Surface Mass Balance Variations of the Greenland Ice Sheet on Decadal to Centennial Time Scales

M194B

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Introduction

We assess the influence of anthropogenic greenhouse gases on the surface mass balance of the Greenland ice sheet in a suite of global simulations of the past millennium using the Community Climate System Model 3 (Collins et al, 2006) at two different resolutions. These simulations use boundary conditions consistent with those produced by the Paleoclimate Modelling Intercomparison Project Phase 3, including two different volcanic reconstructions and time-varying orbital forcing. We first examine how ice sheet conditions vary over the preindustrial period. We present connections between Greenland surface temperatures and precipitation and natural sources of variability, including external forcings like volcanic and solar, as well as internal modes of variability. From these connections, we create an empirical model of Greenland surface temperatures and precipitation, which we compare against those variables obtained directly from simulations over the industrial period. Thus, we make an estimate of the direct effect of greenhouse gases and anthropogenic aerosols on Greenland surface conditions in CMIP5 industrial simulations using CCSM3.

EXTERNAL
Volcanic
Solar

INTERNAL
ENSO
NAO/NAM
East Atlantic
Pacific/North American

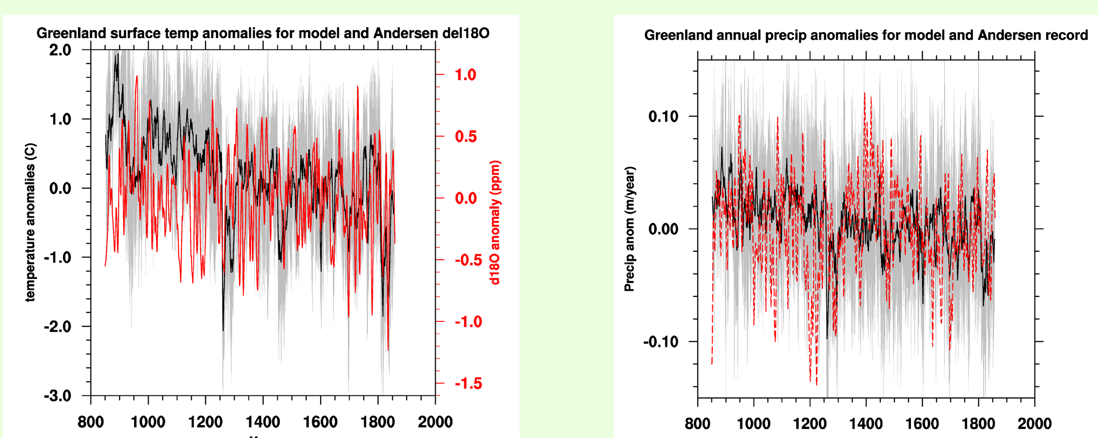
North Atlantic conditions
Sea ice
Greenland temperature
Greenland precipitation
Atlantic Meridional Overturning Circulation
Atlantic Multidecadal Oscillation

Simulations & Validation

Five millennium simulations initialized from equilibrated control runs at two different atmospheric resolutions (T42 and T85)

- One run at each resolution using Gao et al (2008) volcanic time series and fully transient forcings
- One run at each resolution using Crowley et al (Pers. Comm. 2009) volcanic time series and fully transient forcings
- One run at T42 with Gao et al (2008) volcanics, other forcings transient except greenhouse gases

Five industrial simulations extending millennium simulations to 2000, using CMIP5 forcings (and RCP historical ghg concentrations)

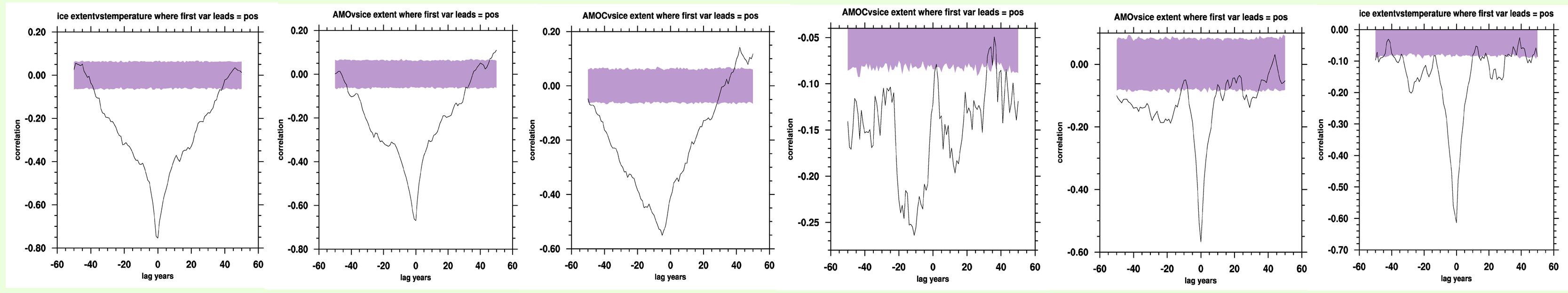


Comparing Greenland temperature and precipitation time series (black) over past millennium against d18O and accumulation records (red) compiled from multiple ice cores in Greenland (Andersen et al, 2006)

