CLIMATOLOGICAL FEATURES OF OROGRAPHIC LOW-LEVEL JETS WITHIN FROBISHER BAY

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1. INTRODUCTION

Geographically, as seen in Figure 1, Baffin Island is characterized by a rugged coastline, indented by countless fjords, and permanently snow and ice capped mountains in the interior. The atmospheric boundary-layer flow is influenced by the topography and, in coastal regions, by land-sea interactions and varying sea ice and snow conditions. Due to the year-round stable stratification of the atmosphere, even relatively small orographic features at high-latitudes may be responsible for a significant deflection of low-level winds.

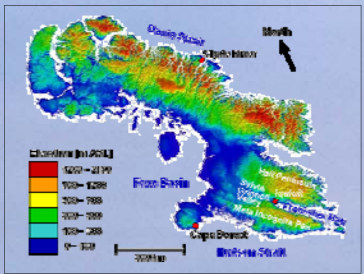

Figure 1: The topography of Baffin Island, Nunavut

Large differences between channelled valley winds and the flow aloft have the potential to create intense turbulence, frequently leading to hazardous flying conditions. Additionally, strong surface winds can cause damage to infrastructure on the ground. In winter they are associated with significant windchill, and may lead to reduced visibility and icing due to blowing snow near the surface. Intense snowdrift can hamper mobility on the ground, destroy buildings, and affect local hydrology. At the coast, strong onshore surface winds may be responsible for the forcing of high tides in summer, and may have a strong impact on sea ice conditions in spring and autumn.

2. OBJECTIVES

No systematic analysis has been carried out of strong orographic boundary-layer flows in the Canadian Arctic in the presence of significant local relief. Given the importance of such winds, the objective of this study is to determine the seasonal climatological features of low-level jets and associated vertical wind shear. Due to the availability of surface and upper air data, as well as due to its importance as a community and transportation centre, the focus of this study is on Iqaluit. Due to its coastal location and the absence of trees or any tall vegetation and manmade structures on Baffin Island, surface winds are generally strong throughout the year.

3. DATA

The primary data source for this study is routine hourly surface data at Iqaluit, Cape Dorset and Clyde River (→ Figure 1), obtained and archived by Environment Canada. This includes measurements of air pressure, temperature, relative humidity, visibility, and 10-m wind speed and direction, as well as weather observations. Additionally, 12-hourly upper-air data at Iqaluit is used from operational weather balloon releases at 6:15 and 18:15 EST.

4. METHODOLOGY

To identify unique properties of the atmosphere associated with and leading to the formation of orographic low-level jets, average boundary-layer conditions are determined for situations in which the surface wind speed at Iqaluit is at least 10 m s^{-1}, and compared with the corresponding average conditions for weaker surface winds. Among the calculated climatological properties of the surface flow at Iqaluit are the annual cycle in the prevailing wind direction, and the relationship of the actual wind direction to the direction of the hypothetical, large-scale pressure gradient driven flow that would exist in the absence of any boundary-layer forcing, referred to as the geostrophic wind. Among the upper-level characteristics within the lowest 5 km of the atmosphere, determined from sounding data, are average profiles of temperature and wind speed.

5. RESULTS

As shown in Figure 2, the significant influence of the surrounding topography on strong and weak surface winds at Iqaluit is clearly seen in the prevailing wind directions offshore from the northwest, and onshore from the southeast, in both cases following the prevailing orientation of Sylvia Grinnell Valley and Frobisher Bay. Shifts between the dominant wind directions occur with geostrophic winds (→ Section 4) roughly perpendicular to the valley axis, indicating the controlling influence of large-scale pressure gradients in combination with local channelling effects on the forcing of surface winds at Iqaluit.

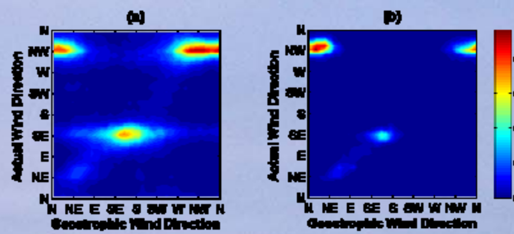

Figure 2: Joint occurrence of actual and geostrophic surface wind directions at Iqaluit for (a) weak actual winds with speeds less than 10 m s^{-1}, and (b) strong actual winds with speeds of at least 10 m s^{-1}. Colour shading represents normalized relative occurrence, defined as the total joint occurrence of hourly actual and geostrophic wind directions divided by the occurrence of the most frequent combination of wind directions.

As shown in Figure 3, there is a well defined annual cycle in dominant wind direction from southeast between June and September to northwest throughout the rest of the year. Referring again to Figure 2, this corresponds to a shift in prevailing surface geostrophic wind directions between east and southwest to between west and northeast, indicative of seasonal variations in the large-scale pressure field and a northward shift in the prevailing storm tracks in summer.

