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Low-level baroclinicity and the ABL evolution during cold-air outbreaks in high latitudes: a simple model

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Cold-air outbreaks in polar regions represent regimes with extremely large surface heat fluxes. The heating produces strong horizontal gradient of temperature in the atmospheric boundary layer and thus low-level baroclinicity. It has been argued that this kind of baroclinicity might lead to an acceleration of the flow in the ABL and to a formation of a low-level jet (LLJ).

Here, a simple steady-state eulerean dry mixed layer (ML) model is used to describe the effect of baroclinicity on the wind speed in the ABL during Arctic cold-air outbreaks. Baroclinicity is represented in the ML model by two terms which are due to: 1) the horizontal gradient of air temperature in the ABL; 2) sloping of the inversion layer at the ABL top. The results of the ML model are compared with results of the 3D non-hydrostatic mesoscale model NH3D.

It is shown that an analytical solution of the ML model reproduces the ABL growth and heating and the baroclinic component of the geostrophic wind in the ABL well. Both the ML model and NH3D produce a LLJ with similar magnitudes in a certain range of external parameters. Furthermore, there is a range of parameters where both models produce a strong deceleration of the ABL flow, also as a result of baroclinicity. The magnitude of the baroclinic wind component is strongest close to the ice edge and is comparable to the large-scale synoptic geostrophic wind. Consequently, baroclinicity has a strong effect on surface fluxes of heat and momentum as demonstrated by both models. Also, both models produce a gradual decay of the magnitude of the baroclinic component of geostrophic wind downwind from the ice edge. It is shown that the characteristic horizontal scale of this decay is related with the horizontal scale of the ABL growth and warming and is of order of several hundred kilometers.

To summarize: these results confirm previous findings by others that the main physical mechanism of the LLJ during cold-air outbreaks is the effect of low-level baroclinicity. It is shown that a simple model, which can be solved analytically, reproduces the ABL evolution as obtained by a complex numerical model. The effect of baroclinicity on wind speed depends strongly on external parameters and can lead to both acceleration and deceleration of the flow. The typical horizontal scale at which the baroclinic component of geostrophic wind decays is larger than previously thought.