EFFECTS ON CLIMATE AND VEGETATION OF A MELTED GREENLAND ICE SHEET

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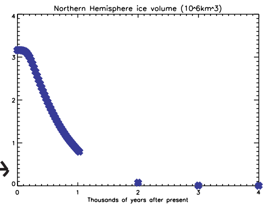
(1) INTRODUCTION

Increasing atmospheric CO2 concentrations, and the resulting temperature increases, have led to speculation that the Greenland ice sheet could disappear, or at least be greatly reduced, in the relatively near future.

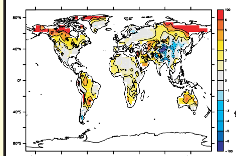
Indeed, forced by anthropogenic CO2 emission scenarios, and calculated changes in the earth's orbit, the LLN 2-D earth-system model points to a possible complete melting of the Greenland ice sheet within the next 2,000 years[1]



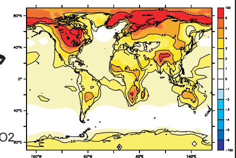
Using a coupled ocean-atmosphere model, and a vegetation model, we investigate the effect of a melted Greenland ice sheet, on both climate (in particular the dynamics of the atmosphere), and vegetation.

(2) MODEL DESCRIPTION

Our version of the IPSL[2] coupled ocean-atmosphere general circulation model (GCM)[3] is made up of an atmosphere model, an ocean model, a sea-ice model, and a land surface scheme. The model resolution is 5º longitude by 4º latitude. The present day simulated climate compares reasonably well with observations, although there is a positive surface temperature bias over the continents. Ocean models typically take hundreds of years to reach equilibrium. In order to overcome this difficulty, we use a version of the model in which the deep ocean temperatures and salinity are damped towards those of present day observations, although regions of deep mixing are left to evolve freely. By applying this damping, the time taken to reach equilibrium is greatly reduced. The model has been run under x3 CO2 conditions, and the resulting changes in 2m air temperature reproduce all the geographical and temporal changes seen in most fully coupled GCMs, as summarised by the IPCC[4].



Annual mean simulated surface temperature error in the control.

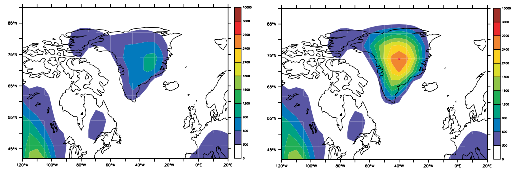


Simulated surface DJF temperature change under 3xCO2 conditions.

(3) METHODOLOGY

We run the GCM to spin up, under control conditions, and with a melted Greenland ice sheet. In the no-Greenland case, the topography in the Northern Hemisphere is taken to be the current level of the bedrock. This neglects any isostatic rebound which may take place.

The ice sheet surface type in the northern hemisphere control is replaced by bare soil in the no-Greenland case, and consequently the albedo over Greenland is reduced by up to 35% in the annual mean. The sea level rise which is expected to take place, of approximately 6m, is neglected, as is the input of fresh water into the Atlantic. This is because we are carrying out an equilibrium simulation, and due to the ocean damping are unlikely to correctly simulate transients.

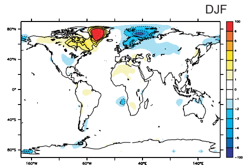


Altitude (metres) in the melted Greenland simulation........and in the control.

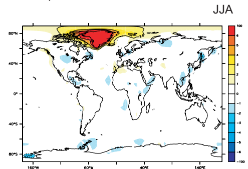
(4) RESULTS

The 2m air temperature in the no-Greenland simulation, minus that in the control, is shown below, for the DJF (northern hemisphere winter) and JJA (northern hemisphere summer) seasons.

DJF

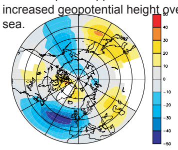


JJA

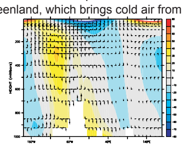


The dominant change is a year-round increase in temperature over Greenland, due directly to the decrease in albedo and to the decrease in altitude. The warming is greater in JJA than in DJF because the mean daily insolation is greater in JJA, and because the albedo change is greater in JJA due to the lack of snow cover.

