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A One-Dimensional Model Study of the Occurrence and the Termination of Polar Boundary-Layer Ozone Depletion Events

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The tropospheric ozone depletion events (ODEs) in polar spring have attracted increased attention in the last thirty years. A dramatic decline of the surface ozone mixing ratio from tens of parts per billion (ppb) to less than one ppb within a few days is observed in various observation sites in polar regions. Previous studies suggest that the halogen species, especially bromine, acts as a catalyst in a chemical reaction cycle, which causes the destruction of ozone in the polar boundary layer. Moreover, a group of heterogeneous reactions with the involvement of HOBr occur on the surface of different substrates such as suspended aerosols and sea ice, leading to the activation of bromide from these substrates, and a following enhancement of the total bromine amount in the boundary layer occurs. This phenomenon is widely known as the "bromine explosion" mechanism. However, the initiation and the termination steps of the ODEs are still not well understood.

In the present study, a one-dimensional model, KINAL-T, is developed with the aim of investigating the role of the boundary layer in the occurrence and the termination of the ODEs. The 1-D model is an extension of the previous box model study[1], explicitly including the vertical convection of gas. The parameterization of the vertical profile of the turbulent diffusivity from Pielke and Mahrer (1975)[2] is adopted. Moreover, in the 1-D model, a bromine-related reaction scheme taken from Cao et al. (2014)[1] is used, in which not only the gas phase but also the heterogeneous reactions are implemented. The simulation results show that the tropospheric ozone depletion event in a 200 m boundary layer starts after 12 days under the condition of a potential temperature gradient of $0.7\,\mathrm{K\,km^{-1}}$ and a wind speed of $5\,\mathrm{m\,s^{-1}}$. The whole depletion process of ozone takes approximately 2.5 days. The vertical profiles of ozone and bromine-containing compounds at different days are also captured. Instead of preventing the ozone from the free troposphere entering the regions lacking ozone, it is found that the boundary layer is of more importance for containing the reactive bromine species released from the underlying surface. As a result, an accumulation of the bromine occurs in the boundary layer, leading to the consequent ozone consumption. Towards the end of the ODEs, when the boundary layer height increases due to a reduced strength of the temperature inversion, the "severe ozone depletion event" becomes a "partial ozone depletion event", which is in consistence with recent observations[3]. When a breakup of the boundary layer occurs in a strong wind speed and very weak temperature inversion situation, the lack of ozone in the lowest troposphere is rapidly compensated with the ozone from the free troposphere within two hours, which terminates the ODEs. Thus, the 1-D model in the present study helps to clarify the characteristic phenomena occurring within the boundary layer in polar regions, in particular the starting and the terminal periods of the ODEs.

[1]Cao et al., *Atmos. Chem. Phys.* **14**: 3771–3787 (2014).
[2]Pielke and Mahrer, *J. Atmos. Sci.* **32**: 2288–2308 (1975).
[3]Bottenheim et al., *Atmos. Chem. Phys.*, **9**, 4545–4557 (2009).