Model simulations of polar boundary layer ozone depletion events in spring

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Abstract

In the last several decades, significant depletion of boundary layer ozone events (ODEs) has been observed in both Antarctic and Arctic, especially over sea ice zones. ODEs are attributed to catalytic destruction by bromine radicals (Br and BrO), especially during bromine explosion events (BEs), when high concentrations of BrO periodically occur. However, neither the exact source of the bromine nor the mechanism of the formation of ODEs is completely understood. Here, by considering an additional bromine source from sea ice (through blowing snow events), we can successfully reproduce observed BEs in a 3D global transport model, pTOMCAT. Modelled tropospheric BrO compares well, in general, with the tropospheric BrO column retrieved from the GOME satellite instrument. However, the simulated surface ozone at polar regions are hard to drop below 10 ppbv, which could be due to the limited model ability in reproducing stable boundary layer. Here, we will show that the combined effects of the stability of the boundary layer and BrO concentrations within the BL will determined the observed/simulated surface ozone.

1. Snow-sourced sea salt and Br

Lying snow on sea ice is quite saline, as it can be contaminated by sea water ions through several pathways, such as by frost flowers grown on newly formed ice, upwards migration of brine within snow, input of sea salt aerosols from the open ocean/leads, and flooding. These salty snow particles can be carried into the air during the blowing snow events and some small particles may loss water and form naked sea salt through sublimation processes.
We derive a method for estimating sea salt aerosol production and bromine release rates through blowing snow events by using the observed snow salinity frequency, the measured suspended snow particle size distribution and the calculated sublimation rate (*Yang et al*., 2008). Under typical polar weather conditions, the blowing snow-sourced sea salt production rate can be more than an order in magnitude higher than that from open ocean.

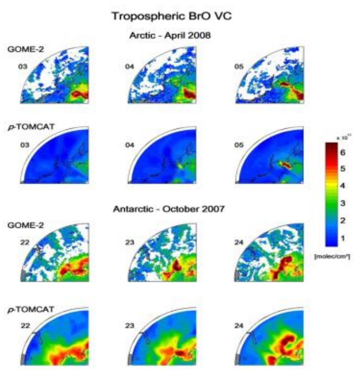

Figure 1: Tropospheric BrO vertical column from GOME-2 and pTOMCAT (2.8x2.8 degree) simulation in Arctic (top) and Antarctic (bottom). *Theys, et la., 2011.*

2. Simulation of bromine explosions and ozone depletions

It can be seen from Figure 1 that the model, pTOMCAT, with blowing snow-related sea salt production can successfully reproduce the observed bromine explosion events. The calculated column BrO from both model and satellite retrieval are in good coincidence in magnitude, space and time for some cases.

Elevated BrO or BEs are associating with lower tropauses, as indicated in Figure 2. This also means the BEs are always accompanying by a low pressure system or storm in the troposphere. Thus high surface wind speeds could corresponding to elevated BrO as shown in Figure 3a. However, not all elevated BrO cases associating with elevated BrO as shown in Figure 3b, indicating non-local source and long-distance transports.

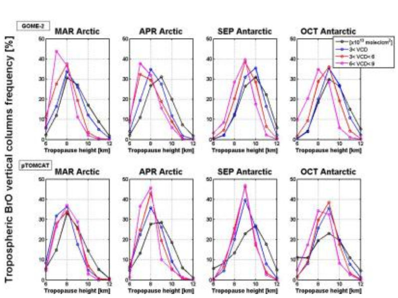

Figure 2. Frequency distribution (in %) of the GOME-2 and pTOMCAT tropospheric BrO column as a function of the altitude of the tropopause, for different range of vertical columns. *They et al., 2011.*

