WAVE BREAKING OVER GREENLAND AND A BARRIER JET IN EASTERLY FLOW

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Abstract: Severe turbulence was observed over S-Greenland on 6 December 2005. Numerical simulations reveal amplified mountain waves that break both in the troposphere and in the stratosphere. At the surface, there are locally strong winds. Sensitivity studies indicate that horizontal resolution as high as 3 km is needed to reproduce the observed turbulence. It is suggested that real-time simulations at that resolution would improve aviation forecasts.

Keywords: *wave breaking, turbulence, cat, Greenland, barrier wind*

1. INTRODUCTION

Several studies indicate that Greenland may be able to generate very amplified and even breaking gravity waves (e.g. the FASTEX case reported by Doyle et al., 2005 and Rögnvaldsson and Ólafsson, 2003). Incidents of strong turbulence over Greenland have been reported by commercial aircrafts, but to the knowledge of the authors of this paper, such cases have so far not been investigated. On 6 December 2005 a commercial aircraft flying at a high level encountered severe turbulence over South-Greenland. Such incidents have occurred before, but generally in westerly flow. Here, the 6 December case is simulated. The wave activity and the surface jets close to the tip of Greenland are explored.

2. OBSERVATIONAL DATA AND A NUMERICAL SIMULATION

The observations are from a commercial aircraft, flying out of Iceland towards N-America. The aircraft experienced severe turbulence and very abrupt changes in wind speed over S-Greenland at about 200 hPa. There were neither any significant structural damages nor injuries on board. The flow is simulated with the numerical model MM5 (Grell et al., 1994), using the Eta PBL parameterization. Initial and boundary conditions are from the ECMWF. The vertical resolution is 40 levels and the horizontal resolutions are 9 km and 3 km. The topography of S-Greenland and the simulation domains are shown in Fig.1.

3. RESULTS

Figure 2 shows a radiosounding from Narsarsuaq, S-Greenland at 12 UTC on 6 December 2005. The sounding shows strong easterly winds throughout most of the troposphere. At low levels, the airmass is conditionally unstable, but there is a stable layer above 650 hPa. In the stratosphere, there are weaker southwesterly winds. Figure 3 shows the simulated flow at 200 hPa (close to the flight level) and a cross section along the low level flow for horizontal resolutions of 9 km and 3 km. There is indeed a pronounced wave activity throughout the troposphere. The steepness of the waves and the turbulence indicate breaking at middle tropospheric levels and also above the tropopause, where severe turbulence was observed by the aircraft. The stratospheric waves and the associated turbulence are greater and more realistic in the 3 km simulation than in the 9 km simulation. Figure 5 shows surface winds, mean sea level pressure and temperature at 925 hPa. There is a barrier jet at the east coast of Greenland and a corner wind downstream of the southernmost mountains. The strongest winds are found over Greenland, further to the north, below the amplified waves. Downstream of the strongest winds, there is a wake with weak winds.

