Abstract

The atmosphere-ocean general circulation models (AOGCMs) used for the IPCC AR4 climate model projections are evaluated for the Greenland ice sheet (GrIS) current climate modelling. The most efficient AOGCMs are chosen by comparison between the 1970-1999 outputs of the Climate of the Twentieth Century experiment (20C3M) and reanalyses (ECMWF, NCEP/NCAR). This comparison reveals that surface parameters such as temperature and precipitation are highly correlated to the atmospheric circulation (500 hPa geopotential height) and its interannual variability (North Atlantic Oscillation). The outputs of the three most efficient AOGCMs are then used to assess the changes planned by three IPCC greenhouse gas emissions scenarios (SRES) for the 2070-2099 period. Future atmospheric circulation changes should dampen the west-to-east circulation (zonal flow) and should enhance the Meridional Overturning Circulation (MOC). As a consequence, this provides more heat and moisture to the GrIS, increasing temperature on the whole ice sheet and precipitation on the north-eastern region. It is also shown that the GrIS surface mass balance (SMB) anomalies from the SRES A1B scenario are about -300 km³/yr with respect to the 1970-1999 period, leading to 5 cm of global sea-level rise (SLR) for the end of the 21st century. This work helps to choose the boundaries conditions for AOGCMs downscaled future projections.

1. GrIS modelling by IPCC AR4 AOGCMs outputs

- Results (projected onto a common 2.5° X 2.5° grid) from AOGCMs for the IPCC AR4 are used to select the most efficient AOGCMs for modelling the GrIS current climate (1970-1999) (Fettweis et al., 2009).
- The models are mainly evaluated by their ability to simulate surface parameters (near-surface temperature and precipitation) and the atmospheric circulation over Greenland.
- The atmospheric circulation pattern (Fig. 1) and its interannual variability (Fig. 2) over the GrIS can be evaluated through the simulated 500 hPa geopotential height. The dominant mode of the regional atmospheric variability around Greenland is the North Atlantic Oscillation (NAO), which controls the climatic conditions and surface parameters over the GrIS.
- However, any AOGCMs are able to model both the geopotential height and surface conditions of the current climate. Consequently, we choose MPI, HadCM3 and HadGEM1 as “middle-way” models for the circulation and surface conditions modelling.
- The atmospheric circulation changes induce only higher precipitation over the north-eastern GrIS (+10 mm yr⁻¹ in 2100), as shown in Fig. 2b.

2. AOGCM projections over 2070-2099

Future projections on Greenland are performed with the selected global models (MPI, HadCM3 and HadGEM1) and are based on the SRES A1B, A1B and A2. The selected AOGCM outputs are also interpolated onto the common 2.5° X 2.5° grid.
- The highest anomalies of the 500 hPa geopotential height should take place in northern Greenland (Fig. 3a), which should dampen the zonal circulation (zonal flow) and enhance the Meridional Overturning Circulation (MOC), providing more heat and moisture to the GrIS.
- The atmospheric circulation changes induce only higher precipitation over the north-eastern GrIS (+10 mm yr⁻¹ in 2100), as shown in Fig. 3b.
- The temperature increase should be up to +4°C in a verage over the GrIS and will be more pronounced along the northern coast (about +4°C due to changes in Arctic ice concentration, not shown).

3. GrIS SMB future projections

- Finally, we provide estimations of the GrIS SMB changes from 2010 to 2100 based on a multiple regression model. 4 uses AOGCM-projected anomalies of GrIS summer temperature and GrIS annual precipitation, computed on specific regions for the 1970-1999 period and extended to the 21st century. We refer to Fettweis et al. (2008) for more details.
- The projected SMB anomalies are estimated to be -350 mm yr⁻¹ in 2100 compared to the current climate (Fig. 4a) and lead to about 5 cm of sea-level rise (Fig. 4b), as projected by the IPCC (2007).

Fig. 1: Difference (in m) between 1970-1999 and projected 2070-2099 surface mass balance.

Fig. 2: Standard deviation (in m) of the 500 hPa geopotential height simulated by the AOGCMs for the 20C3M experiment and the reanalyses over the 1970-1999 period.

Fig. 3: (a) Annual 500 hPa geopotential height (in m) simulated by the selected AOGCMs (MPI, HadCM3 and HadGEM1) for three SRES scenarios over the 2070-2099 period. The anomalies from the 20C3M are marked in solid lines (for positive anomalies) and in dashed lines (for negative anomalies). In brackets, the average of absolute anomalies compared to the 1970-1999 period over the GrIS.

Conclusions

- Efficient AOGCMs for the current climate modelling can be used to evaluate GrIS SMB anomalies for the 21st century. However, large uncertainties remain in these SMB projections.

References