Diurnal and Seasonal Variations of Nitrogen Oxides Within Snowpack Air and the Overlying Atmosphere at Summit, Greenland

C. Toro[1], R.E. Honrath[1†], L.J. Kramer[1], D.Helmig[2], B.A. Van Dam[2], B. Seok[2], L. Ganzeveld[3], P.V. Doskey[1]

[1]Atmospheric Sciences Program, Michigan Technological University
catoro@mtu.edu

[2]Institute of Arctic and Alpine Research, University of Colorado
detlev.helmig@colorado.edu

[3]Department of Earth and Environmental Sciences, Wageningen University
Laurens.Ganzeveld@wur.nl

Overview

The Arctic is one of the Earth's most sensitive regions to climate change. Reductions in snow cover concomitant with a warming atmosphere will affect cryosphere-atmosphere exchange of trace gases; thus, improved understanding of atmospheric and surface processes is required to predict future impacts of climate change on the atmospheric chemistry of the Arctic.

Our research focuses on snowpack chemistry and air-snow exchange of nitrogen oxides and ozone. Specific goals of the research are to improve representations of surface and atmospheric processes that influence the oxidative capacity of the Arctic atmosphere and to develop and evaluate global chemistry-climate models that simulate effects of snowpack processes on the overlying atmosphere.

Here, we present the first set of continuous measurements of nitrogen oxides within and above snowpack that detail the annual cycle of these trace gases at Summit, Greenland. Seasonal and diurnal variations of the reactive species are discussed.

Experimental Site Description

The GEOSummit Flux Facility was designed for air-snow exchange studies. Conduits for sampling tubes and cables run from the 10 m tower to a heated, insulated facility that is located under the snow (downwind from the tower during clean sector flow), and which is accessed through the entryway visible on the right of the photo.

To the right is a picture of the snowtower with paired air inlets at levels separated by 30 cm between them.

The experiment started in June 2008 with 8 levels on the snowtower. Six new levels were added in August 2009, as the inlets were buried by accumulating snow. As of February 2010, the snowtower has a vertical profile of 4.2 meters with 2.5 meters into the snowpack.

***Figure 1**: Snow Tower*

Acknowledgements: This work is funded by National Science Foundation grants ARC0713992 and ARC0713943. Michael Dziobak provided essential instrumentation and field support.
We especially thank the Summit Science Technicians and support staff and the Flux Facility design and construction team for their assistance.