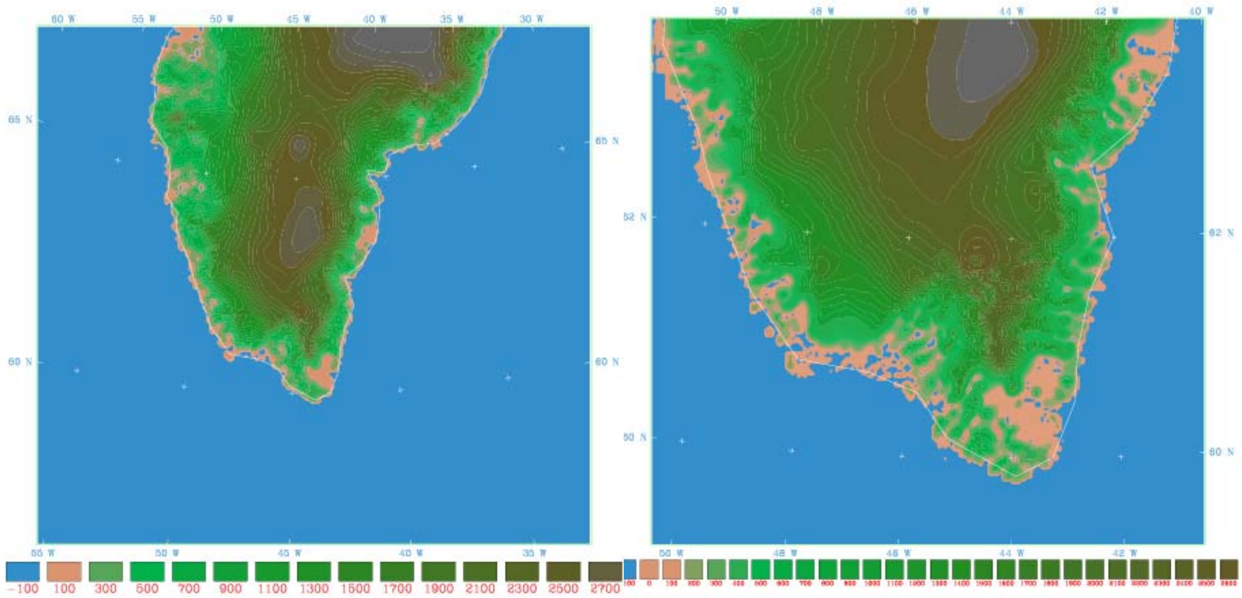

Figure 1: Topography (m) in the numerical simulations. Horizontal resolution 9 km (left) and 3 km (right).

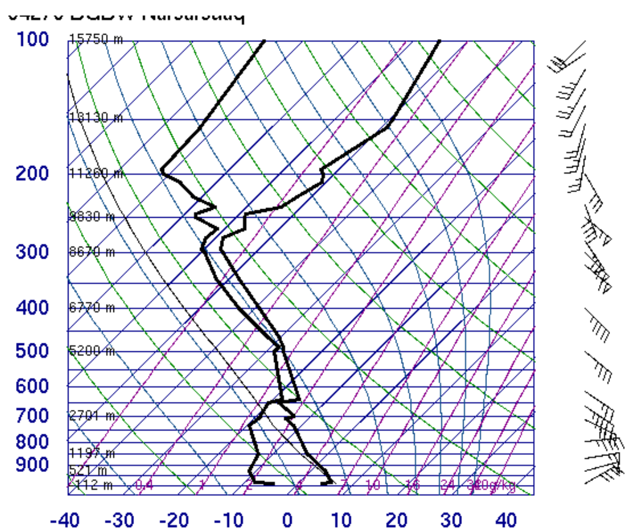

Figure 2: Radiosounding from Narsasuaq, South-Greenland at 12 UTC on 6 December 2005 (retrieved from the University of Wyoming, USA).

4. DISCUSSION

The atmospheric conditions for mountain wave generation are quite good: strong low level winds perpendicular to the mountains and a stable layer not far from the top of the mountains. Weakening of the winds with height at middle tropospheric levels contribute to the breaking of the waves at these levels. In spite of tropospheric breaking, some of the wave energy is evidently able to penetrate up to the stratosphere, where the waves break. This is the first time to the knowledge of the authors of this paper that evidence is given of gravity wave breaking in easterly flow over Greenland. Strong easterly flow in this region of the world is in most cases associated with a reverse vertical windshear (e.g. Ólafsson and Ágústsson, 2007), which in many cases would inhibit the waves to propagate up to the stratosphere.

The low level (barrier) winds along the east coast of Greenland become increasingly ageostrophic as one moves to the south along the coast and there is only a very limited low level west-east temperature gradient to contribute to these winds. Both the shooting flow below the waves and the corner jet downstream of the southernmost part of the mountains are very much ageostrophic. These local winds that are generated around Greenland in easterly flows are well known to forecasters, but they have so far not been the object of many scientific studies apart from Moore and Renfrew (2005) (see Doyle and Shapiro (1999) for the

