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Effects of arctic sulphuric acid aerosols on wintertime low-level atmospheric ice crystals, humidity and temperature at Alert, Nunavut

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Abstract

The effect of pollution-derived sulphuric acid aerosols on wintertime arctic lower atmospheric ice crystals is investigated. These anthropogenic aerosols differ from natural background aerosols by their number concentration, strong solubility and reduced homogeneous freezing temperature when internally mixed with other compounds. Furthermore, observations suggest that the ice-forming nuclei concentration is reduced by one to four orders of magnitude when the sulphuric acid aerosol concentration is high.

Simulations performed using a column model and analysis of observed data for the period of 1991–1994 at Alert (82° 30’N, 62°20’W) are used to assess the changes of the boundary layer cloud characteristics by sulphuric acid aerosols and the potential effect on arctic climate. Results show that aerosol acidification leads to depletion of the ice crystal number concentration and an increase of its mean size. As a result, low-level precipitating ice crystals occur more frequently than ice fog and thick nonprecipitating clouds during high concentration of pollution-derived aerosols. This result is in agreement with observations that indicate an increase by more than 50% of the frequency of precipitating ice crystals when the weight proportion of sulphuric acid is greater than its mean value of 20% of the total aerosol mass. Consequently, the ice crystal size increases and number decreases, and the sedimentation flux of ice crystals and the dehydration rate of the lower troposphere are accelerated in the presence of high sulphuric acid aerosol concentration. As a result, the infrared radiation flux reaching the surface and the greenhouse effect are decreased. This process is referred

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to as the dehydration–greenhouse feedback. One-dimensional simulation for Alert during the period of 1991 to 1994 shows that a negative cloud radiative forcing of -9 W m^{-2} may occur locally as a result of the enhanced dehydration rate produced by the aerosol acidity.

Keywords: Aerosols; Climate; Arctic; Clouds

1. Introduction

Lower tropospheric ice crystal events are common in the Arctic during the cold season, from November to May (Curry et al., 1990). Depending on the ice crystal concentration in the air and the associated visibility, these events occur as either diamond dust or ice fog. Observations show a frequency up to 50% for diamond dust and around 10% for ice fog during the cold season (Maxwell, 1982; Curry et al., 1990; Girard and Blanchet, 2001b). Due to the difficulties of observing these events, their frequency may be even higher than reported by meteorological stations and indicated by satellite imagery analysis (Curry et al., 1990).

During the cold season, synoptic systems that form in the strong baroclinic zone in the Northern Hemisphere regularly inject mild and moist air to the Arctic. The absence of solar radiation leads to rapid infrared cooling of the surface. The surface cooling progressively spreads upward, and ultimately, the warm and moist air mass is transformed to cold and dry arctic air mass. In the process of cooling, air becomes supersaturated with respect to ice and ice crystals nucleate. Observations (Wexler, 1936) and modelling (Curry, 1983; Girard, 1998) have shown that the air mass transformation takes about 2 weeks to reach typical arctic air temperatures. The arctic air mass formation depletes the lower atmosphere of its internal energy via infrared cooling but increases its available potential energy. Dynamically, at large scale, the internal energy deficit in the Arctic leads to an intensification of baroclinic instabilities, which in turn perturb large-scale circulation through cyclogenesis. Energy balance between the pole and lower latitudes is then achieved by the new injection of mild and moist air from mid-latitude synoptic systems. The enhanced circulation further promotes the transport of pollutants into the Arctic. Therefore, not only there is a local feedback between dehydration and infrared radiation but also between synoptic circulation and pollution injection. The injection is maximum in the lower troposphere between 700 and 900 hPa. The Arctic wide infrared cooling of mild, moist and polluted air injected from mid-latitudes is probably the main source of widespread and continuous formation of ice crystals in the Arctic lower atmosphere (Curry et al., 1990).

To our knowledge, no quantitative definition of diamond dust and ice fog exists. A quantitative definition of diamond dust and ice fog can be suggested based on observations (Curry et al., 1990 for a comprehensive review) and modelling (Girard and Blanchet, 2001a,b). In this paper, a diamond dust event is defined as a cloud with ice crystal concentration below 1000 l^{-1} and crystal size larger than 30-μm diameter forming in the boundary layer and slowly precipitating to the ground. Ice crystals precipitating from thin liquid or mixed-phase clouds are also considered to be diamond dust as long as they meet