Greenland and the Northern Hemispheric Winter Circulation

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ABSTRACT

The impact of Greenland's orography on the general circulation is investigated. Two 10 year simulations are conducted using the NCAR Community Climate Model (CCM3), run at T106 horizontal resolution; A control simulation and a simulation where Greenland's orography is set to sea level. A comparison of the two simulations indicates that Greenland has a significant impact on the general circulation at middle and high latitudes on the Northern Hemisphere. The storm tracks over the North Atlantic are shifted northward in the presence of the mountain. The difference fields of sea level pressure, geopotential height and temperature have a wave-like pattern that extends around the earth. The first wave of this pattern is linked to the blocking and diversion of cold low level air masses west of Greenland. The result is a trough on the upstream side of the mountain. Thus, Greenland's impact on the general circulation is fundamentally different from the impact of the Rocky Mountains and the Tibetan Plateau where a trough is created downstream of the mountains.

1. Introduction

Despite the size and location of Greenland near the North Atlantic storm tracks, little is known about its impact on the general circulation. So far, the meteorological research on the effect of Greenland has mainly been limited to the surface energy balance, precipitation and katabatic flow. On a larger scale the impact of Greenland on the airflow east of southern Greenland has been studied through case studies, and Greenland's orography found to be important for the synoptic systems in its vicinity (e.g. Kristjánsson and McInnes, 1999; Ólafsson, 1998; Doyle and Shapiro, 1999). These studies indicate the possibility that Greenland not only affects the atmosphere in its vicinity but also in areas farther downstream. The aim of this study is get a better understanding of how Greenland affects the Northern Hemispheric circulation on large spatial and temporal scales.

2. Experimental setup

The atmospheric general circulation model CCM3 (Kiehl et al., 1998) is applied in this study. The horizontal resolution T106 spectral truncation (approximately $1.1^\circ \times 1.1^\circ$ transform grid) is applied, at which the southern tip of Greenland is well resolved and reaches above 2000 m. The vertical coordinate is a hybrid sigma-pressure coordinate and there are 18 levels. The CCM3 includes a land surface model and is here run with a data ocean model, using climatological sea surface temperatures. The experiments consist of two 10 year simulations, a control simulation, termed 'Control', and a simulation where the orography of Greenland is set to sea level, termed 'NoGreen'. Outputs are monthly averaged values, as well as 6-hourly values for a few basic variables. The results presented are mean winter (December-February) Northern Hemisphere simulated climates.

3. The results

A comparison of the mean sea level pressure in the Control simulation and the NoGreen simulation (figure 1) shows that when Greenland's orography is removed the Icelandic low does not curve around the southern tip of Greenland as it does in its presence. There is also lower sea level pressure over northern Canada, Alaska and northern Siberia in the Control simulation than in the NoGreen simulation. Over Britain and western Europe the effect is opposite. Here Greenland contributes to higher sea level pressure. The major troughs at the 500 hPa geopotential level are not as well developed in the NoGreen simulation as in the Control simulation (figure 2) and the gradient between Iceland and Scotland is slightly weaker, resulting in a decrease in the wind speed and a southward shift of the jet stream (not

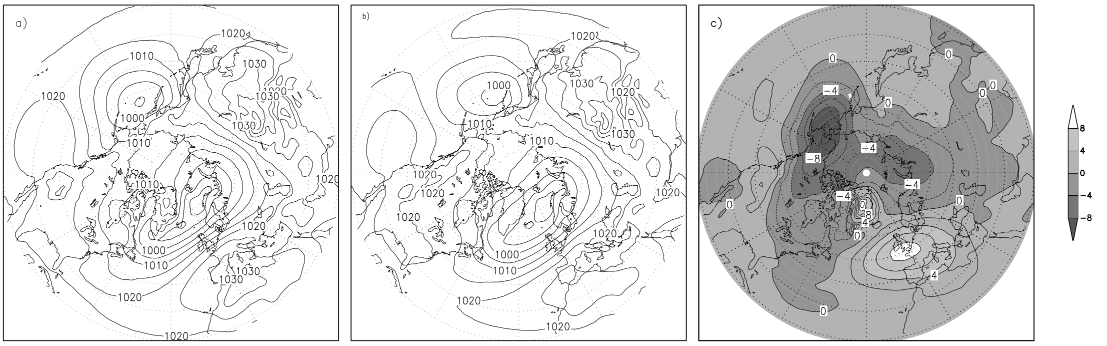

Figure 1: The mean winter (DJF) sea level pressure (hPa) in a) the Control simulation and b) the NoGreen simulation. c) The mean sea level pressure difference Control-NoGreen. The contour interval is 5 hPa in a) and b) but 2 hPa in c).