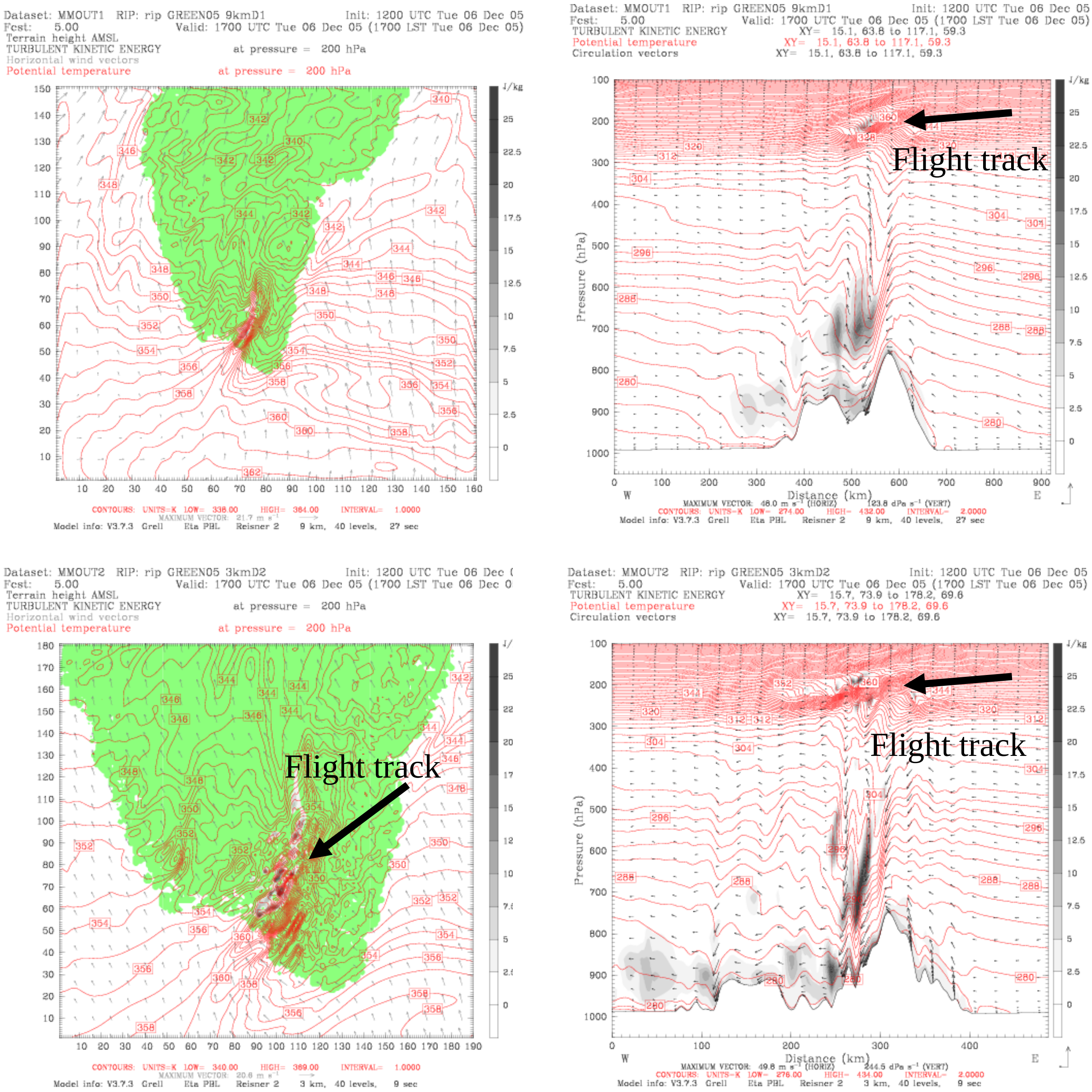

Figure 3: Potential temperature (K), turbulence (J/kg) and wind vectors at 200 hPa and in a cross section over S-Greenland along the flow. Top panels: horizontal resolution 9 km. Bottom panels: horizontal resolution 3 km.

westerly tip jet). This may change after the Greenland Flow Distortion Experiment (http://lgmacweb.env.uea.ac.uk/e046/research/gfdex).

5. CONCLUSIONS

Breaking of gravity waves over Greenland is possible in easterly flows and it can indeed be a hazard to aviation. Moving from 9 km horizontal resolution to 3 km increases the simulated breaking intensity and makes it more realistic at the intercontinental air traffic level in the lower stratosphere. This indicates strongly that aviation forecasts of turbulence in this region are likely to improve if they are based on high-resolution real-time simulations.

