MESOSCALE MODELLING OF FLOW RESPONSE TO GREENLAND

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The mesoscale atmospheric flow response to Greenland is difficult to predict. Flow over and around Greenland is affected by (i) the large and very steep elevation change between the coastal margins and the central plateau (~3000m), (ii) the combination of very rough surfaces (roughness length z_o~1-10m) and jagged mountains around the coasts, (iii) the strong katabatic flows from the plateau down to the coasts (van den Broeke and Gallee 1996), (iv) the presence of the semi-permanent Icelandic Low, and (v) air-sea-ice interaction processes (Scorer 1988). Here and in other coastal flows there are extremely sharp gradients in roughness and elevation. These result in local scale phenomena that have long been observed but are only described by mesoscale models when they are run with fine resolution (e.g. Hunt et al. 2001, Capon 2002). But these local scale phenomena can have large scale climate effects, e.g. drag, wind waves, upwelling, etc.

At University College London, we are investigating these fine scale features through a combination of numerical mesoscale modelling using the Met Office Unified Model version 4.5 (UM4.5), new analytical modelling of idealised flows (Hunt et al 2002), and planned laboratory work at the Coriolis turntable facility at Grenoble. Systematic errors in mesoscale predictions may have been overlooked in the past because there has been some conceptual uncertainty about the upwind and lateral effects when the atmosphere is stably stratified and there are sharp changes of surface boundary conditions, as is the case with Greenland. In particular, the idealised modelling suggests that the flow response to changing surface conditions has both similarities and differences when there are elevation changes and drag effects due to surface roughness changes. For example, both have upwind effects but only drag causes significant increases in the wind speed perturbation in the downwind flow direction or parallel to roughness change, which recent research shows occurs even for low level roughness change (e.g. along coasts or ice-water boundaries) (Hunt et al. 2002). These mesoscale features are also important at synoptic scales. For example, the downstream wind-jet we identify in figure 2 extends to a distance of ~1000km into the North Atlantic Ocean – a region of cyclogenesis – and influences air-sea-ice interaction processes at synoptic scales. Our studies should help define the magnitudes and spatial and temporal scales of these flows, which will improve the parameterization and interpretation of mesoscale processes in weather or climate prediction models.

Our idealised model is a general linearised shallow water perturbation model (consisting of a shallow surface layer inversion of thickness h situated below an upper layer) developed for typical mesoscale atmospheric flows where the troposphere is slightly stable, with significant Coriolis effect, and sharp variations in surface roughness length and mountainous elevation. Figure 1 shows the main shallow layer model results, demonstrating the importance of fine scale modelling. At horizontal resolutions of order h or less (i.e. 2km), numerical mesoscale results are consistent with very fine scale features of the shallow water flow (e.g. Capon 2002). However, even at a larger resolution of 12km, certain broad features (e.g. parallel wind-jets) are well captured. Figure 2 shows the 10m-wind speed over Greenland on 18Z November 9 2002 at 12km resolution derived from the UM4.5 numerical model. The features described are all consistent with aspects of the shallow water flow over a rough elevated strip that is very wide compared to the Rossby Deformation radius L_R.

References

Capon, R., 'Modelling low level winds with the Met Office New Dynamics model', Internal report No. 133, NWP Scientific Paper No. 66, Joint Centre for Mesoscale Meteorology, Reading, UK.

Hunt, J. C. R., Olafsson, H. and Bougeault, P., 'Coriolis effects on orographic and mesoscale flows', *Q. J. R. Met.. Soc.*, Vol. 127, pp 601-633, 2001.

Hunt, J. C. R., Orr, A., Rottman, J. W. and Capon, R., 'Coriolis effects in mesoscale flows with sharp changes in surface conditions', to be submitted, 2002.

Scorer, R. S., 'Sunny Greenland', *Q. J. R. Met. Soc.*, Vol. 114, pp 3-29, 1988.

van der Broeke, M. R. and Gallee, H., 'Observation and simulation of barrier winds at the western margin of the Greenland ice sheet', *Q. J. R. Met. Soc.*, Vol. 122, pp 1365-1383, 1996.