Results

I. NOx enhancements (snowpack concentrations minus ambient mixing ratios measured at 2 m above snow).

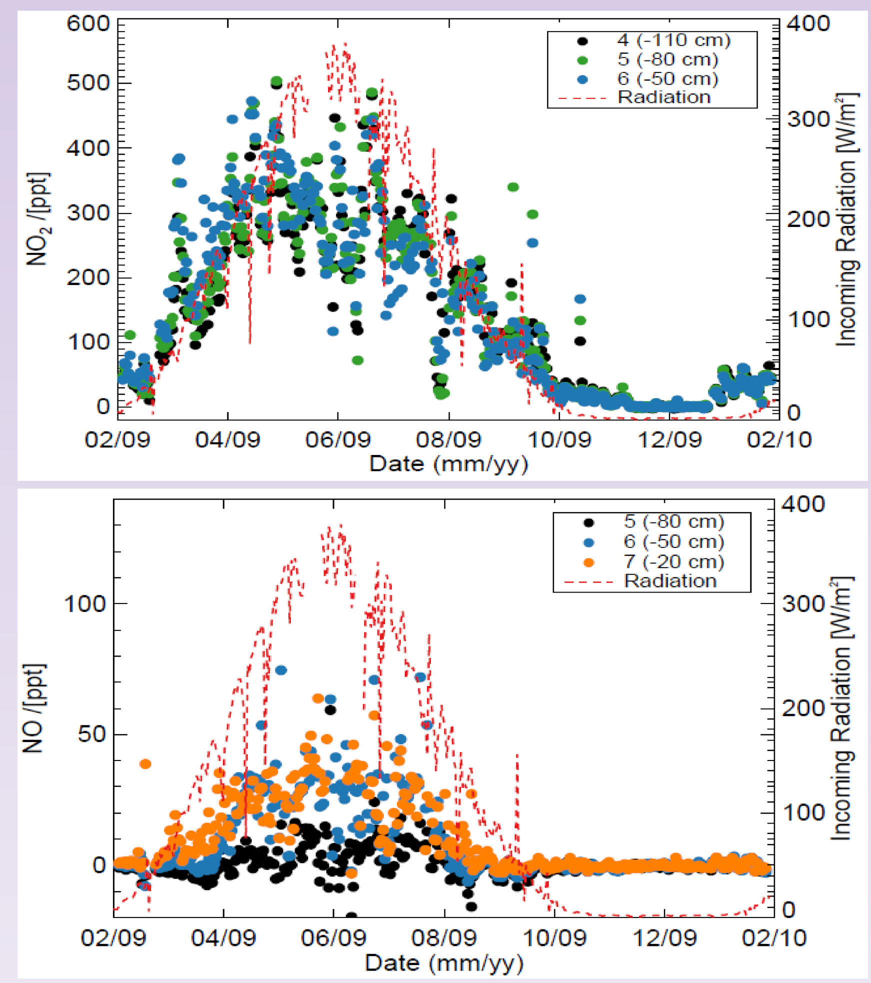

***Figure 2**:* Time series of daily NO_2 (upper plot) and NO (bottom plot) enhancements at the major activity levels for each species.