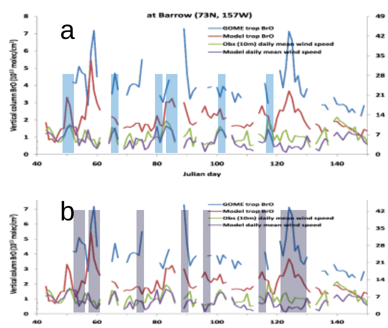

Figure 3: Daily series of tropospheric vertical BrO column at Barrow from GOME and pTOMCAT, together with daily mean surface wind speeds from model output and observation at Barrow airport station. *Yang et al., 2010.*

Obviously, these different relationship between wind speeds and column BrO has important indications for surface ozone behaviors in both observation and simulations. As shown in Figure 4, the complete surface ozone removal at 4th of March/1998 is corresponding to very weak winds and stable boundary layer, during which period, BrO concentration (~10pptv) are high. However, during blowing snow events, though high Br releases, it is hard to 'see' complete ozone removal due to the strong vertical mixing of ozone rich air above BL. Due to limited model ability in polar regions (in reproducing stable BL), our modelled surface ozone are hardly drop below 10 ppbv.

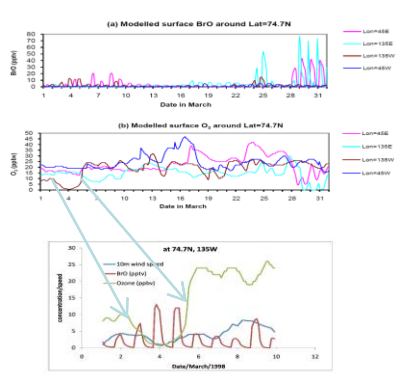

Figure 4: Modelled tropospheric BrO (a) and surface ozone (b) at different sites in Arctic in March of 1998 (*Yang et al., 2010.*). The bottom shows the corresponding surface wind speeds during a period of a completely ozone removal indicating the importance of boundary layer dynamics and bromine chemistry.

3. Comparison with observation

A big BEs over Weddell Sea on 9th of October 2007 is well reproduced (Figure 5). A complete ozone depletion event at Halley was observed (Figure 6a, from Jones et al., 2009), which is corresponding to a post-storm period (figure 6c). A significant ozone drop of more than 10ppbv at Halley during 9th Oct. is also simulated (Fig. 6d) which is corresponding to higher BrO (>20pptv) concentration (Fig. 6e).

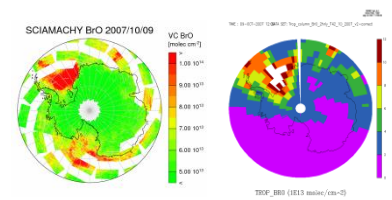

Figure 5: total satellite BrO vertical column (left) and pTOMCAT tropospheric BrO column at local noon time near Halley (right).

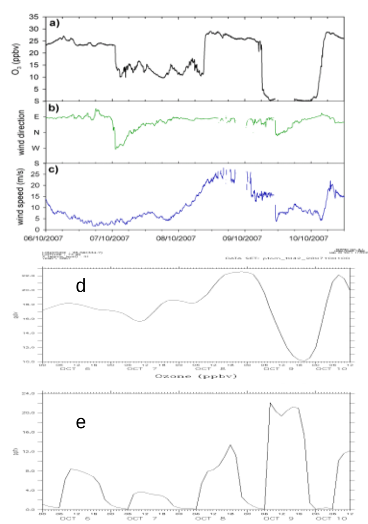

Figure 6: Observed data at Halley: a) surface ozone; b) wind directions; c) wind speeds, and modelled d) surface ozone (in ppbv); e) surface BrO i(in pptv) at Halley.

4. Conclusions

- By introducing a parameterization in a global model to estimate sea salt and bromine release from snow on sea ice from blowing snow events, we can successfully reproduce the bromine explosion in polar regions. The modelled tropospheric column BrO well match the satellite data.
- The elevated BrO plumes at sits can be local produced or by long-distance transport. High surface BrO concentrations during post-storm period are 'seen' by the model, which corresponds to significant ozone loss within the isolated air mass in the stable BL.

References:

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