P2.22 OROGRAPHIC DEFORMATION OF AN EXTRATROPICAL CYCLONE IN THE LEE OF GREENLAND

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1. INTRODUCTION

The main object of this study is to investigate the impact Greenland has on the formation of the Icelandic trough, either through gravity waves aloft or through other orographic processes such as blocking of the airflow. For this purpose we have chosen to study in depth a case from the Fronts and Atlantic Storm Track EXperiment (FASTEX) campaign.

The numerical model used for this study is the PSU/NCAR mesoscale model MM5 (Wang et al 2001). Unless otherwise stated, the simulations are run with a twofold nesting; a horizontal resolution of 12 km inside a mother domain with 36 km resolution and a 4 km resolution in the innermost domain. The mother domain covers most of Greenland, all of Iceland and extends to Britain in the east. The mother domain size is 3200×3200 km^2, domain two is 2160×2160 km^2 and domain three is 600×600 km^2 in dimension. Three types of vertical resolution have been employed, 25, 40 and 65 σ layers (refered to as FX25, FX40 and FX65, respectively). Initial conditions and boundary values were acquired from the ECMWF reanalysis.

2. SYNOPTIC OVERVIEW AND COMPARISON WITH OBSERVATIONS

Figures 1 and 2 show the evolution of the mean sea level pressure and the low level temperature fields as simulated in FX40. At 28/12 UTC (t_0+00h), there is a 1004 hPa low between Iceland and Greenland and a stationary high over Britain. The low moves to the NE and deepens, but leaves behind a trough with a secondary pressure minimum along the southeast coast of Greenland. At 30/00 UTC (t_0+36h), the main low has deepened to 984 hPa and passed Jan Mayen and the trough with the secondary low has disappeared. The deepening of the main low

28/12 UTC (t_0+00h)

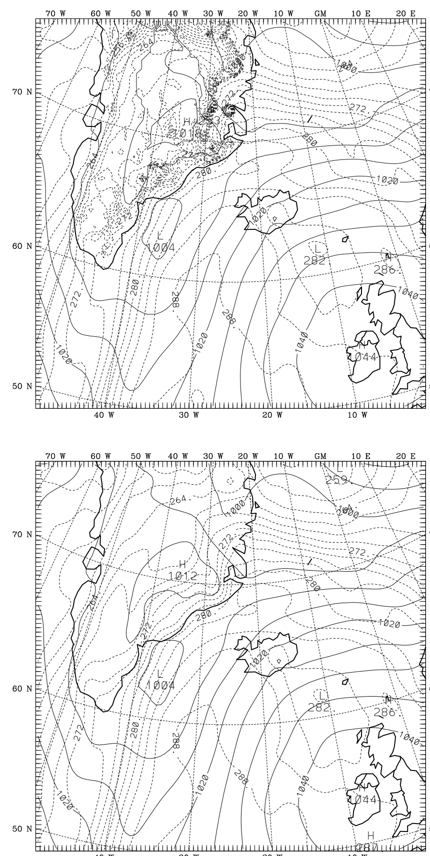

Figure 1: *Top: Mean sea level pressure [hPa] and potential temperature [K] at 850 hPa for FX40. Bottom: Same as top, but with the topography of Greenland reduced to one meter.*

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29/12 UTC (t_0+24h)

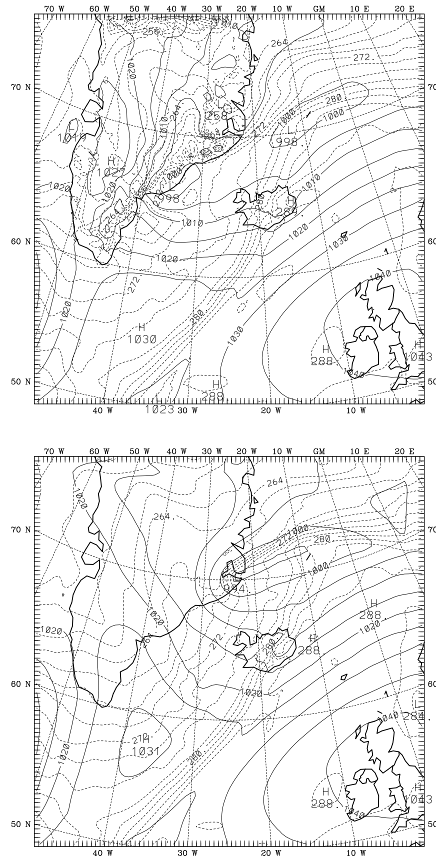

Figure 2: *Same as Figure 1 but at 29/12 UTC.*

29/12 UTC (t_0+24h)