Results

II. Seasonal response of NO_2, NO, ozone and dependence on snowpack temperature and winds.

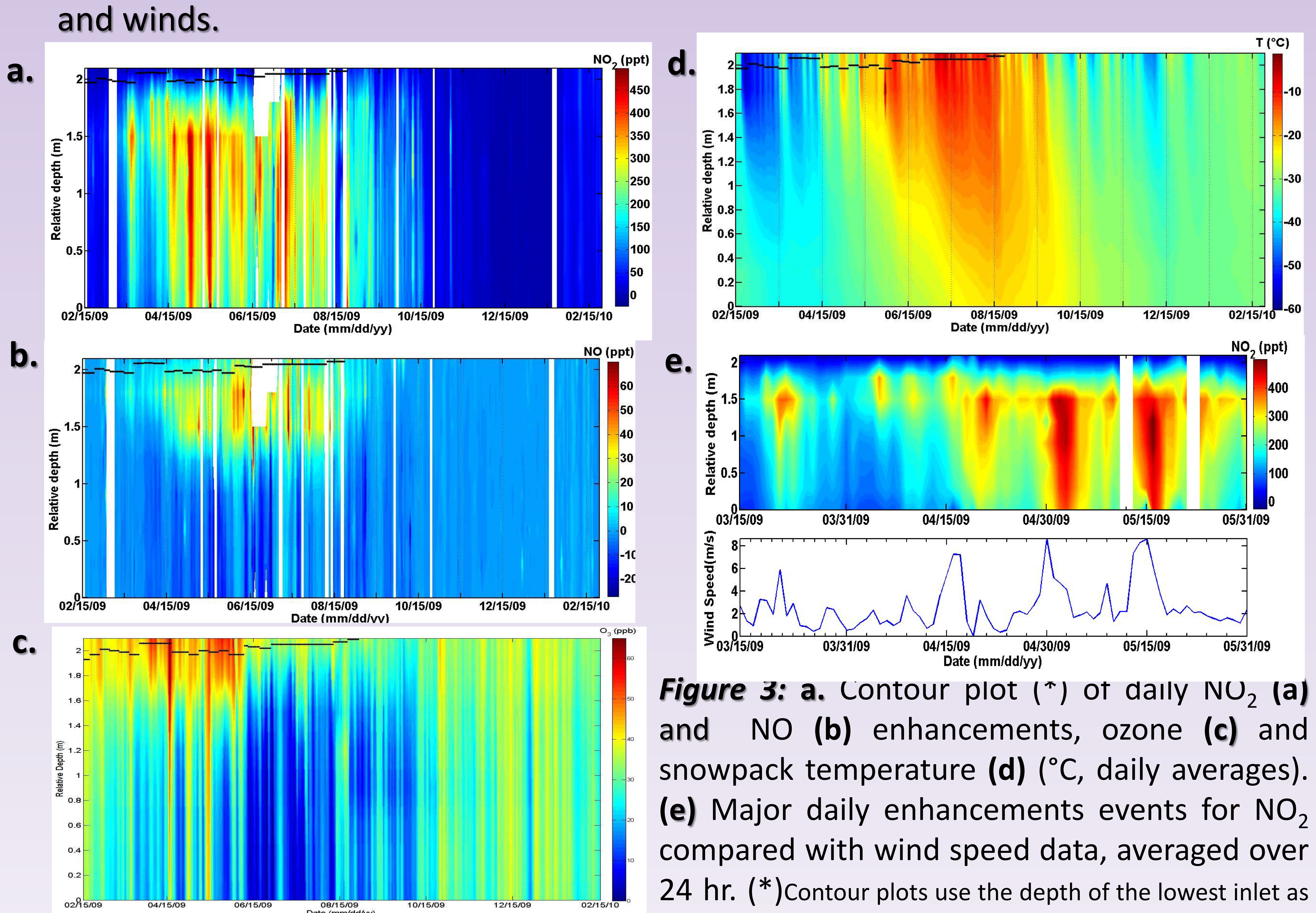

Figure 3**: **a. Contour plot (*) of daily NO_2 **(a)** and NO **(b)** enhancements, ozone **(c)** and snowpack temperature **(d)** (°C, daily averages). **(e)** Major daily enhancements events for NO_2 compared with wind speed data, averaged over 24 hr. (*)Contour plots use the depth of the lowest inlet as reference. Snowpack surface is over plotted with black dots

Results

IV. Snowpack emissions to the atmosphere

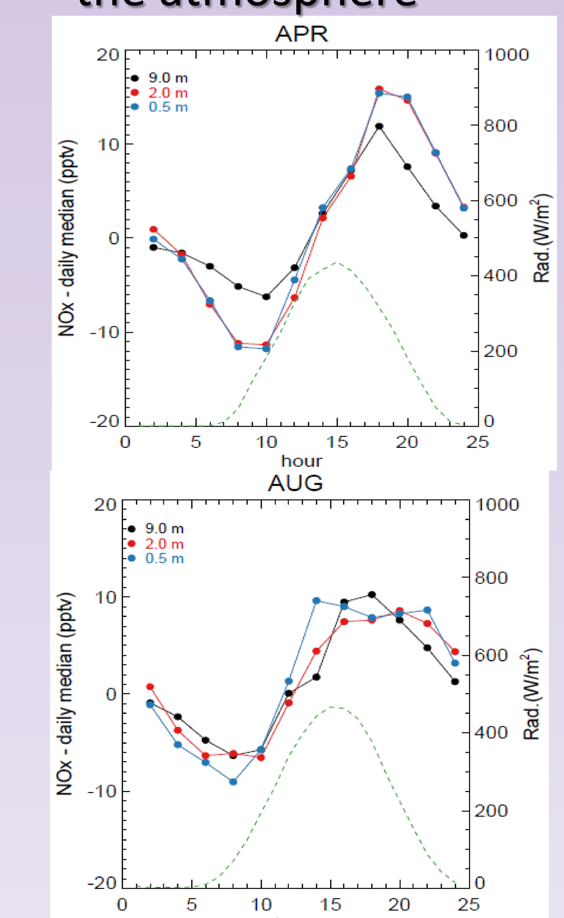

Figure 5: Two-hourly averaged data for NO_x at three different heights above the snowpack during April and August of 2009. Values are expressed as NO_x with daily median subtracted.

