Nitrogen oxides and ozone in and above the snowpack at Summit, Greenland: Continuous observations of photochemical release and uptake

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1 Overview

We present early results from a multi-year study of the interactions that reactions in snowpacks have upon NO, O3, and in the overlying ambient air. Snowpack photochemistry releases NO, which can lead to ozone formation above the snowpack, and destroy O3 in the snowpack [e.g., 1–4].

The full study. The overarching objective is to improve the ability of global chemistry-climate models to simulate the impact of in-snow processes upon the overlying atmosphere, in particular on ozone and NOx. Parameterizations of in-snow processes will be incorporated into the model ECHAM, which can be used to simulate climate-snowcover-chemistry interactions. Snow-tower: The upper 3 levels are visible; 5 more levels are present. Study site in Summit, Greenland (snow over glacial ice; the northern mid-latitude U.S. snow over biologically active soil; and northern Alaska (snow over permafrost soil).

Field studies. Air-snow exchange fluxes and snowpack interstitial air gradients are being determined under a variety of snow conditions, in order to characterize the range of snow-air processes affecting snow-covered regions. Studies include Summit, Greenland (snow over glacial ice; the northern mid-latitude U.S. snow over biologically active soil; and northern Alaska (snow over permafrost soil).

Presented in this poster. Here, we focus on results from measurements at Summit, Greenland (72°N, 28.5°W, 2020 m a.n.) made during summer 2008, with a focus on interstitial air processes. Summit measurements are ongoing this winter and will continue until August 2009.

2 Need for interstitial air measurements

Motivation. Interstitial air is key to understanding how snowpack photochemistry affects the ambient atmosphere and the climate system.

• Time-varying interstitial air composition should provide clues to processes occurring in the snow.

• Interstitial air is a photochemically active medium separate from the ambient atmosphere. In many cases, e.g., for ozone and some organic gases, gaseous photochemistry in the snowpack may control overall air-snow fluxes.

• Natural snow contains impurities not included in laboratory studies of snow photochemistry. Whether this affects the application of laboratory results to natural snow can only be determined by using field observations.

Limited available field data. Reported observations of nitrogen oxides in interstitial air include the following:

• Observations designed (only) to document the presence of elevated NO, [1, 7].

• Observations using natural snow but in a controlled setting (e.g., a quartz volume) [8–11].

• Observations in natural snowpacks but using high flow rates (~100 Lpm) which make interpretation of the location sampled and evidence of in-snow atmospheric air intrusion more problematic [10, 11].

• Observations of NO and NOx using a low flow rate (~1 Lpm). [1 study (12)].

Model assumptions. Reflecting the limited number of observations and inadequate knowledge of interstitial air composition, models that simulate the impact of snowpack photochemistry on nitrogen oxides and ozone in the overlying atmosphere are in the initial stages of development.

• Some models neglect interstitial air reactions entirely, and assume that all emissions into the interstitial air are transported into the overlying atmosphere [13–16].

• In contrast, [17] assumed that all NOx photochemically released into the interstitial air reacts with water on the snow surface to form HNO3.

3 Measurements

Objectives. Above-snow and interstitial air oxides and ozone gradients and NOx profiles.


Measurements. NO, NOx (NO, NO2, and N2O), O3, and NH3 at 10 m (July 2008–August 2010; a separate study).

3.1 Study area

• Summit, Greenland (72°N, 28.5°W, 2020 m a.n.)

• Snow depth: 100 cm.

• Interstitial air measurements of multiple species provide information that should help us tease out the separate effects of air-snow interactions and interstitial photochemistry. Weather data for daynight (0–24), 10 m height.

4 Early Results: July–August 2008 interstitial air observations

Vertical gradients in the interstitial air. (Figure 3, left)

• NO: Maximum levels are observed at -100 cm. Reduced NO at ~20 cm (near the snow-air interface). Concentrations are consistent with a partial sampling of ambient air. Below -50 cm, where it is darker (~1% in ambient radiation) NOx, NO increases with time, i.e., during downward transport.

• O3: NOx over time at all levels, and is nearly uniform at and below -50 cm. This suggests rapid vertical exchange not apparent in the NOx.

• NO, NOx levels do not recover to ambient values.

Behavior of NO and NOx. (Figure 4).

• NO: accounts for most of the NOx, even during the day, as expected for emissions of NOx (mainly and reduced NOx) photolysis below the surface. NO is present to below 100 cm, implying ventilation (possibly driven by the jump in volume), since radiation should be nearly absent at those depths.

• NOx: decreases from 1400 to 2000, but then changes very little overnight at any depth.

Discussion. During the day, vertical ventilation occurred (indicated by the flat O3 profile), but NOx enhancements are focused in the upper snowpack. This suggests that NOx levels reflect a balance between formation (at the upper levels) and loss (at all levels), i.e., re入口 the snowpack by 22:00. At 00:00, the NOx enhancements are located at 50 cm and 150 cm. Reduced NOx levels are sampled at 3 m (~1400), preserved by the snowpack, but NOx levels are significantly greater at 3 m levels.

Oxidation states in the interstitial air. (Figure 5).

• O3: the O3 measurements are shown, based on all July–August 2008 interstitial air measurements.

• NOx: Peak midday NOx is highest near the surface, and drops monotonically with depth. The morning increase is shifted to later times at lower depths, consistent with the suggestion that snowpacks have daytime maxima.

• NO: midday NO is nearly identical from -80 to -100 cm, consistent with the apparent efficient photolysis noted above. NOx recovery toward ambient levels occurs more slowly at the deeper depths, with NOx increasing at -120 cm. NOx, NO and to recover ambient levels before photolysis (O3, destruction, NOx formation) restarted the following day.

Concluding comments. These initial results suggest that continuous in-snow measurements of multiple species provide information that should help us tease out the separate effects of air-snow interactions and interstitial photochemistry. Weather data for daynight (0–24), 10 m height.

In-snow measurements of multiple species provide information that should help us tease out the separate effects of air-snow interactions and interstitial photochemistry. Temperature, wind speed, solar angle, humidity, light. Increased magnitude and variability at 3 m indicates that impacts of snowpack emissions are significantly greater at 3 m height than even at 10 m height.