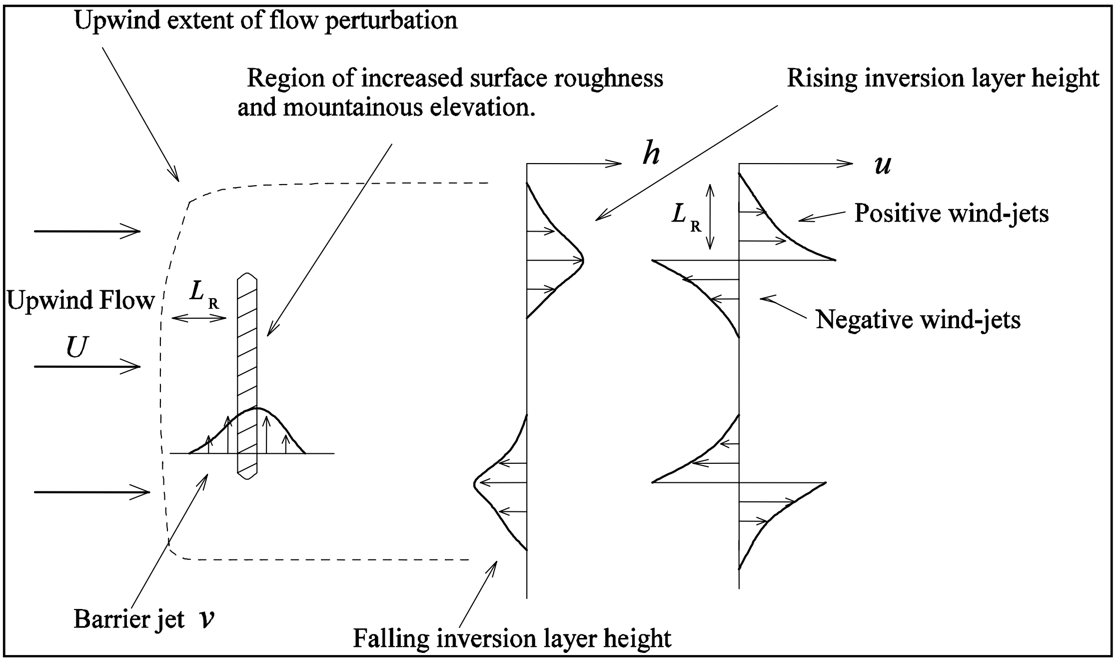

Figure 1. Perturbations in the height of the inversion layer and in velocity components near sharp changes in surface roughness and elevation calculated using the shallow water model for a strip perpendicular to the flow. The main results are; (i) the upwind extent of the flow perturbation is of order of the Rossby Deformation radius L_R, (ii) if the wind direction is parallel to the edge-line separating the change in surface conditions, positive and negative wind-jets are formed on length scales similar to the depth of the inversion layer (~1km), and are most pronounced in elongated regions with transverse length scales of the order L_R, explaining very high coastal winds

within 1km of the coast (Capon 2002), and (iii) in flows approaching parallel or at an angle to the edge-line, the inversion height varies, for example increasing inland over a distance L_R when stable airflow approaches from the sea. This explains the observed increasing cloudiness inland from the coast.

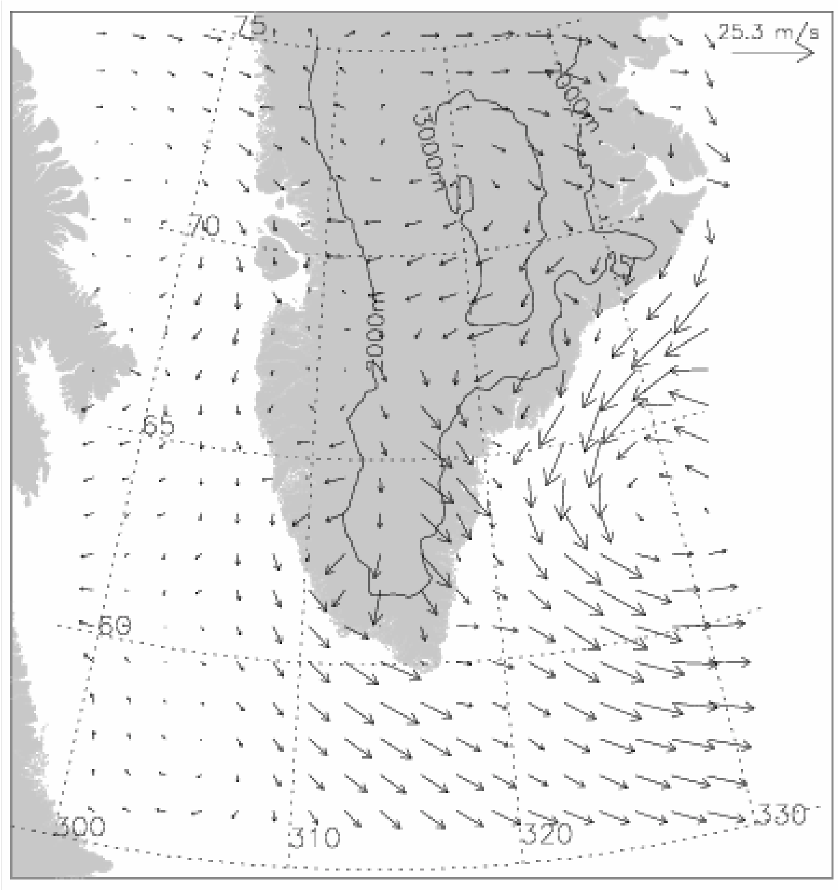

Figure 2. 10m-wind speed (ms^{-1}) vectors (every 8 grid points) for atmospheric westerly flow over Southern Greenland, computed using a horizontal resolution of 12km. Orography elevation contours are 2000m and 3000m. Surface roughness length z_o varies from 1mm over the ice sheet to 1-10m over the mountainous coastal margins. Clearly evident are; (i) on the upwind westerly side the flow is affected nearly 500km upwind, (ii) the blocked flow develops into a well defined wind-jet travelling parallel to the coastline and speeds up markedly to above 16ms^{-1} as it reaches the southern tip of Greenland, (iiii) there are sharp velocity gradients parallel to the entire coastline, with the highest velocities and wind-jet centred close to the coastline, decreasing over a transverse length scale of order the Rossby deformation radius L_R (150-200km), (iv) on Greenland itself are katabatic winds over the ice sheet, predominately in an easterly/south-easterly direction, which are channeled into the wind-jet, (v) very strong winds are generated by the Icelandic Low (> 20ms^{-1}), (vi) the air flow separates at the southern tip of Greenland where there is a sharp change in the direction of the coastline. As the flow continues downwind of the tip, in the wake, its velocity decreases gradually down to 10ms^{-1} over 1000km and impacts on the Icelandic Low.