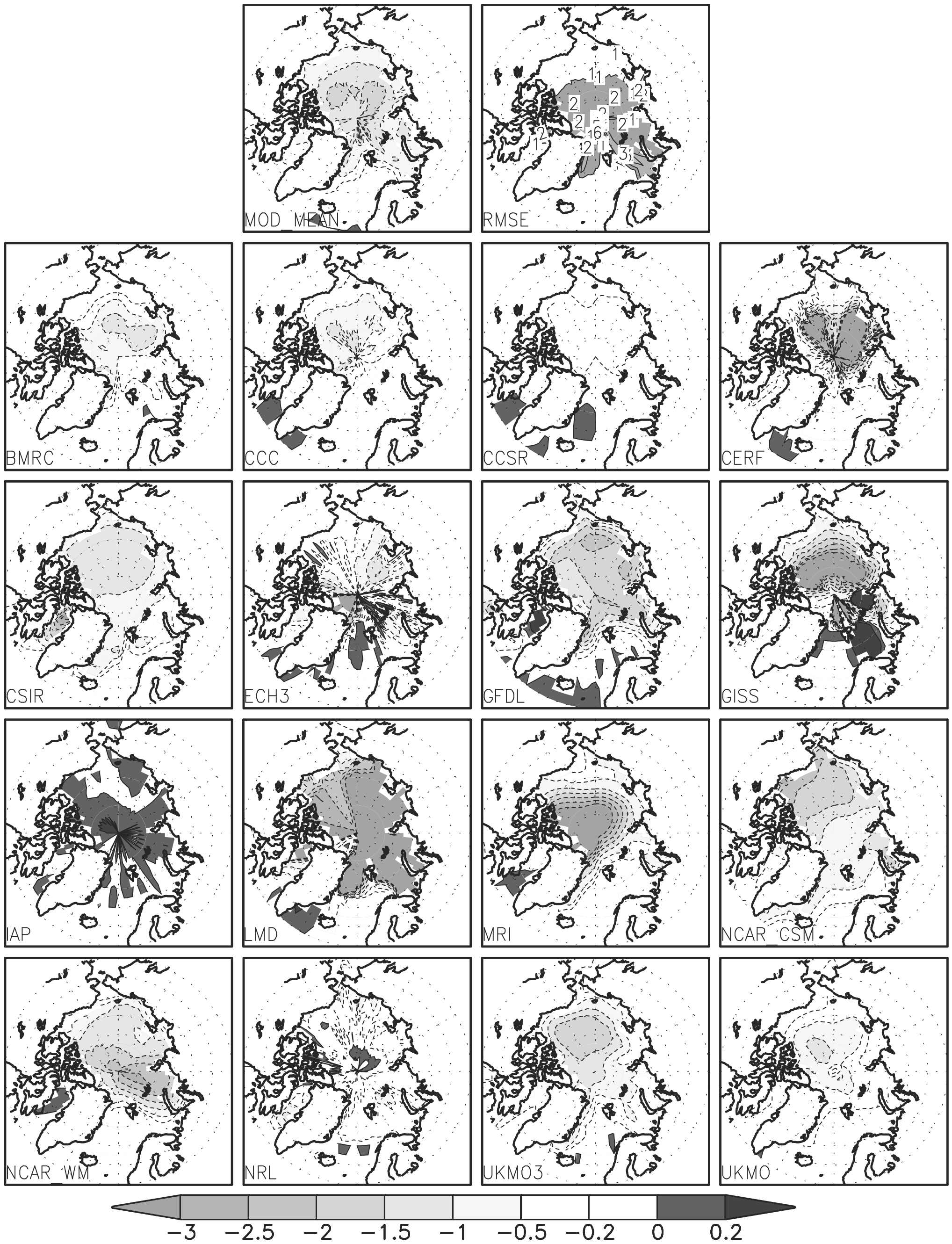
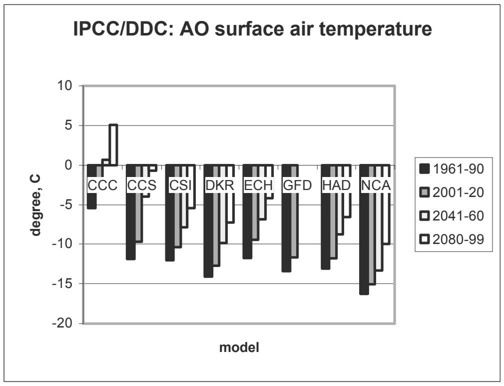


Figure 3. CMIP2 AOGCM annual mean sea-ice thickness projected change (m) by the time of CO_2 doubling. Top two plots show, correspondingly, the model composite mean difference with the mean control climate, and across-model standard deviations of the change. The rest of the plots are the changes for the individual models. The individual model local maxima of melting vary both geographically and in intensity. Some models show local increases of sea-ice thickness.



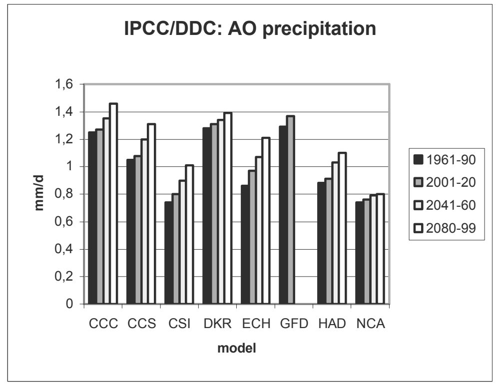


Figure 4. IPCC DDC AOGCM annual mean surface air temperature (left) and precipitation (right) over the Arctic Ocean region within 70^0N (ocean only) simulated under GHG-only increase (IS92a scenario) – for different time slices. The projected changes, at least by the mid-21st century, are generally smaller than the across-model scatter of the present day values.

4. Conclusions

Climate change projections with current AOGCMs are consistent in indicating at high latitudes as the regions of the strongest warming and pronounced relative increase of precipitation due to increasing concentrations of greenhouse gases. At the same time the high latitudes are marked with a considerable (probably, the most considerable) across-model scatter in current climate simulations and projections of climate change.

The across-model scatter reflects existing limitations of GCMs (in particular, those associated with differences in model climate sensitivities) resulting in significant uncertainties of the projections.

While modelling sea ice and associated feedbacks in the climate system appears to be a stumbling stone of the climate projections with the current generation of AOGCMs, comparable across-model scatter and biases obtained in AGCMs forced by prescribed SST/Sea Ice presume that coupling is not the only cause of major systematic errors in the polar regions.

The considerable biases in simulating basic features of current climate in the Arctic region and across-model scatter in projections of future Arctic climate change point to urgency in improvement of model descriptions of high-latitude physical processes and feedbacks along with further developing the observational data base in polar regions.

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