Modeling the Effects of Greenland Ice Sheet Melting on AMOC Variability and Predictability

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Introduction

The evolution of the Atlantic meridional overturning circulation (AMOC) is one of the key uncertainties of future climate projections. State-of-art climate models that took part in the CMIP5 project show that over the 21st century the AMOC might reduce by 20-30% under the intermediate RCP4.5 scenario and by 36-44% under the high end RCP8.5 scenario relative to preindustrial values[1]. In the centuries thereafter, most models project a slow AMOC recovery (Figure 1).

However, a major uncertainty in these projections is the lack of enhanced meltwater input from the Greenland Ice Sheet (GIS) in the future scenarios. During the last decade a strong increase in mass loss of the GIS has been observed[2], a trend that is expected to continue into the future[3].

To improve AMOC projections, we have developed a future melt scenario of the GIS that is based on a relationship between 500mbar temperature changes and runoff. This parameterization of future GIS melt will be used in a model intercomparison project of RCP4.5 and RCP8.5 simulations and will allow us to assess:

1) The potential impact of future GIS melt on the AMOC evolution over the course of the next 200-300 years.
2) The likelihood of an AMOC collapse in the next 200-300 years.
3) How a weakening of the AMOC could in turn influence future melt rates of the GIS.

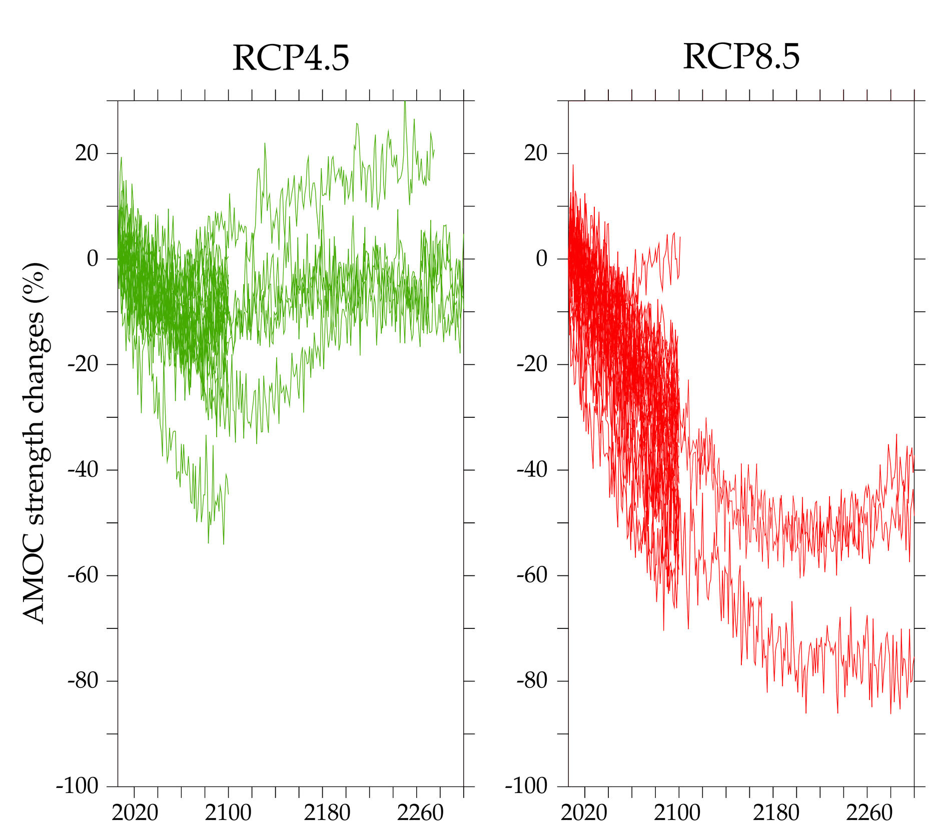

Figure 1:
RCP4.5 and RCP8.5 projected 2006-2300 AMOC evolution for a large ensemble of different models and different realisations. AMOC strength changes are defined here as the percentage change in the maximum of the annual mean meridional overturning mass streamfunction (kg s^{-1}) at 30^0N relative to the year 2006. For RCP4.5 (RCP8.5) a total of 21 (39) model/ensemble runs has been included.

