NUMERICAL SIMULATION OF COLD EASTERNLY CIRCULATIONS OVER THE CANADIAN WESTERN PLAINS USING A MESOSCALE BOUNDARY-LAYER MODEL

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(Received in final form 23 August, 1976)

Abstract. Arctic outbreaks over the Canadian Western Plains during the late spring period frequently take the form of a cold east-northeasterly flow over a warmer, sloping surface. A mesoscale numerical model is developed in an attempt to simulate such circulations. Following Lavoie (1972) the atmospheric structure of the cold air mass is represented by three layers: a constant flux layer in contact with the earth's surface, a well-mixed planetary boundary layer capped by an inversion, and a deep stratum of overlying stable air. Averaging the set of governing primitive equations through the depth of the mixed layer yields predictive equations for the horizontal wind components, potential temperature, specific humidity, and the height of the inversion. Time-dependent calculations are limited to this layer by parameterizing the interactions between the mixed layer and both the underlying and overlying layers. Precipitation from limited convective clouds, and latent heat within the layer are included in terms of mesoscale variables.

A 47.6-km by 47.6-km grid mesh of 1369 points covering the Canadian Prairie Provinces is used to represent the variables. The governing equations are solved numerically with terrain influences, surface roughness, temperature variations, and moisture fluxes allowed to perturb the mixed layer from its initial conditions until resultant mesoscale boundary-layer weather patterns evolve.

The mean spring topographic precipitation pattern is successfully reproduced by the simulated late spring upslope flow with limited convective precipitation. Mesoscale planetary boundary-layer weather patterns appear to exert a dominant control over the location and intensity of perturbations in the spring precipitation pattern. The elimination of surface heating significantly reduces the area and intensity of precipitation. A case study based on observed initial conditions showed that the model could reproduce a persistent limited convective precipitation pattern maintained by upslope flow and that a low-level trough exerts a marked influence on the location and the intensity of the precipitation.

List of Symbols

- $A$: grid point value of a variable
- $a$: parameter associated with precipitation rate; also used as parameter associated with drag coefficients for an unstable atmosphere
- $b$: smoothing parameter
- $C_D, C_1$: drag coefficient; skin drag coefficient; terrain drag coefficient; drag coefficient for a neutral atmosphere, respectively
- $C_E, C_H$: evaporation and heat transfer coefficients, respectively
- $C_p$: specific heat capacity of air at constant pressure
- $c$: isothermal speed of sound; also used as parameter associated with transfer coefficients for an unstable atmosphere
- $D$: depth of cloud
- $F_i$: pressure gradient at level $h_i$

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Boundary-Layer Meteorology 11 (1977) 307–327. All Rights Reserved
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1. Introduction

Late spring over the Canadian Western Plains is often dulled by extensive stratocumulus clouds. Cool, moderately moist winds gust out of the east-northeast and blow over the relatively warmer snow-free surface of the Western Plains; this type of weather is not only unpleasant for those trying to expand the short summer recreation period, but also has severe-economic implications. In an area where agriculture is still the major industry, the grey clouds retard surface drying and the precipitation further moistens the ground; this tends to keep the farmers off the land during the critical spring sowing period. The extensive low cloud also causes concern to those interested in aviation.

Climatological charts (Longley, 1972) indicate that spring over the Canadian Western Plains is characterized by increasing cloudiness and precipitation. Most certainly one of the contributing factors is the occurrence of late spring upslope weather. The term upslope here refers to a persistent, shallow east-northeasterly circulation associated with outbreaks of Arctic air moving up the gently rising slope of the Western Plains. In late spring, the cold air mass moving southwestward is heated from below by contact with the snow-free ground. This often produces turbulent winds and extensive decks of stratocumulus clouds accompanied by light drizzle, showers, or snowflurries. The atmosphere is characterized by an unstable stratification of limited depth which is topped by a marked stable stratum (Willet and Sanders, 1959). The air is moistened from below by: (a) the numerous lakes making up over half the area of the thawing Canadian Shield including lakes Winnipeg, Manitoba, and Winnipegosis which lie to the east of the