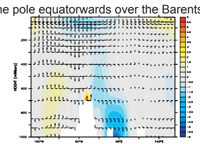
Associated with the direct changes in surface temperature due to albedo and altitude changes, there are indirect changes in the atmospheric circulation. The removal of the Greenland ice sheet results in an increase in geopotential height in the Greenland region. Associated with this, there is a region of decreased geopotential height in the North Atlantic, accompanying which there is a wavenumber three pattern of geopotential anomalies centred around 50ºN. The response is essentially barotropic, with the anomalies propagating without a change of sign throughout the troposphere. The region of cooling in the Barents Sea in DJF is seen to be most intense at the surface. The cooling is associated with substantial growth of the sea ice throughout the year. The cooling appears to be forced from above by the atmosphere, and amplified by the sea-ice albedo effect. The cooling from the atmosphere appears to be linked with enhanced equatorword flow east of Greenland, associated with the increased geopotential height over Greenland, which brings cold air from the pole equatorwards over the Barents sea.



DJF 850mbar geopotential height anomaly, no Greenland - control

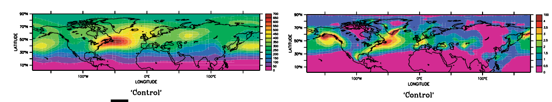


Geopotential height at 75oN, no Greenland - control. Horizontal vectors are zonal wind changes, vertical arrows are meridional wind changes



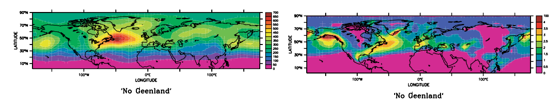
Temperature at 75oN, no Greenland - control. Horizontal vectors are zonal wind changes, vertical arrows are meridional wind changes

As well as changing the stationary waves in the atmosphere, the removal of Greenland also has affects on the transient behaviour of the atmosphere. Regions of high transient activity are called 'storm tracks', and they are of interest because they influence the large scale precipitation.



Storm tracks ($\overline{Z'^2}_{500mbar,\ high\ pass}$) in DJF

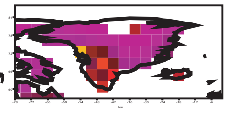
Large scale precipitation (mm/day) in DJF



In the no-Greenland case, the intensity of the north atlantic winter storm tracks is decreased. Associated with this is a corresponding decrease in large scale precipitation. The decrease in storm track activity is likely to be related to the fact that in the no Greenland case, the meridional temperature gradient is decreased over the North Atlantic.

To test the response of vegetation to a melted Greenland ice sheet, we have run the vegetation model ORCHIDEE, forced by the no-Greenland climate.

Fraction of grass-like vegetation over Greenland, from the vegetation model ORCHIDEE, forced by the no-Greenland climate.



This points to a dominance of grass-like vegetation over the majority of Greenland, replacing the ice sheet. The remainder is bare soil (two gridboxes on the northern coast of Greenland) and tree-like vegetation on the southern borders. The simulation of vegetation will be soon extended over the globe.

(5) CONCLUSIONS

This work implies that a future melting of the Greenland ice sheet will:

(1) Directly increase surface temperature locally over Greenland, due to the decrease in altitude and change in albedo.

(2) Indirectly lead to a cooling over the Barents Sea, associated with an increase in geopotential height over Greenland and advection of cold air equatorwards east of Greenland, and amplified by the sea-ice albedo effect.

(3) Result in weaker storm tracks and an associated decrease in large scale precipitation.

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Thanks to Marie-France Loutre for providing the data from LLN-2D.

Thanks to Masa Kageyama for the storm track analysis code.

REFERENCES AND NOTES

(1) Loutre (2001), 'Global climatic features over the next million years and recommendation for specific situations to be considered', BIOCLIM Deliverable D3.

(2) Institut Pierre Simon Laplace, Paris

(3) 'Towards an Earth System Model : Key results of the new IPSL Coupled Model', The IPSL group on coupled climate modelling. EGS - AGU - EUG Joint Assembly, Nice, France, April 2003 - PosterEAE03-A-09399; CL8-1TU2P-0881

(4) Intergovernmental Panel on Climate Change, Houghton et al (2001), 'Climate Change 2001: The Scientific Basis'.