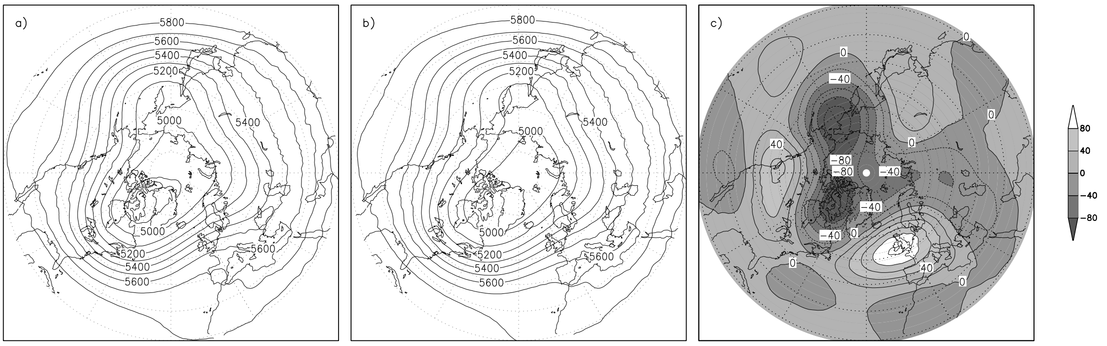

Figure 2: The mean winter (DJF) 500 hPa geopotential height (m) in a) the Control simulation and b) the NoGreen simulation. c) The mean 500 hPa geopotential height difference Control-NoGreen. The contour interval is 100 m in a) and b) but 20 m in c).

shown). The difference field for the 500 hPa height (figure 2c) shows that Greenland generates a planetary scale disturbance with a wave number equal to 3, the largest anomalies being a low over Northeast Canada, a high over western Europe and a low over the northern part of the Pacific. The temperature difference in the lower troposphere can shed light on the cause of the pattern seen in figure 1 and 2. Figure 3 shows the mean winter potential temperature differences at the 850 hPa level and the 500 hPa level. The presence of Greenland leads to colder air masses over Northeast Canada, Northeast Siberia and also immediately east of Greenland. The air masses over western Canada, the eastern Atlantic and Britain, on the other hand, are warmer in the presence of the Greenland mountain. Note that while the difference over North America and Eastern Siberia is largest in the lower troposphere, the difference is greater at the 500 hPa level over the eastern Atlantic and Britain. Due to the symbiotical link between the planetary scale flow and the storm tracks, it is reasonable to expect some influence of Greenland on the storm tracks. In order to investigate the storm track structure of the simulations the geopotential height data was bandpass filtered with a 2.5-6 day filter. In the Control simulation the storm track structure over the North Atlantic south of Greenland curves slightly and runs parallel to the southeastern coast of Greenland (figure 4a). It has its greatest intensity from Newfoundland towards Iceland and least intensity in the area extending from northeastern Siberia over the North Pole and into northeastern Canada. When Greenland's orography is removed, the storm tracks have less intensity over the North Atlantic, i.e., the storm track structure in the NoGreen simulation is no longer parallel to the southeastern coast of Greenland but has shifted slightly to the south (figure 4b). This leads to less activity over the North Sea, Scandinavia and Eastern Europe while the intensity has increased over the Bay of Biscay and southwestern Europe. This southward shift in the location of the storm tracks results in a compatible change in the precipitation pattern (not shown).