Millennium Period

North Atlantic sea ice extent

Greenland temperatures are highly anti-correlated with N. Atl. sea ice extent (T42 runs ~-0.7 and T85 runs ~-0.6). Correlations peak for sea ice lags of 0-1 year behind Greenland temperatures and precipitation, so assume little causal influence, but the processes are affected by common climate features.



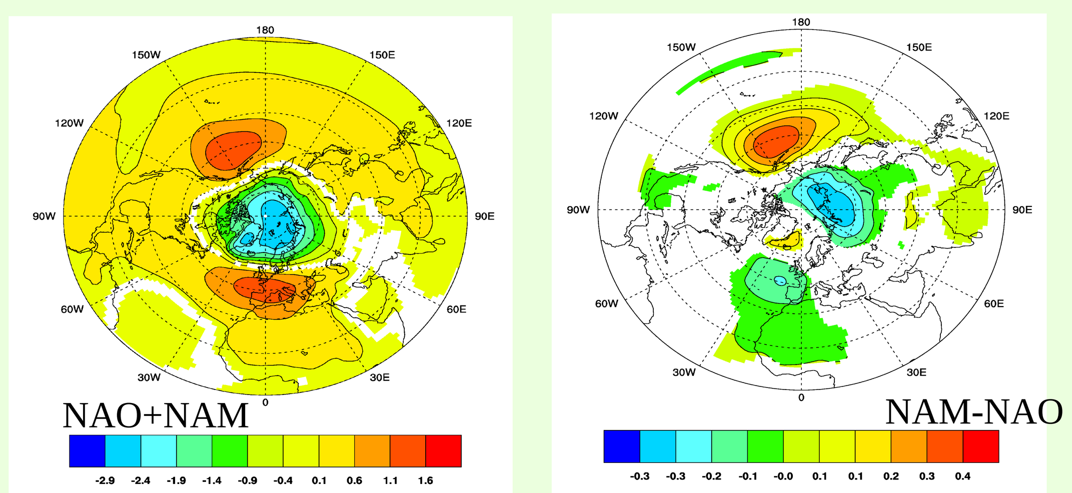
Lagged correlations for a T42 (left) and T85 (right) run between temperature, sea ice, AMO and AMOC

AMO and AMOC

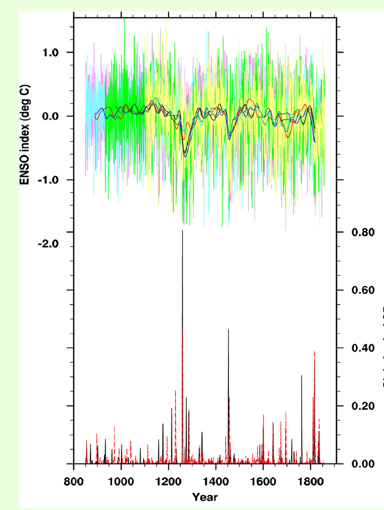
AMO and AMOC appear strongly connected to sea ice. Both sea ice and the AMO have strong relationships with volcanic and solar forcing. AMOC, however, shows no significant response to volcanoes, although it is correlated with the AMO and anti-correlated with sea ice at a lag of 4-8 years. Thus, since AMO and AMOC follow Greenland temperatures, we exclude them from regression analysis.

NAO and NAM

Both NAO and NAM are effectively white-noise processes on timescales longer than a year. Although they are highly correlated (~0.9), including both in the regression analysis explained more Greenland variance than just one. Therefore, defined two new indices, one as NAO+NAM and the other NAM-NAO.



Regression of NAO+NAM and NAM-NAO against sea level pressure. Significant values in colours.



ENSO time series with volcanic AOD. 30-yr smoothed values overlain.

ENSO

ENSO periods in CCSM3 are overly strong in 2-3 year time-scales, but also include multi-decadal power. The coincidence of multi-decadal variations with large volcanic events yields anti-correlations of -0.6.