References
1) Collins et al. (2013). Long-term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.
2) van den Broeke, M.R., Bamber, J., Ettema, J., Rignot, E., Schrama, E., van de Berg,W. J., van Meijgaard, E., Velicogna, I., and Wouters, B.: Partitioning recent Greenland mass loss, Science, 326, 984-986, 2009.
3) Fettweis, X., Franco, B., Tedesco, M., van Angelen, J.H., Lenaerts, J.T.M., van den Broeke, M.R. and Gallée, H.: Estimating Greenland Ice Sheet surface mass balance contribution to future sea level rise using the regional atmospheric climate model MAR, The Cryosphere 7, 469-489, 2013.
4) van Meijgaard, E., van Ulft, L.H., van de Berg, W.J., Bosvelt, F.C., van den Hurk, B.J.J.M., Lenderink, G., and Siebesma, A.P.: The KNMI regional atmospheric model RACMO version 2.1. Technical Report 302, KNMI, De Bilt, The Netherlands, 2008.
5) Wouters, B., Chambers, D. and Schrama, E.J.O.: GRACE observes small-scale mass loss in Greenland, Geophysical Research Letters, 35, L20501, 2008.

Methodology

The high resolution regional climate model RACMO2[4], has shown to be able to produce a regional climate that compares favourably with insitu and satelite-based observations[2].
In a simulation for the period 1960-2012 a high correlation is found in RACMO2 between summer (JJA) temperature changes at 500mbar and annual mean runoff for 8 different basins (Figures 2 & 3).

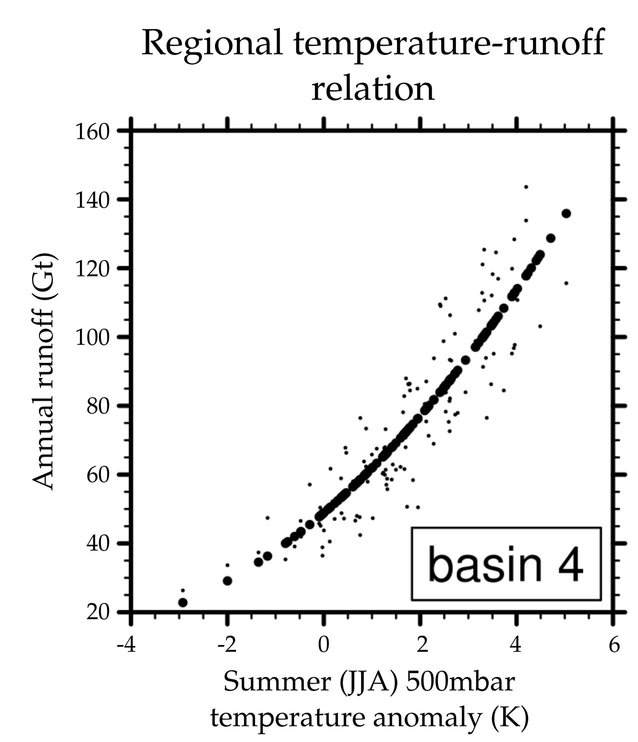

Figure 2:
Relation between JJA 500mbar temperature changes and annual mean runoff within a single basin of the Greenland Ice Sheet, as found in a RACMO2 simulation for the period 1960-2012.

Figure 3:
Basins of the Greenland Ice Sheet following[5], interpolated on the RACMO2 grid. White line indicates the RACMO2 ice margin.

A second order polynomial fit to the relation between 500mbar summer temperature changes and annual runoff as found for the 8 basins, are used to translate CMIP5 multi-model-mean RCP4.5 and RCP8.5 temperature projections (Figure 4), into projections of Greenland runoff changes for the period 2006-2300 (Figure 5).
The projections will be used to force state-of-the-art global climate models within a large AMOC-MIP setup. Moreover, the developed methodology enables the inclusion of GIS runoff changes in GCM climate change projections not only as a forcing, but also as a climate feedback through the coupling with upper air temperature changes.

