Greenland ice sheet projections from IPCC AR4 global models

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Abstract

*The atmosphere-ocean general circulation models (**AOGCMs**) used for the IPCC 4th Assessment Report (**IPCC AR4**) 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) (Franco 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.

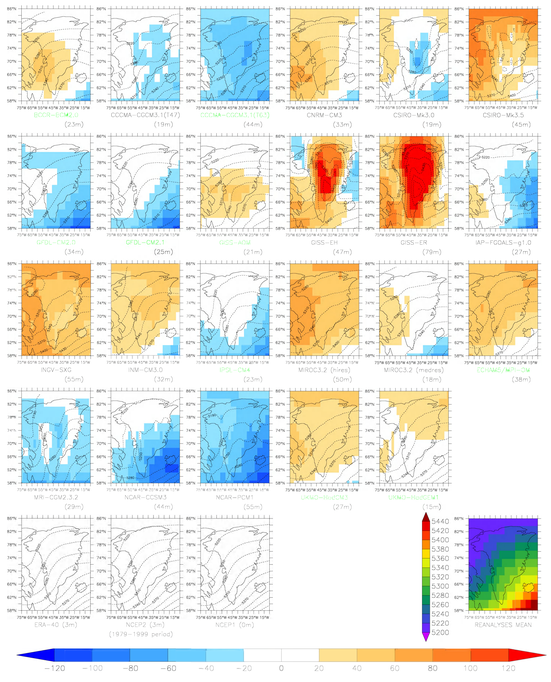


Fig. 1 : *Difference (in m) between the annual mean 500 hPa geopotential height simulated by the AOGCMs for the 20C3M experiment and the annual 500 hPa geopotential height from the reanalyses mean (ERA-40 and NCEP1) over 1970-1999. The 500 hPa geopotential height (in m) simulated by the AOGCMs is represented with dashed lines. In brackets, the average of the absolute bias in respect to the reanalyses over the GrIS. Efficient AOGCMs for the modelling of the atmospheric circulation on Greenland are written in green.*

• 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 with reliability both general circulation and surface conditions of the current climate. Consequently, we chose MPI, HADCM3 and HADGEM1 as "middle-way" models for the circulation and surface conditions modelling.

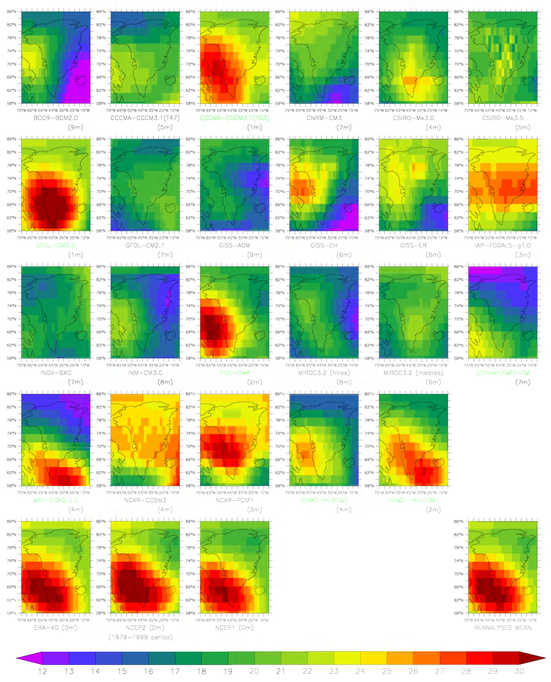


Fig. 2 : *Standard deviation (in m) of the annual 500 hPa geopotential height simulated by the AOGCMs for the 20C3M experiment and the reanalyses over 1970-1999. In brackets, the average of the absolute bias over the GrIS compared to the reanalyses mean. Efficient AOGCMs for the modelling of the NAO are written in green.*

2. AOGCMs 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 B1, A1B and A2. The selected AOGCMs 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 west-to-east 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 (+60 mm/yr 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 +8°C) due to changes in Arctic ice concentration (n ot shown).

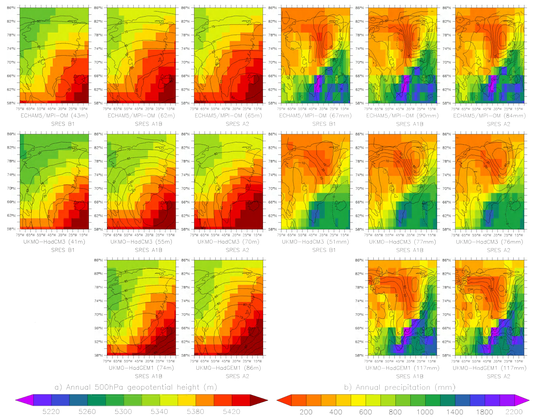


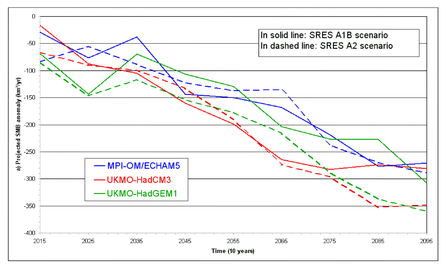
Fig. 3 : (a) *Annual 500 hPa geopotential height (in m) simulated by the selected AOGCMs (MPI, HADCM3 and HADGEM1) for three SRES scenarios over the 2070-2099 period. The anomalies (in m) compared to the current climate 500 hPa geopotential height (from the 20C3M) are marked in solid lines (for positive anomalies) and in dashed lines (for negative anomalies). In brackets, the average of absolute anomalies compared to the 1970-1999 period over the GrIS.* ***(b)*** *The same as a), but for the projected precipitation in mm/yr.*

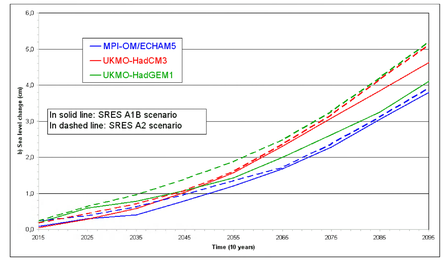
3. GrIS SMB future projections

• Finally, we provide estimations of the GrIS SMB changes from 2010 to 2100 based on a multiple regression model. It 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 -300 km³/yr 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. 4 : (a) *Time series of projected SMB anomalies for the 21st century, using AOGCMs outputs. The anomalies are decadal means and refer to the 1970-1999 period where the mean SMB rate is estimated to be about 350 km³/yr.* ***(b)*** *The same as a), but for the projected GrIS SMB changes expressed in equivalent sea-level rise (in cm). The computation was made using an ocean area of 361 million km².*





Conclusions

• The simulation of the atmospheric circulation and the NAO is assumed to be the main criterion for the GrIS modelling.

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

• A regional model coupled with a snow model and nested in a performing AOGCM could bring more precise results, by using more sophisticated physics and surface parametrizations adapted for polar regions.

• This work helps to choose a global model used as regional model boundaries conditions for future projection experiments, and represents a first step of Ph. D. researches dedicated to the GrIS modelling.

References

• Fettweis X. (2007) Reconstruction of the 1979-2006 Greenland ice sheet surface mass balance using the regional climate model MAR. The Cryosphere 1 : 21-40

• Franco B., Fettweis X., Erpicum M., Nicolay S. (2009) Greenland ice sheet projections from IPCC AR4 global models. Submitted in Climate Dynamics