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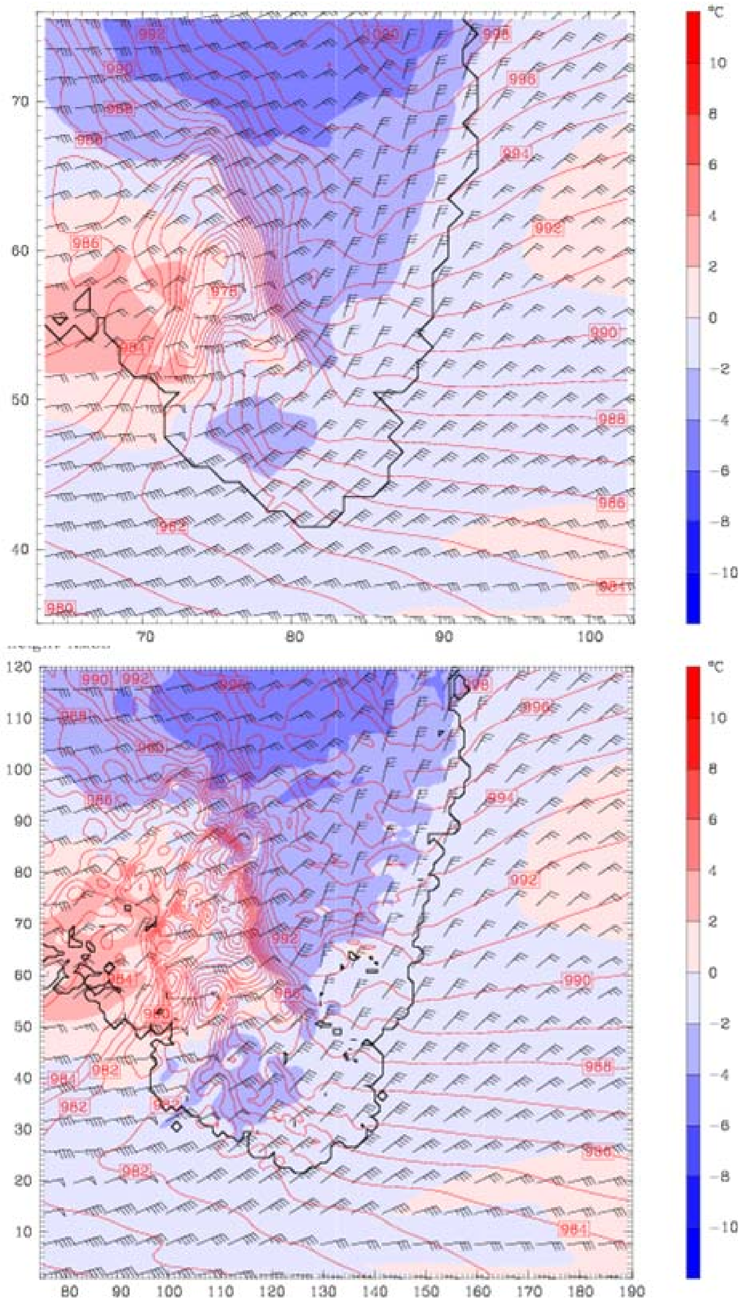

Figure 4: Temperature (K) at 925 hPa, mean sea level pressure (hPa) and wind barbs (one full wind-barb corresponds to 5 m/s) in a simulation with horizontal resolution 9 km (top) and 3 km (bottom).

REFERENCES

Rögnvaldsson, Ó. and H. Ólafsson, 2003: A case study of the Icelandic trough. Proc. Int. Conf. Alp. Meteorol. (ICAM), Brig, CH, May 2003, 4 p.

Doyle, J. and M. A. Shapiro, 1999: Flow response to large-scale topography: The Greenland tip jet. *Tellus*, **51A**, 728-748.

Doyle, J., M. A. Shapiro, Q. Jiang and D. Bartells, 2005: Large-amplitude mountain wave breaking over Greenland. *J. Atmos. Sci*., **62**, 3106-3126.

Grell, G. A., J. Dudhia and D. R. Stauffer 1994. A Description of the Fifth–Generation. Penn State/NCAR Mesoscale Model (MM5). *NCAR/TN-398+STR.* National Center for Atmospheric Research, Boulder, CO, 107 pp.

Moore, G. W. K. and I. Renfrew, 2005: Tip jets and barrier winds: A QuikSCAT climatology of high wind speed events around Greenland, *J. Climate*, **18**, 3713-3725.

Ólafsson, H. and H. Ágústsson, 2007: The Freysnes downslope windstorm. Meteorol. Zeitschrift, **16**, 123-130.