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Impacts of terminal velocity on the trajectory of winter precipitation types

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ABSTRACT

It is common to observe many types of precipitation such as wet snow, ice pellets, and freezing rain during winter storms. The vertical temperature profile composed of a melting layer aloft and a refreezing layer below, plays an important role in the formation of these precipitation types. The horizontal wind also influences the particle trajectories and displaces them into different atmospheric conditions as they fall. This study investigates the sensitivity of the precipitation type distribution and intensity at the surface to the precipitation terminal velocity variation down through the atmosphere. To address this issue, the trajectories of precipitation types are investigated using a bulk microphysics scheme coupled with a two-dimensional kinematic cloud model. The model is initialized with idealized atmospheric conditions associated with a warm front leading to many types of precipitation at the surface. A systematic study was carried out assuming two melting snow scenarios: snow melting aloft into rain and snow melting aloft into semi-melted snow and rain. First, the results show good agreement with observations collected during the Canadian CloudSat/Callipso Validation Project (C3VP) field campaign. Second, the sensitivity experiments show that the intensity and location of precipitation vary depending on the melting scheme. The precipitation rate at the surface can be up to 55% higher if snow melts into semi-melted snow and rain compared to directly into rain. Overall, the terminal velocity of the precipitation types observed during winter storms is critical for better predicting the location and intensity of precipitation.

1. Introduction

Various precipitation types often occur in the transition region of winter storms, which is bounded by rain on one side and snow on the other (Stewart, 1992). These types include ice pellets and freezing rain, as well as mixtures of both liquid and ice particles such as wet snow, slush and liquid core pellets (Thériault and Stewart, 2007). In particular, precipitation types containing liquid (such as freezing rain and wet snow) can lead to catastrophic icing events when falling on subfreezing surfaces. A good example is the 1998 Ice Storm in Montreal and surrounding areas, the most catastrophic weather event in Canadian history (Henson et al., 2007).

The transition region of a winter storm is often associated with a warm front, which is a favorable environment for the formation of a temperature inversion. This type of temperature profile, consisting of a warm layer of temperature >0°C aloft and a refreezing layer (temperature <0°C) below, is required to form some of the hazardous types of precipitation (e.g. Wagner, 1957; Zerr, 1997). For example, snowflakes falling through this melting layer either partially of completely melt, depending on their size and atmospheric conditions. The degree of melting governs whether or not these particles refreeze into different types of precipitation such as freezing rain, ice pellets, and refrozen wet snow when falling into the refreezing layer.

In frontal regions, organized horizontal and vertical air motions exist. These air motion patterns not only influence the temperature fields; they also carry particles through different environmental conditions (Donaldson and Stewart,

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1993). Vertical air velocity changes the air temperature by adiabatic warming (cooling) of the air through descent (ascent). The variation of the degree of saturation can also alter the precipitation types through changes in the rate of evaporation, sublimation and melting (Hanesiak and Stewart, 1995).

Existing microphysics schemes generally address the melting process based on the bulk amount of water melted from the snow category using the melting equation (Ferrier, 1994; Kong and Yau, 1997; Thompson et al., 2004; Milbrandt and Yau, 2005b). This is acceptable but when the temperature is near 0 °C, many types of precipitation may occur depending on the degree of melting of the ice particles. Thériault and Stewart (2010) began to address this issue by improving the melting rate of snow in a modeling scheme. According to Fujiyoshi (1986), when snow starts to melt, water droplets form on the lattice structure. At later times, the snowflake shape is no longer discernible and the particle is a mixture of ice and liquid water until it is completely melted into a liquid drop. During the melting process, the terminal velocity of snow increases gradually until the liquid fraction reaches approximatively 70%. At that liquid fraction value, the terminal velocity increases rapidly until the snowflake is completely melted (Mitra et al., 1990). For example, the different terminal velocity can lead to different precipitation distribution at the surface. A quantitative understanding of these changes is critical but has never been thoroughly addressed.

Given this gap in our understanding, the goal of this study is to investigate the sensitivity of the precipitation type trajectory formed through different melting regimes, especially in the region associated with a rain–snow transition. The melting regimes influence the type of precipitation formed, which have different fall speeds. This implies that the precipitation falls through different environmental conditions before reaching the surface. A two-dimensional kinematic cloud model was developed and coupled with a double-moment bulk microphysics scheme (Thériault and Stewart, 2010) to address this issue. The sensitivity experiments of the trajectories of two different melting schemes were carried out in this study.

The paper is structured as follows. The model is described in Section 2 and the experimental design is given in Section 3. Comparison with observations is analyzed in Section 4. The characteristics of the particle trajectories such as their trajectories and width of the peak in precipitation amount at the surface is discussed in Section 4. The implication of the results is discussed in Section 5 and the conclusions are stated in Section 6.

2. Model description

A bulk microphysics scheme coupled with a two-dimensional cloud model was used to study the trajectories of precipitation types across a transition of precipitation particles at the surface during a winter storm. This two-dimensional kinematic model is designed to use constant environmental conditions and can be used with quasi-steady state atmospheric conditions. If a snowflake falls at 1 m s^{-1} from 3 km above the surface, it will take approximately 50 min to reach the surface. Therefore, if the atmospheric conditions had not changed for 1 h, it is appropriate to neglect the thermodynamic and dynamic feedback to study the evolution of precipitation.

2.1. Overview of the microphysics scheme

The microphysical processes forming the various types of winter precipitation were examined using a bulk microphysics scheme in Thériault and Stewart (2010). The bulk scheme includes five ice hydrometeor categories: ice crystals (i), snow (s), refrozen wet snow (rws) and two ice pellet categories (ipA and ipB); two liquid hydrometeor categories: rain (r) and cloud droplets (c); and one semi-melted category: slush (sl). In addition, the scheme also includes precipitation categories that depend on whether the temperature is above

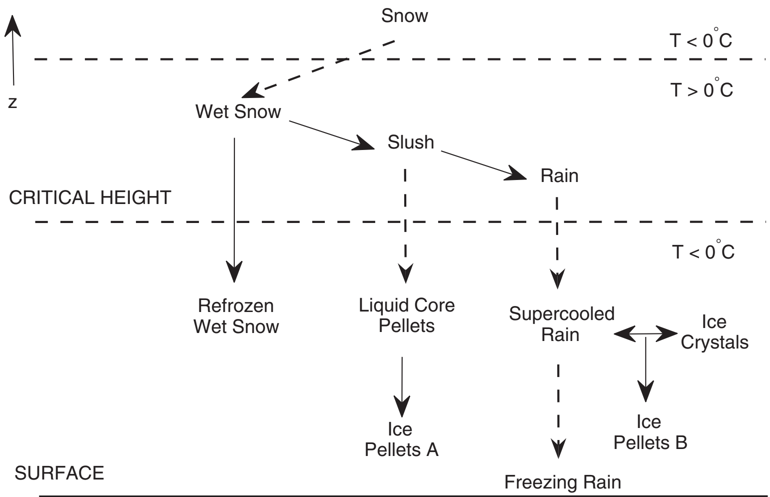

Fig. 1. Schematic diagram of the evolution of precipitation types when falling through the melting layer and the refreezing layer below it. The critical height is indicated as well as the temperature of the atmospheric layers. The solid line is the ground level. The solid arrows between precipitation type categories indicate changes of prognostic variables. The dashed arrows redefine the same of the prognostic variables.
Adapted from Thériault and Stewart (2010).