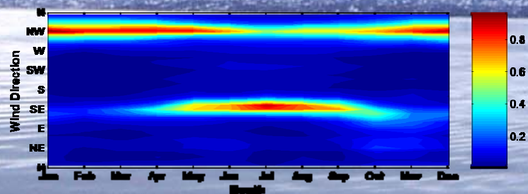

Figure 3: Seasonal cycle of prevailing surface wind conditions at Iqaluit. As in Figure 2, colour shading represents normalized relative occurrence.

Due to land – sea differences, strong northwesterly surface winds at Iqaluit, on average, are colder than southeasterly winds in winter, and warmer in summer. As a result, as shown in Figure 4 (a) and (b), there is a large seasonal difference in the boundary-layer mean temperature profiles associated with these wind conditions. In winter, strong northwesterly surface winds occur with well defined temperature inversions, extending from the surface to about twice the typical ridge-top level of about 600 m. In summer, due to the high surface temperatures, no mean low-level temperature inversion exists, leading to a reduced static stability, a reduced channelling efficiency by the surrounding topography, and therefore to a reduced occurrence of strong northwesterly surface winds. Conversely, enhanced static stability contributes to the more frequent occurrence in summer of strong boundary-layer flows from the southeast.

For the purpose of this study, orographic low-level jets are defined as boundary-layer flows, which in some way are constrained by elevated terrain, with wind speeds at or below ridge-top level of the large-scale surrounding topography greater than those of the essentially unconstrained flow immediately above, and with surface wind speeds of at least 10 m s^{-1}. Referring to Figure 4 (c) and (d), the low-level jet character of boundary-layer flows associated with strong along-valley surface winds at Iqaluit, as opposed to those associated with weak surface wind conditions, is evident.

The increased occurrence of strong surface winds from the northwest in winter, and from the southeast in summer is accompanied by a strengthening of the corresponding low-level jet, through increased wind speeds at ridge-top level and below, and a weakening of mean winds above. In addition to large-scale forcing and enhanced static stability, stronger downward momentum fluxes contribute to the more frequent occurrence of strong southeasterly surface winds at Iqaluit in summer, whereas strong northwesterly surface winds in winter are protected from weaker winds aloft by the strongly stable stratification near the surface.

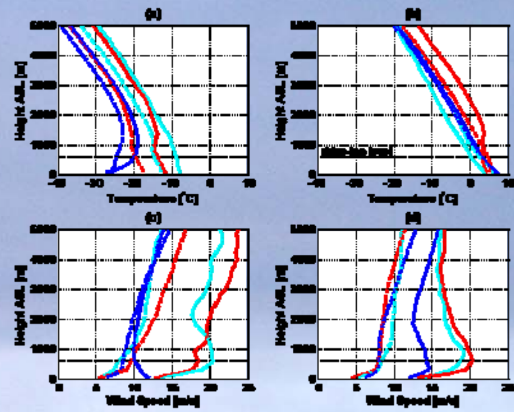

Figure 4: Mean vertical profiles of temperature and wind speed corresponding to surface winds from northwesterly (blue), southeasterly (red), and northeasterly (cyan) directions, with speeds of less than 10 m s^{-1} (dashed lines) and at least 10 m s^{-1} (solid lines), for (a) wintertime (Jan – Mar), and (b) summertime (Jul – Sep) conditions.

6. CONCLUSIONS

Strong low-level winds and vertical wind shear are a common phenomenon within Frobisher Bay, and frequently lead to hazardous flying conditions and hardship on the ground. Due to the surrounding topography, significant channelling of surface wind occurs at Iqaluit, with prevailing wind directions from the northwest and southeast. Shifts between the dominant wind directions occur with geostrophic winds roughly perpendicular to the valley axis, indicating the controlling influence of large-scale pressure gradients in combination with local channelling effects on the forcing of surface winds. Following seasonal shifts in the major storm tracks across the southern Arctic, there is a shift in prevailing wind direction from northwest in winter to southeast in summer. The importance of the topography for the generation of strong boundary-layer flows is also evident in the presence of speed maxima at the typical ridge-top level and below, associated with strong along-valley surface winds. Unusually cold surface temperatures and enhanced static stability of the boundary-layer flow, leading to enhanced channelling efficiency, exist with northwesterly surface flows in winter, and with southeasterly surface flows in summer. The resulting increased occurrence of strong northwesterly surface winds in winter, and of strong southeasterly surface winds in summer, is accompanied by a strengthening of the corresponding low-level jet, and a weakening of mean winds above. A more detailed discussion of the boundary-layer flow at Iqaluit may be found in *Nawri and Stewart* (2005).

Acknowledgement

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Reference

Nawri, N., and R. E. Stewart, Climatological features of orographic low-level jets within Frobisher Bay, submitted to *Atmosphere-Ocean*, 2005.