Results

III. Diurnal cycle of NO_x: seasonal and vertical variations through the snowpack.

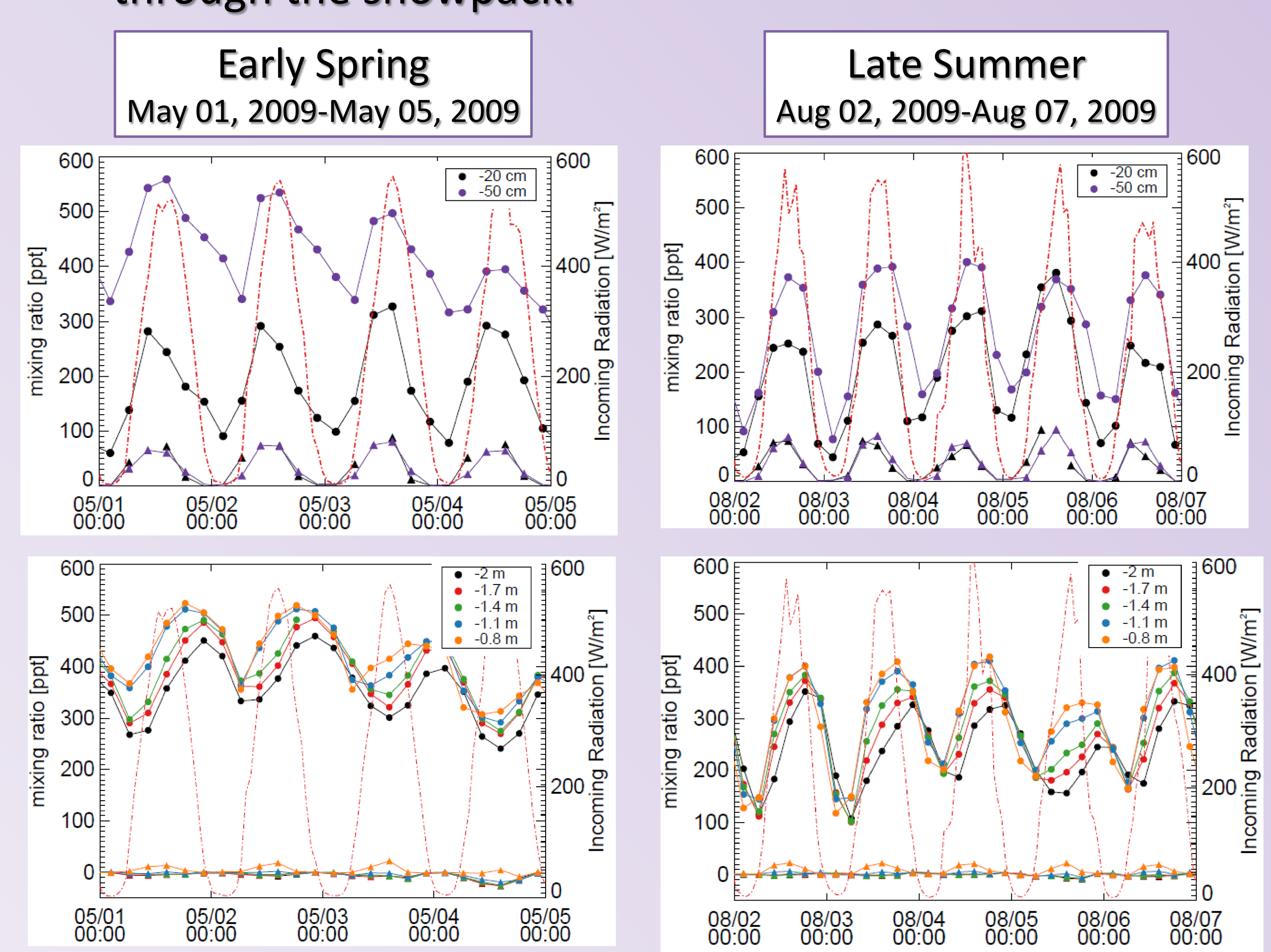

Figure 4: Diurnal cycles for NO_2 (circles) and NO (triangles) enhancements at different depths in the snowpack, during two periods: early spring and late summer. Each point is a 4 hr average and all times are expressed as local solar time. The legend detail colors and depths for NO_2 and must be considered the same for NO.

Conclusions

❖ ***NO_2 represents most of NO_x in the snowpack at Summit***, with a maximum approximately 4-5 times higher compared to the maximum period of NO production.

❖ ***NO_x in the snow shows a high seasonal variability and a different behavior between NO and NO_2.*** NO_2 profile is clearly shifted to early spring, while NO follows the radiation profile with a peak around June-July (see Figure 2).

❖ ***NO_x levels are strongly dependant on depth.*** NO is produced at the upper levels in the same magnitude, while NO_2 shows about 100 ppt of difference between -20 cm and -50 cm (see Figure 4, upper plots). At deeper levels, NO is nearly zero while NO_2 shows high values even at 2 m of depth (see Figures 3a and 3b).

❖ ***High wind speed events increase the transport and mixing of gases through wind pumping mechanism.*** This is clearly observed in NO_2 and O_3 profiles (see Figures 3c and 3e) in the snowpack. In the first case, high values of NO_2 are observed at deep levels, showing an increase in mixing through the snowpack. In the second case, high O_3 values are observed in upper levels of the snowpack mainly due to intrusions from the overlying atmosphere during these events.

❖ ***No evidence of a strong relationship between NO_x and ozone***. Minimum values of O_3 are observed during maximum of NO production, but the magnitude of this last specie does not account for the decrease in ozone concentrations within the snowpack.

❖ ***Diurnal cycles of NO_x were observed above the snowpack***. The influence of snowpack emissions are clear in early spring, producing evident vertical gradients between 2 m and 9 m above the snow. In late summer, though vertical gradients are smaller, the influence of the snowpack is still clear with diurnal cycles at all heights measured.

❖These new observations will improve significantly the understanding of diurnal and seasonal NO_x surface exchanges and the mechanistic description of the snowpack NO_x chemistry.