The Impact of Upstream Wind Direction on Wake Flow

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ABSTRACT

A series of idealized simulations is conducted in order to investigate how the wind direction affects the airflow past an elliptical mountain of Greenland's size. The initial conditions are simple, the upstream stability and wind speed are constant, and the wind direction is varied from southwest to northwest between simulations. Preliminary results indicate that for upstream winds from the northwest, the flow in the lee of the mountain is more stable with respect to eddy shedding and that blocking is reached more easily than if the flow is from the west or southwest. In flows from the southwest, the tip jet is discontinuous and weaker than if the flow is from the west or northwest. The surface pressure drag has a sinusoidal shape.

1. Introduction

A number of studies have during the last decades investigated nonlinear flow past elliptical mountain ridges. The experiments have mainly been of a simple character with constant upstream profile of wind and stability and the elongated mountain perpendicular to the incoming flow. Furthermore in most of the studies neither surface friction nor rotation is included (e.g. Smolarkiewicz and Rotunno, 1989; Ólafsson and Bougeault, 1996; Epifanio and Durran, 2002). A few studies have investigated the role of surface friction and rotation (e.g. Grubišić et al., 1995; Thorsteinsson and Sigurðsson, 1996, Ólafsson and Bougeault, 1997), but on the other hand little can be found in the literature about variations in the upstream wind or stability. The purpose of this study is to investigate how the wind direction affects the airflow past an elliptical mountain.

2. Experimental setup

The numerical model MM5 (MM5 User's Guide, 2001) is applied in this study. The model is run with 40 σ-levels in the vertical, the horizontal grid resolution is 36 km and there are 150×150 grid points. To prevent wave reflection, a Rayleigh damping layer, which is not a standard parameterization

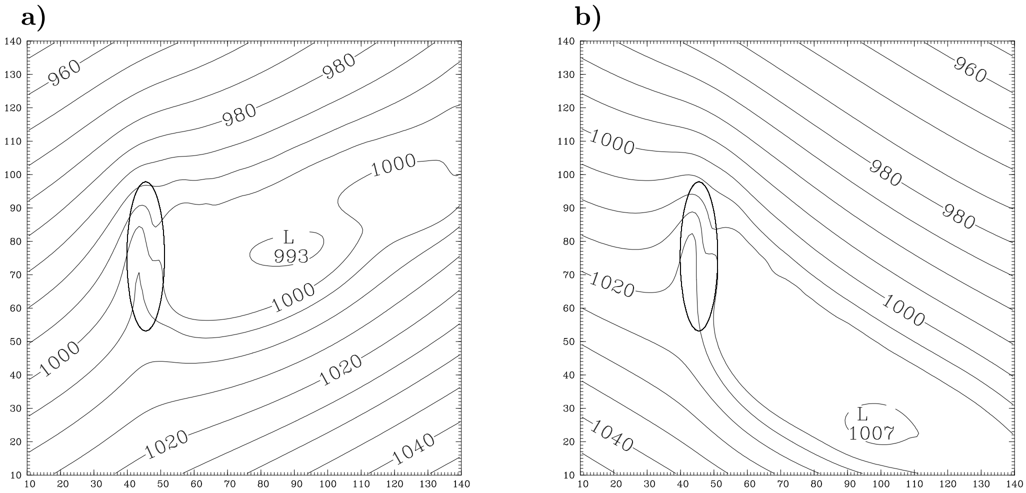

Figure 1: The sea level pressure (hPa) for upstream wind from a) west-southwest (240°) and b) west-northwest (300°). The contour interval is 5 hPa and the topography is shown at $0.35h$.

in MM5, is placed above 13 km height. Since this study is a part of a larger study on Greenland, our mountain is located at high latitudes on a rotating plane, the Coriolis parameter being equal to $1.2 \cdot 10^{-4}$ s^{-1}. The mountain height is 3000 m and its half-length and half-width are 800 km and 200 km respectively. The mountain is elongated south-north. The upstream stability and wind speed are held constant at 0.01 s^{-1} and 10 m s^{-1}, but the wind direction is varied between 180° and 360°.