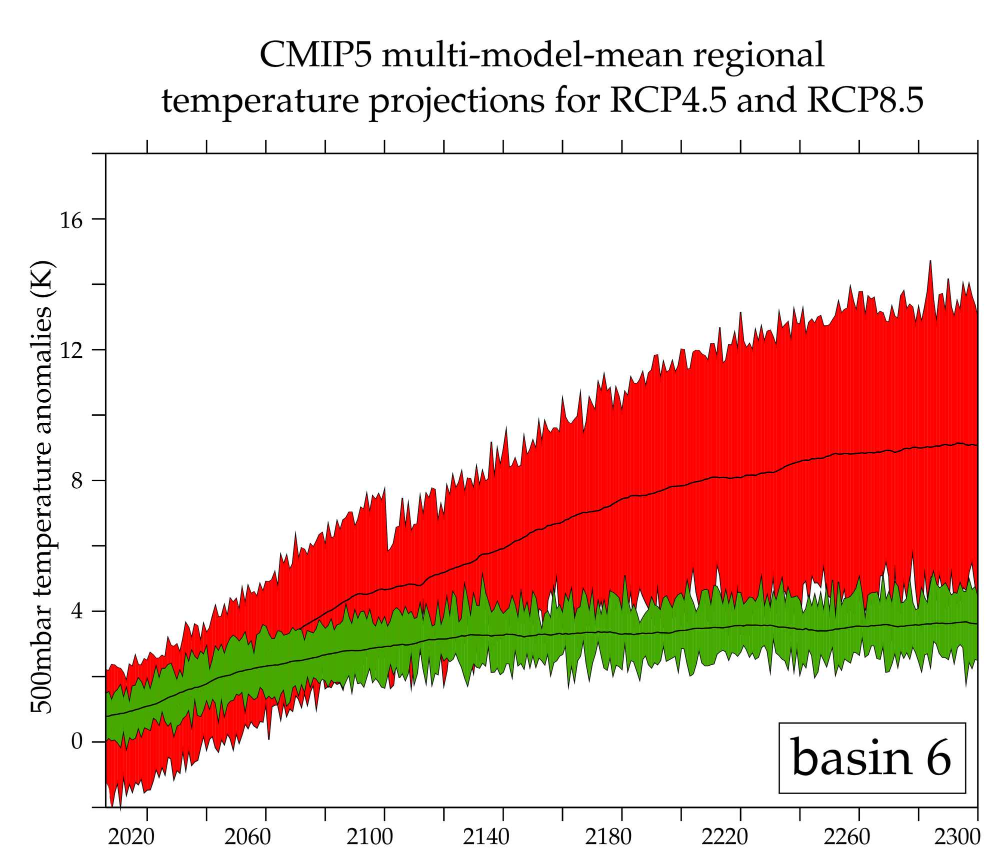

Figure 4:
CMIP5 multi-model 500 mbar temperature changes for basin 6 for RCP4.5 (green) and RCP8.5 (red).
Note that the number of available simulations strongly decreases after 2100 AD. Thick black lines give multi-model-mean and shaded area the model spread (1σ). All model output is regridded to a common 1^0x1^0 grid and anomalies are taken with respect to the 1971-2000 AD period of the corresponding historical CMIP5 simulation. In case multiple ensemble members where present in the CMIP5 database, an ensemble mean was used per climate model.

