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Impact of melting snow on the valley flow field and precipitation phase transition

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ABSTRACT

The prediction of precipitation phase and intensity in complex terrain is challenging when the surface temperature is near 0 °C. In calm weather conditions, melting snow often leads to a 0 °C-isothermal layer. The temperature feedback from melting snow generates cold dense air moving downslope, hence altering the dynamics of the storm. A correlation has been commonly observed between the direction of the valley flow and the precipitation phase transition in complex terrain. This study examines the impact of temperature feedback from melting snow on the direction of the valley flow when the temperature is near 0 °C. Semi-idealized two-dimensional simulations using the Weather Research and Forecasting model were conducted for a case of moderate precipitation in the Pacific Coast Ranges. The results demonstrate that the temperature feedbacks caused by melting snow affect the direction of the flow in valleys. Several microphysics schemes (1-moment bulk, 2-moment bulk, and bin), which parameterize snow in different ways, all produced a valley flow reversal but at different rates. Experiments examining sensitivity to the initial prescribed snow mixing ratio aloft were conducted to study the threshold precipitation at which this change in the direction of the valley flow field can occur. All prescribed snow fields produced a change in the valley wind velocity but with different timings. Finally, the evolution of the rain-snow boundary with the different snowfields was also studied and compared with the evolution of the wind speed near the surface. It was found that the change in the direction of the valley flow occurs after the 0 °C isotherm reaches the base of the mountain. Overall this study showed the importance to account for the latent heat exchange from melting snow. This weak temperature feedback can impact, in some specific weather conditions, the valley flow field in a mountainous area.

1. Introduction

Precipitation is one of the most important weather elements affecting our society. Its occurrence represents a crucial part of the global water cycle and it is a fundamental aspect of storms. The precipitation phase (i.e., rain versus snow) has a major impact on the water resources in the spring snowmelt season and plays an important role in determining flood hazard (e.g. Barnett et al., 2005; Elsner et al., 2010; White et al., 2002).

Formation and phase changes of precipitation are associated with diabatic heating and cooling of the environmental air due to latent heat exchanges. Cooling due to melting snow can alter the temperature profile, which can in turn induce mesoscale

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circulations and influence the evolution of the storm. Lin and Stewart (1986) showed that melting-induced mesoscale circulation could extend as far as 50 km horizontally. Furthermore, in still weather conditions, the melting of snow often produces a deep isothermal layer of 0 °C (Findeisen, 1940), which also leads to a change in precipitation from rain to snow.

These thermodynamic and dynamical feedbacks have been studied over complex terrain. Steiner et al. (2003) demonstrated through radar measurements that a change from up-valley to down-valley flow and a precipitation phase transition occur simultaneously. In particular, they observed that the top of the radar bright band correlated with the shear level where the flow direction changed. On the other hand, Zängl (2007) conducted numerical simulations of the same event and concluded that the melting process only has a small contribution to the change of the wind flow in the valley.

Similar radar patterns to those discussed in Steiner et al. (2003) were observed in other regions of the world. For instance, in the St-Lawrence River Valley, Quebec, Canada during The 1998 Ice Storm (Henson et al., 2011) as well as in the Whistler Area, British Columbia, Canada (Fig. 1) during the Vancouver 2010 Winter Olympics. In particular, a correlation between the change in precipitation phase, valley flow field, and a rapid decrease in surface temperature was observed on 13–14 February 2010 in the Whistler Area (Thériault et al., 2012) during the SNOW-V10 field project (Isaac et al., 2014). It was hypothesized that the cooling from the melting snow was associated with the change in direction of the valley flow field. The characterization of the rain–snow boundary in mountainous terrain has been addressed in several studies including Medina et al. (2005), Minder et al. (2011), Zängl (2007), and Minder and Kingsmill (2013). In particular, Minder et al. (2011) performed numerical simulations to study the mesoscale features of the rain–snow boundary along mountainside. It was demonstrated that diabatic cooling by melting precipitation, adiabatic cooling from vertical motion, and microphysical timescales associated with melting all influenced the location of the rain–snow boundary along the mountainside, causing it to descend over a mountain windward slope. Their study also showed that the predicted magnitude of the rain–snow boundary's descent varies substantially depending on microphysical parameterization.