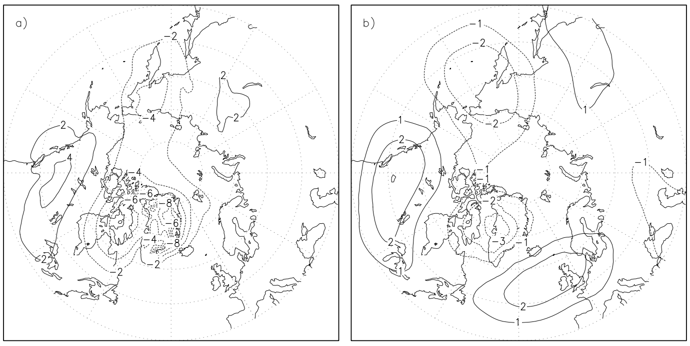

Figure 3: The mean winter (DJF) potential temperature difference (K), Control-NoGreen at a) the 850 hPa level and b) the 500 hPa level. The contour interval is 2K in a) and 1 K in b). The zero contour is suppressed.

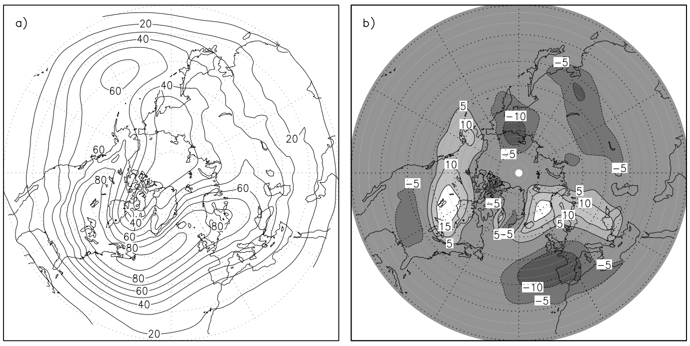

Figure 4: The storm track structure. The winter (DJF) 500 hPa geopotential height 2.5-6 day bandpass statistics. a) Root mean square standard deviation (m) and b) the difference root mean square standard deviation field, Control - NoGreen, (m). The contour interval is 20 m in a) and 5 m in b). The zero contour is suppressed.

4. Discussion

What is the source of the wave-like pattern found in the 500 hPa geopotential height disturbance field? The temperature difference fields show that Greenland contributes to cold low level air on both sides of the mountain. This is due to the blocking effect that prevents passing cyclones from advecting cold air away. On the eastern side of Greenland, cyclones in the vicinity of Iceland advect cold and dense low level air towards Greenland where it accumulates in an orographic blocking. On the west side of Greenland the air mass is cooled down by radiative heat loss during the polar winter over the cold land masses and the sea ice. Here the mountain acts as a barrier, making it more difficult for the cold air to spread out or to be advected by passing cyclones. This barrier effect was found in the case study of Kristjánsson and McInnes, 1999. In the Control simulation the cold low level air over Northeast Canada to the west of Greenland results in a lower geopotential height than is found in the NoGreen simulation, and an intensification of the 500 hPa trough over the northeastern part of North America. The temperature anomaly associated with the 500 hPa North America trough is primarily at lower levels whereas the temperature anomaly in the Western Europe high is greater at middle tropospheric levels. This confirms that the Greenland signal over western Europe should be viewed as part of a wave pattern induced by the amplification of the North American trough, rather than a direct result of the diversion of low level air masses by Greenland. This amplification of the trough perturbs the wave pattern around the Earth. The planetary scale disturbance is in agreement with the model results of Ringler and Cook (1995), where the latitude of the mountain was found to be important for the stationary wave pattern associated with the mountain.

5. Conclusions

This study demonstrates that Greenland's impact on the general circulation of the Northern Hemisphere is fundamentally different from the impact of the Rocky Mountains and the Tibetan Plateau. Unlike in the case of the classic Rossby wave where westerlies impinge on a major mountain range and a trough is created downstream of the mountain, the waves associated with Greenland are generated by blocking and diversion of cold low level air masses, resulting in a trough on the upstream side of the mountain. The present experiment is limited to simulations with the CCM3 applying fine resolution. Nevertheless, since the difference between the simulations can be explained physically, one would expect Greenland to generate qualitatively similar waves if other general circulation models with Greenland's orography well resolved were applied. Furthermore it would probably give more insight applying an interactive ocean instead of the climatological sea surface temperatures.

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