GIS SMB projections

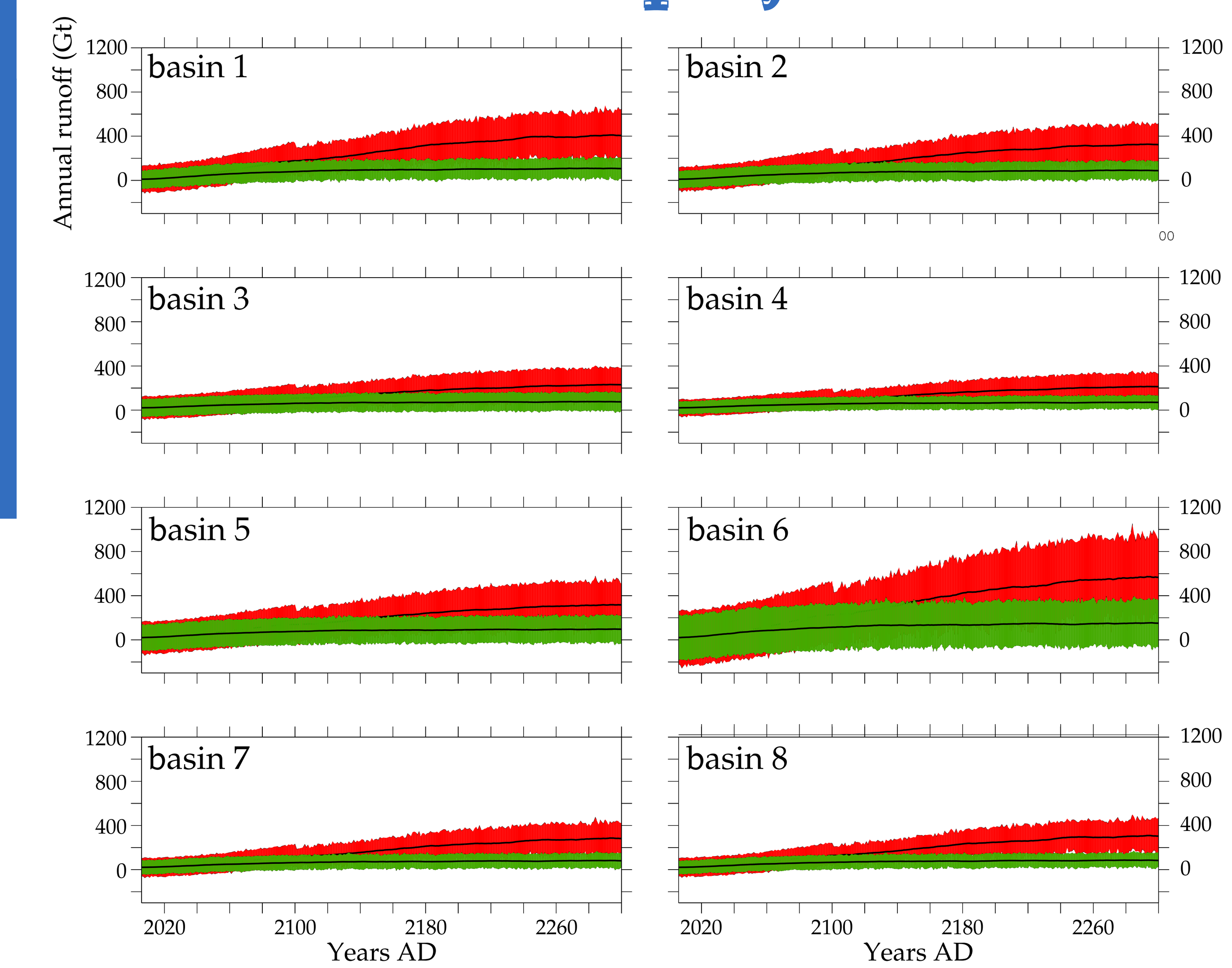

Figure 5: Runoff projections for the 8 different basins of the Greenland Ice Sheet based on RACMO2 500mbar JJA temperature - annual runoff relations and on CMIP5 ensemble mean 500mbar temperature change projections for RCP4.5 (green) and RCP8.5 (red). Thick black lines give mean and shaded area the spread (1σ) based on the spread in the temperature projections.

The parameterized runoff changes thus include projections of local changes in P-E, snow and ice melt based on high resolution regional climate modelling. Basin scale differences in the boundary conditions (most notably topography), and position with respect to the westerly storm tracks, result in considerable spatial differences in projected runoff changes.

AMOCMIP outline

In the coming years we will perform a model intercomparison (AMOCMIP) for several different experimental setups:

1) RCP4.5/8.5 + projected runoff changes
2) RCP4.5/8.5 + interactively calculated runoff changes
3) RCP4.5/8.5 + projected runoff changes + observed/RCM -based baseline runoff and calving fluxes

All modeling groups are more than welcome to participate, please feel free to contact us (pbakker@ceoas.oregonstate.edu).

Group Name	Model Name
CCCMA	CanESM
UNSW	CSIRO-Mk3L-1-2
CSIRO	ACCESS1-4
GISS	GISS-ER-2
OSU	OSUVic
NCAR	CCSM4/CESM1
LANL	CCSM4/CESM1
IMAU	CESM1

Table 1:
Participants in the AMOCMIP so far.