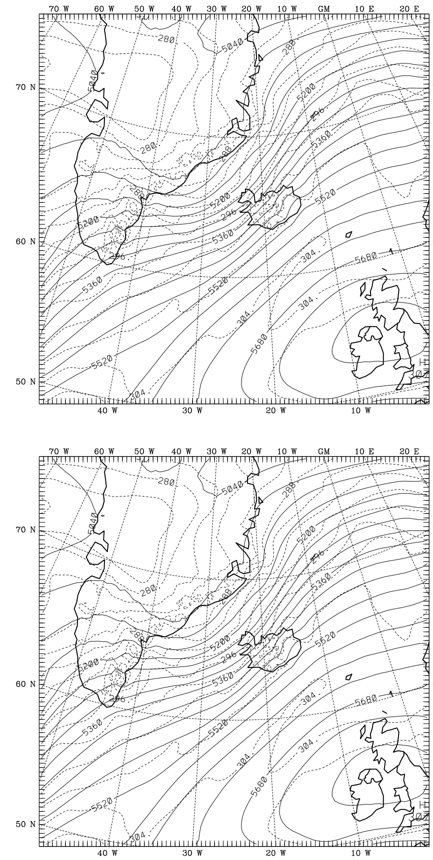

Figure 3: *Top: 500 hPa geopotential height [m] and potential temperature [K] for FX40. Bottom: Same as top, but with the topography of Greenland reduced to one meter.*

is associated with a low level temperature gradient and there is a relatively warm airmass at low levels in the trough behind. The 500 hPa flow field is shown in Figure 3 at 29/12 UTC (t_0+24h). As in a classical example of a developing baroclinic wave, the upper level trough is situated behind the surface low. At 28/12 UTC (t_0+00h), the 500 hPa trough is to the SSW of cape Farewell and during the following 36 hours it moves to the NE and ends up over Jan Mayen, being less pronounced than at the beginning. The flow is definitely baroclinic. The simulated flow described in Figures 1, 2 and 3 (top) is in very good agreement with surface and upper air observations from Greenland, Iceland and Jan Mayen, including all supplementary observations of the FASTEX campaign. We may therefore regard this as a reference flow or control simulation. The choice of case for this study is heavily based on the high-resolution dropsonde data from the flight of the NOAA Gulfstream aircraft in FASTEX IOP–8. During this IOP, the flow disturbance over Greenland was given particular attention. Figure 4 (top) shows the potential temperature field constructed from the dropsonde observations. There is obviously very strong wave activity and presumably wave breaking, reaching from the stratosphere down to approximately 500 hPa. From 500 hPa and down to about mountain top level the flow is smoother, while further below there are steep waves and possibly wave breaking. The flight took place at approximately 200 hPa and at that level there was significant turbulence (M. Shapiro, personal communication). Simulation of the flow, using 65 σ–levels, reveals indeed strong and steep waves

(Figure 4, bottom). The flow is highly non-stationary and shows more waves and wave breaking below 600 hPa and in the stratosphere than in the upper troposphere. Between 500 hPa and the tropopause, the simulated flow is in other words more smooth than observed. The model produces however some turbulence at these levels, but less than at the lower levels.

3. NO–GREENLAND

Experiments with variable horizontal resolution (not shown), of which some almost eliminate the gravity waves over Greenland, do all show almost identical development of the surface pressure pattern in the lee of Greenland. To investigate the connection between the Greenland topography and the flow field between Iceland and Greenland we reduce the height of Greenland down to one meter. Figures 1 and 2 (bottom) show the resulting sea level pressure and potential temperature at 850 hPa. Comparing this to the top shows large differences. In the No–Greenland run, there is no trough left behind the main low and the surface pressure at the east coast of Greenland is some 20 hPa greater than in the control run. At Cape Tobin (70°N), the No–Greenland simulation gives on the other hand about 10 hPa lower surface pressure than the control run. Figure 5 shows the difference between Control and No–Greenland in potential temperature at 850 hPa. It is especially interesting to note the warm zone east of Greenland that advects to the east. At the 500 hPa level there is a slight trough over Cape Tobin at 30/00 UTC (t_0+36h) in the control run which is not present in the No–Greenland run. Apart from this, the 500 hPa flow fields are almost surprisingly similar, in view of the large differences in the sea level pressure field, see Figure 3.

4. DISCUSSION

The simulations presented here manage to a certain extent (although not quite as well as Doyle et al (1998)), to reproduce the observed strong wave activity over the eastern slopes of South Greenland. The steep and presumably breaking waves in the stratosphere and lower troposphere are simulated, while observations indicate wave activity that is stronger than simulated in the upper troposphere. Very high vertical and horizontal resolutions do not alter this. The surface and 500 hPa pressure fields to the east of Greenland and over Iceland are very well reproduced in the simulations. If horizontal resolution is decreased from 4 to 36 km over the Greenland