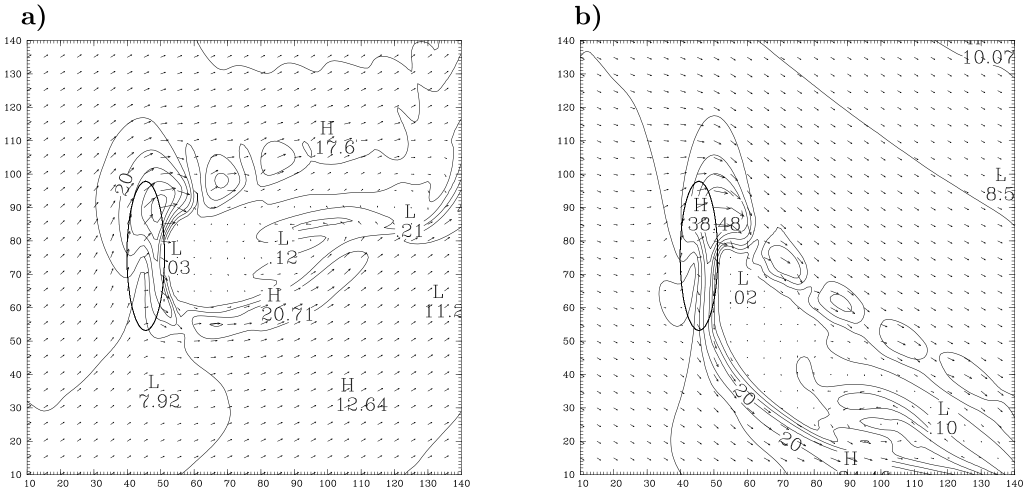

Figure 2: The wind speed (m s^{-1}) at the lowest σ-level for upstream wind from a) west-southwest (240°) and b) west-northwest (300°). Also shown are wind vectors. The contour interval is 5 m s^{-1} and the topography is shown at $0.35h$.

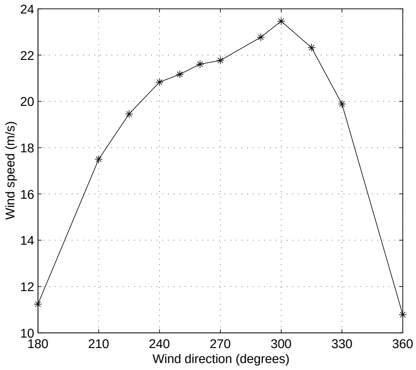

Figure 3: The mean maximum wind speed (m s^{-1}) of the tip jet at the lowest σ-level as a function of the upstream wind direction.

3. Preliminary results

For westerly flow the flow is unblocked, even though there is some eddy shedding. However, when the wind direction is deflected either to the south or to the north, the flow becomes blocked, but less deflection is needed in the northerly direction than in the southerly. Figure 1 shows the sea level pressure for wind from west-southwest (240°) and west-northwest (300°). In the case of west-northwesterly wind the flow is blocked, and the pressure deficit in the wake is almost constant. When the upstream wind is from the west-southwest the flow is unblocked, the wake is more unstable, i.e. experiences more eddy shedding, and the pressure deficit in the wake is larger. The wind direction also affects the tip jet; For deflections to the north the tip jet is narrow and well defined while when the flow is deflected to the south the tip jet is wide and discontinuous near to the mountain where the wind speed falls below 15 m s^{-1} (figure 2). The maximum tip jet wind speed is found for upstream wind from the west-northwest (300°), see figure 3. The orographic drag is an important sink of atmospheric momentum (e.g. Eliassen and Palm, 1960) and knowledge of its behavior is essential in studies of large-scale momentum budgets. The pressure drag along the central cross section of the mountain is largest when the wind is northwesterly and north-northwesterly and of the same amplitude but opposite sign for southerly flow. When the wind is from the west-southwest the drag is almost nonexisting (figure 4).

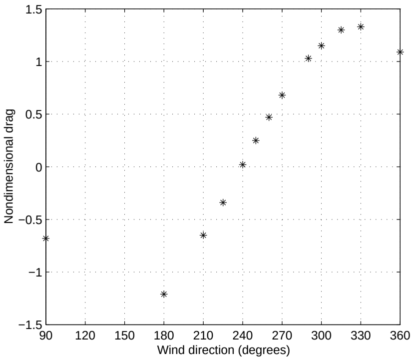

Figure 4: The mean nondimensional surface pressure drag along the central cross section of the mountain as a function of the upstream wind direction. The drag is normalized with $\pi\rho_0 NUh^2/4$ where ρ is equal to 1.25 kg m^{-3}.

4. Discussion

The left-right symmetry of flows on a non-rotating plane is broken when the Coriolis force is included, and the flow is to a greater extent diverted to the left (facing downstream). This effect of the Coriolis force can explain the differences found between southwesterly flow and northwesterly flow. In the case of southwesterly flow upstream, the Coriolis force has an accelerating impact on the airflow that is diverted to the north, while a part of the air that is diverted to the south of the mountain is decelerated and partly reversed. For northerly flow the effect is opposite, the Coriolis force has an accelerated impact on the air mass flowing south of the mountain while the air flowing north of it is partly decelerated and reversed. As can be seen in figure 4, the pressure drag as a function of the upstream wind direction has a sinusoidal shape, which is yet not explained. The study is ongoing and further investigation of the impact of the wind direction on e.g. the tip jet and the drag are needed.

LITERATURE

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