Climate Effect of a Mesospheric Ozone Loss due to Energetic Particle Precipitation
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1. Satellites show Long-Term Impact on Mesospheric Ozone
   - Direct energetic electron precipitation (EEP) effect of odd hydrogen (HOx) causes large long-term ozone variability (up to 34%).
   - This may cause large dynamical changes in the mesosphere and stratosphere, however, these effects from EEP-HOx have not been considered in climate models.

2. Experimental Design
   - Coupled climate model MPI-ESM 1.0 – T63 L195.
   - Setup (input data, model version etc.) as for CMIPS piControl.
   - 80 model years.
   - Control experiment = piControl.
   - Experiment with mesospheric ozone loss: 40% ozone reduction between 60-90 N/S and 0.01 – 0.1 hPa.

3. Changes in the Temperature
   - Mesospheric ozone loss leads to a mesospheric temperature decrease due to a reduced absorption of longwave radiation from the surface.
   - Warming in the stratosphere at the winter pole (up to 2.2 K).

4. Changes in the Zonal Wind
   - We found significant changes in the wintertime dynamics of the polar mesosphere and stratosphere due to an idealized mesospheric ozone loss. The reduced longwave absorption of ozone cools the upper mesosphere and accelerates there the zonal mean zonal wind. Further down, the polar vortex weakens throughout the stratosphere and troposphere. This may be caused by an increased momentum deposition of resolved waves. However, the mechanism how the signal propagates downward is still unclear.
   - Surface temperature anomalies reveal a negative NAM pattern, while previous studies considering a (mostly) stratospheric ozone loss reported a positive NAM pattern.

5. Changes in the Eliassen-Palm Flux
   - More momentum deposition from resolved waves and enhanced equatorward propagation of wave activity in the lower mesosphere.

6. Changes in Surface Temperature
   - Cooling over Northern Europe (up to -2 K) and warming over Northern America (up to 2 K) → Indication of NAM negative phase.
   - In contrast to previous studies considering (mostly) stratospheric ozone loss (e.g., Baumgaertner et al., 2011; ACP).

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Energetic particle precipitation (EPP) produces odd hydrogen (HOx) and odd nitrogen (NOx) in the polar middle atmosphere. Both components destroy ozone, which influences the radiative balance of the middle atmosphere and subsequently the strength of the polar vortex. Recently, Andersson et al. (2014) showed that the direct effect of HOx causes significant mesospheric ozone variability. While several studies have analyzed the potential impact of a stratospheric ozone loss on the tropospheric climate (e.g., Seppälä et al., 2009; JGR), the influence of the direct HOx effect has not yet been investigated.

Here, we analyze the potential impact of an idealized polar mesospheric ozone loss on the atmospheric circulation and surface temperature.