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Climate of the Past Discussions

Interactive comment on "Radiative effects of ozone on the climate of a Snowball Earth" *by* J. Yang et al.

J. Yang et al.

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Dear Editor,
Thanks for editing our paper. Replies to the comments are as follows.

Major point:
I recommend you to emphasize the uncertainties inherent to your study. I agree with both reviewer that other unknown factors (such as the CO_2 level, cloud radiative forcing, parameterization of the surface albedo) may potentially overwhelm any ozone effects on glaciation or deglaciation thresholds. As you already suggest in your answer to the reviewers, this should be clearly stated in the abstract and conclusion of your contribution.

Reply:
We agree with the point, and we add statements in both abstract and conclusions, by pointing out that our results have uncertainties, depending on GCM model parameterizations (marked by bold).

Minor points:
I agree with reviewer 2 that the caption of fig 4 should be clarified. - The point addressed by reviewer 1 (Kasting) about the radiative effect of lowering ozone concentration is pertinent. The fact that the decrease in the net radiative forcing of the stratosphere on the troposphere dominates the heating of the troposphere by the UV flux is not obvious. From energy conservation point of view, the point is where is the energy going ? All the radiative flux not intercepted by the stratosphere may potentially warm the surface. In addition to the citations that you mention, can you give some insights into the physical reasons explaining why the cooling effect dominates ?

Reply:
We add detailed explanation for SW in Figure 4. We also interpret what is the so-called coalbedo. For the net radiative forcing of stratospheric O_3 on the troposphere and surface, we rewrite the third paragraph in Introduction. We add detailed interpretation on how stratospheric ozone has the warming effect on the troposphere and surface. We wish these could help readers.

In the present-day atmosphere, the ozone layer is mainly located in the stratosphere approximately between 10 and 50 km in altitude, with peak concentration at about 25 km high. It is well known that O_3 absorbs solar ultraviolet radiation, which protects life on the surface. On the other hand, O_3 also has a strong absorption band in the infrared region (9.6 µm). Thus, ozone is a greenhouse gas. The radiative effect of O_3 on the troposphere and surface is in two ways. First, solar absorption of the ozone layer directly cools the troposphere and surface. Downward infrared emission by O_3, on the other hand, warms the troposphere and surface. There is also an indirect effect of other stratospheric greenhouse gases (e.g., CO_2 and H_2O) on the troposphere and surface. That is, the CO_2 and H_2O down–emission of energy, which was deposited in the stratosphere due to O_3 solar and infrared absorption, also warms the troposphere and surface. It was estimated that about 50 % of the CO_2 and H_2O down-emission is due to O_3 solar and infrared absorption, and that the net radiative effect of stratospheric O_3 is to warm the troposphere and surface by about 2.4 $W\,m^{-2}$ (Ramanathan and Dickinson1979). Therefore, a decline of stratospheric ozone concentration would decrease stratospheric temperature and reduce the downward emission of infrared radiation, causing a cooling of the troposphere and surface.

Interactive comment on Clim. Past Discuss., 8, 3583, 2012.