The sensitivity to microphysical assumptions related to snow on the diabatic cooling effects and the resulting precipitation phase changes were examined in Milbrandt et al. (2014) in a simple one-dimensional framework for the 13–14 February 2010 case in the Whistler area. The snow quantity aloft corresponding to radar observations was prescribed with an observed temperature and humidity profile with melting and cooling rates simulated with a bulk microphysics scheme. It was shown that the cooling rate due to melting, and hence the resulting timing of the phase transition at the surface, can be quite sensitive aspects of the representation of snow in the model. This includes the assumed fall speed parameters, the number of prognostic moments, and constraints on the size distribution such as the lower limit of the slope parameter and the assumptions of the melting processes in schemes.

Given the difficulty of predicting the precipitation phase and intensity when the temperature is near 0 °C, this study aims to better understand the impact of temperature feedbacks from melting snow on the direction of the valley flow field and on the precipitation phase. Semi-idealized two-dimensional simulations of the 13–14 February 2010 Whistler case were conducted using a mesoscale model in a systematic manner. First, the link between the temperature feedback from melting snow and the direction of the valley flow field is verified. A sensitivity experiment with various microphysical parameterization approaches was also conducted. Second, the sensitivity to different precipitation rates, through prescribing different initial snowfields, is studied to investigate the threshold precipitation rates required to produce a change in the valley

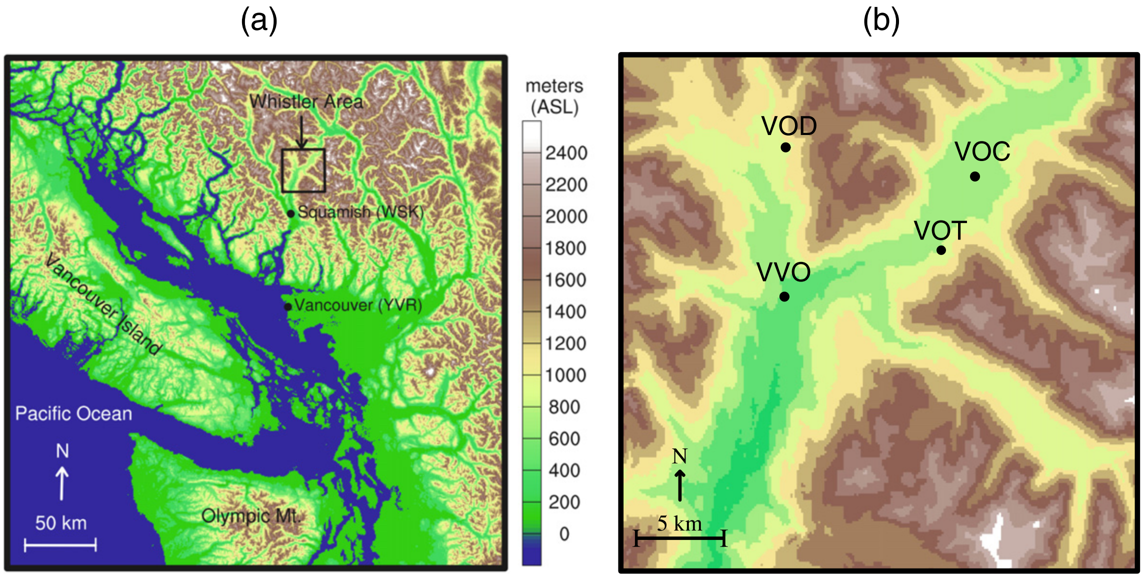

Fig. 1. (a) Western North America and (b) the Whistler area British Columbia. The Callaghan Valley is located at VOD, the radar was located at VVO and the soundings were launched from VOC. The precipitation rate shown in Fig. 2b was measured at VOT because no precipitation sensors were installed in the Callaghan Valley. The figure is adapted from Thériault et al. (2012).