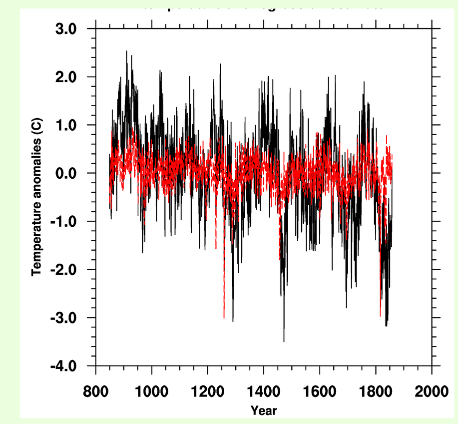
Regression

Perform regressions of Greenland temperatures, precipitation against volcanic aerosol optical depth (lag=1 year), total solar irradiance, NAO+NAM, NAM-NAO, ENSO, East Atlantic Pattern, Pacific North American Pattern. At low frequencies, these variables explain at most 15% of the variance of any of the other variables, with the exception of volcanic forcing and ENSO who share about 50% their variance in common.

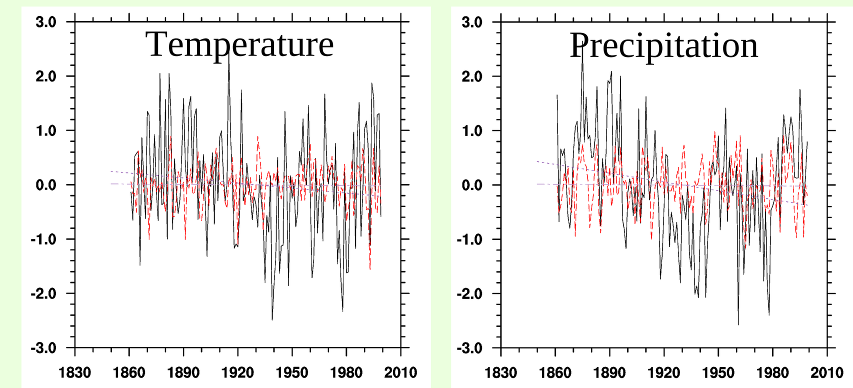
Although the total power of the regressions is low (R^2 ~20% for T42, 12% for T85), the low-frequency components are quite well modelled. (~60% for temperature, 50% for precipitation). Uncertainties in regression coefficients are 0.03, but solar and ENSO datasets have autocorrelations that raises their uncertainties to as much as 0.10.

Industrial Period

Plots show modelled Greenland temperatures and precipitation in black and regression model estimates in red.

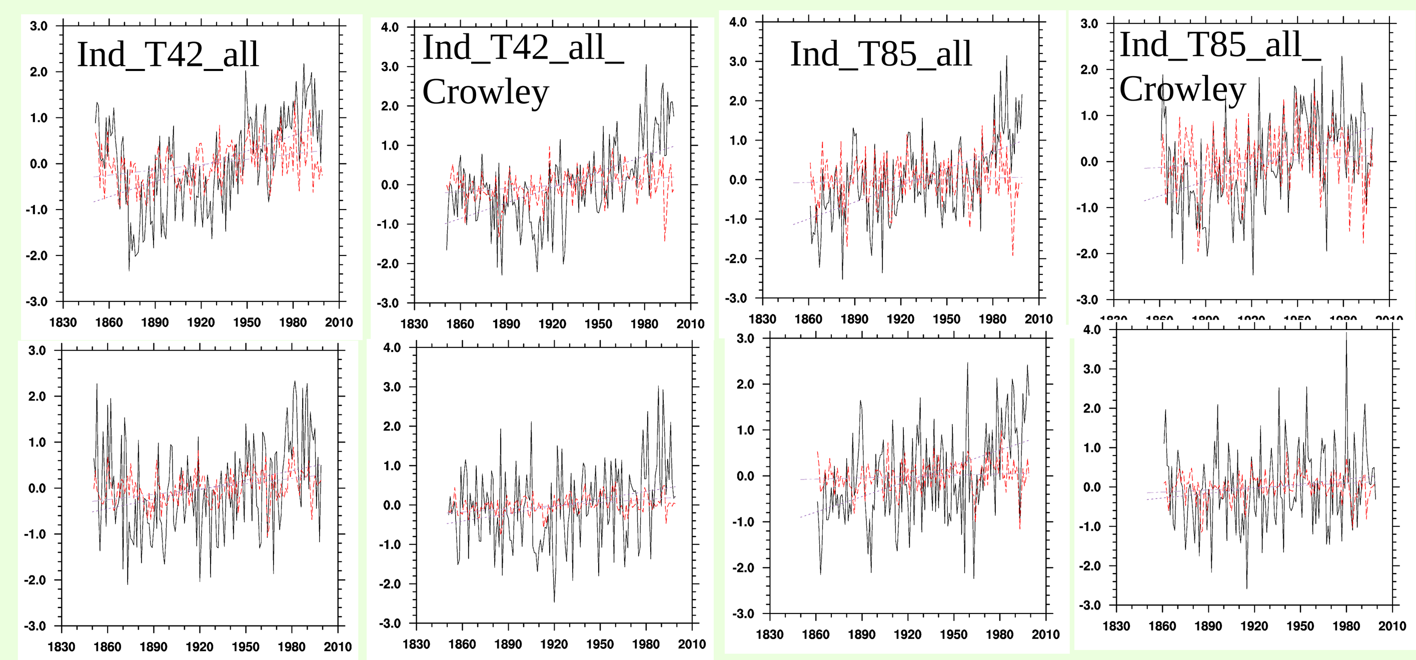


Example of residual fit for T42 run.