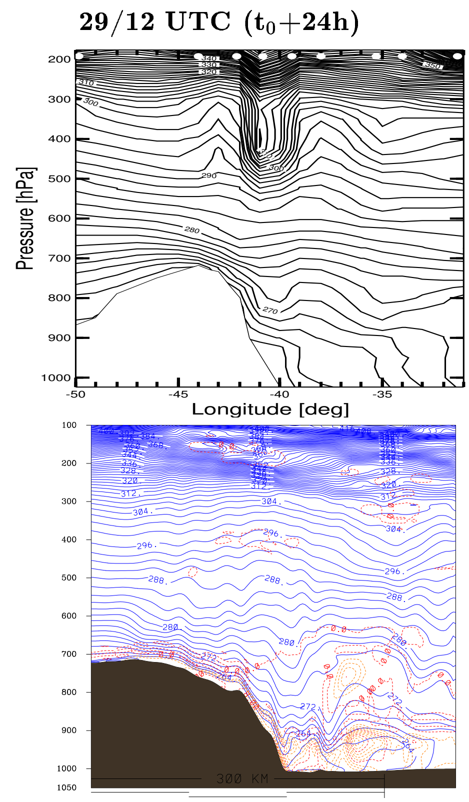

Figure 4: *Top: A cross section along the line of flight showing potential temperature [K] at approximately 29/12 UTC (t_0+24h). Vertical isentropes indicate regions of possible wavebreaking. White dots at the top show the location of dropsondes. Bottom: Simulated potential temperature [K] and TKE [J/kg] for FX65. Contour intervals for TKE is 2 J/kg and 2 K for isotherms. The cross section is approximately between 46° and 36° W at about 65° N.*

lee slopes, the waves are largely eliminated and yet the surface flow field east of Greenland is almost unchanged. Small values of TKE in the 36 km simulations confirm that a possible effect of wave breaking is not being dealt with by the subgrid turbulence scheme. The apparent lack of connection between the waves and the surface flow field is an interesting result, since the scale of the observed waves is large enough to allow for some geostrophic adjustment and thereby an impact on the synoptic flow.

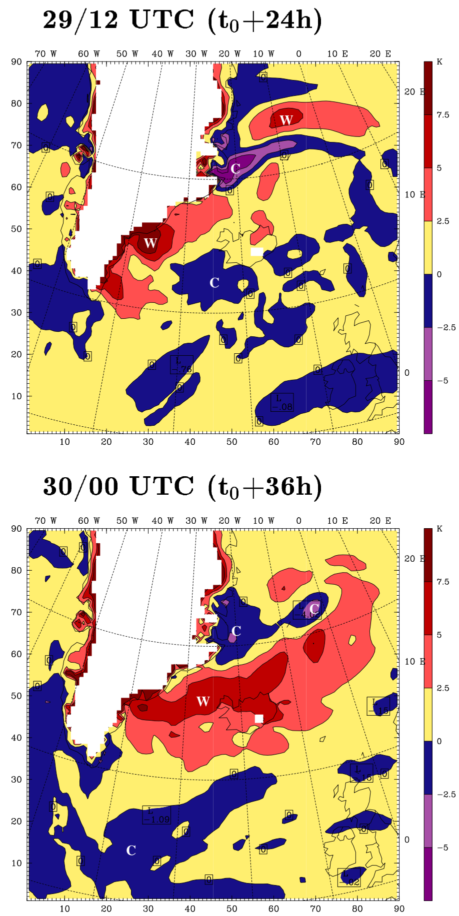

Figure 5: *Difference in potential temperature [K] between Control and No–Greenland (Control - No–Greenland) at 850 hPa. W and C indicate warm and cold areas, respectively.*

Removing Greenland has large impact on the surface pressure field, but small effect at 500 hPa. The elimination of the residual trough that the mother low leaves behind between Iceland and Greenland is in agreement with the case investigated by Kristjánsson & McInnes (1999) (hereafter KM99). They explained this by Greenland's blocking effect, hindering advection of cold low level air to the west of the mother low. Another way of looking at this is to compare the low level flow field (Figures 1 and 2) and the difference in potential temperature at 850 hPa in the control run and the No–Greenland run (Figure 5). From these figures it becomes apparent that Greenland forces a permanent descent of warm air to levels below the mountain top. The residual low appears as a source for the warm air that is being advected to the east, over Iceland. The removal of Greenland reduces the sea level pressure at Cape Tobin, an effect that we also relate to blocking of Greenland. The dense low level air is diverted to the south along the east coast of Greenland (north of 70°N) giving a pressure rise compared to the No–Greenland flow. This feature is also present in KM99, confirming that their results have a more general value than in the case they studied. The similarity of the 500 hPa flow fields in simulations with and without Greenland, is somewhat surprising since the perturbations over the lee slope travel easily up through the troposphere. This is however consistent with the climatology showing the Icelandic low to be mainly a low level phenomenon.

5. CONCLUSIONS

The numerical experiments of the FASTEX IOP–8 case of waves over Greenland indicate that the synoptic flow, especially the deformation of a cyclone passing between Iceland and Greenland is not significantly influenced by the mountain waves over Greenland, in spite of the waves being amplified and breaking. Although the simulations show little connection between the Greenland mountain waves and the surface trough and residual low between Iceland and Greenland, the topography of Greenland appears nevertheless to be a governing factor in the deformation of the passing cyclone, not through gravity waves, but blocking of cold air at low levels and permanent downward deflection of potentially warm air.

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