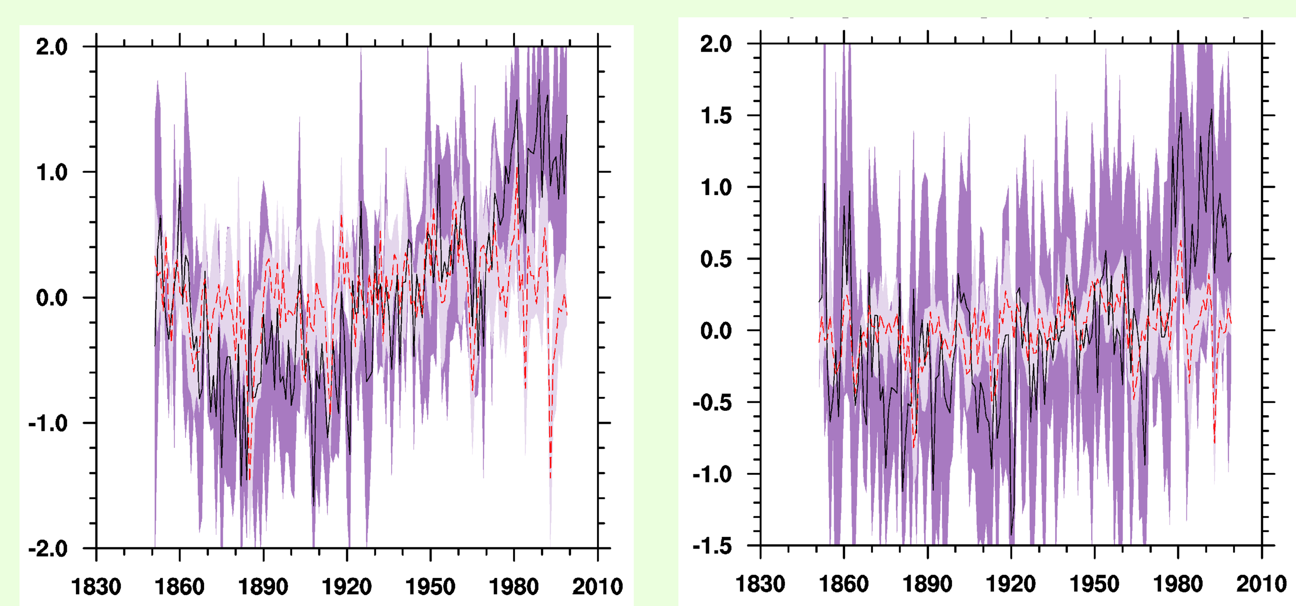


Ind_T42_sol – no transient greenhouse gases

The plots of the remaining runs are shown below, with temperature on top, and precipitation below.



Temperature trends are 3-5 times larger from the model than estimated by the regression relationships for all simulations except Ind_T42_sol, which has greenhouse gases and aerosols held fixed. Differences for precipitation are less strong, with similar trends between the modelled and estimated datasets until the 1970's.



Temperature (left) and precipitation (right) averaged over all fully-transient runs for values extracted from the model (black) and those from regressions (red).

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NAME	Volcanic		Solar		NAO+NAM		NAM-NAO		ENSO		EA		PNA	
	Temp	Precip	Temp	Precip	Temp	Precip	Temp	Precip	Temp	Precip	Temp	Precip	Temp	Precip
Mill_T42_all	-0.17	-0.13	0.22	0.10	-0.22	0.13	-0.16	-0.23	0.12	0.03	0.13	-0.09	-0.13	-0.11
Mill_T24_all_Crowley	-0.21	-0.13	0.13	0.07	-0.21	0.08	-0.14	-0.14	0.07	0.06	0.12	-0.03	-0.12	-0.12
Mill_T42_sol	-0.22	-0.13	0.09	0.04	-0.23	0.12	-0.24	-0.30	0.06	0.01	0.18	-0.04	-0.13	-0.13
Mill_T85_all	-0.32	-0.18	0.08	0.06	-0.43	-0.08	-0.06	-0.13	0.09	0.06	0.07	-0.16	-0.01	-0.05
Mill_T85_all_Crowley	-0.32	-0.23	0.07	0.04	-0.44	-0.10	-0.05	-0.07	0.11	0.02	0.03	-0.20	-0.04	-0.04

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