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Modeling study on the polar middle atmospheric responses to medium energy electron (MEE) precipitation

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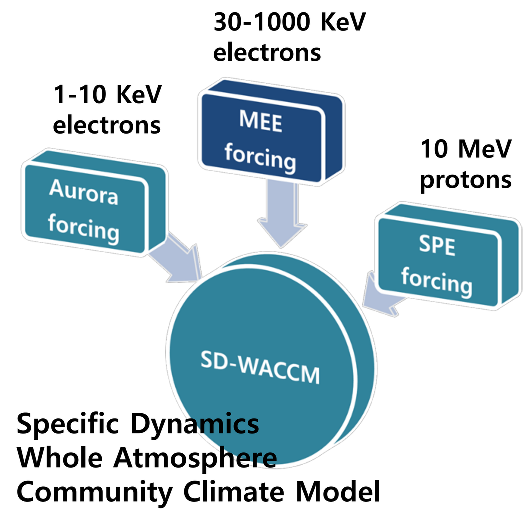
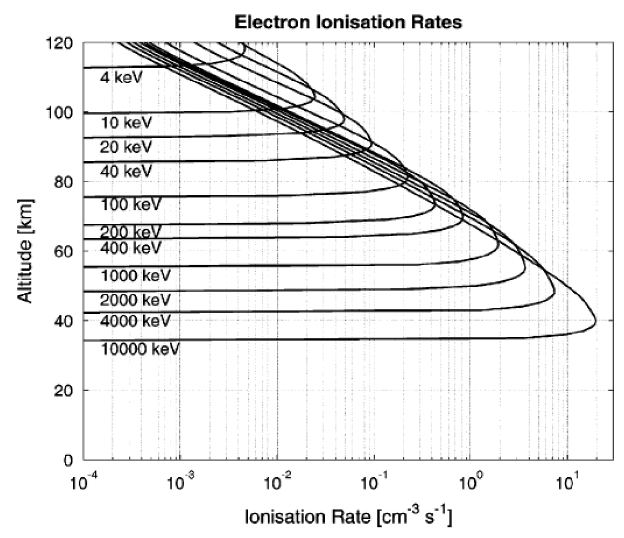
1. Abstract

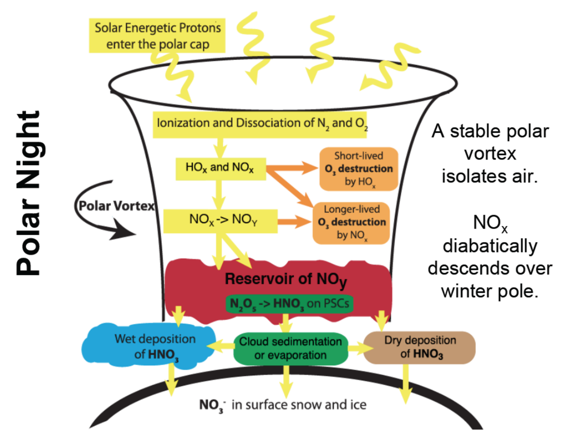
Energetic particle precipitation (EPP) is an important source of chemical changes in the polar middle atmosphere during winter. Recently, it has been suggested from modeling study that chemical changes by EPP can cause dynamical changes of the atmosphere. Here, we study the atmospheric and climatic responses to the precipitation of medium-energy electron (MEE) during 2005-2013 by using Specific Dynamics Whole Atmosphere Community Climate Model (SD-WACCM). Results show that MEE precipitation significantly increases the amount of NOx and HOx, resulting in mesospheric and stratospheric ozone decreases by up to 60% and 25% respectively during polar winter. The ozone loss due to MEE precipitation induces the warming in the polar lower mesosphere by 1 K averaged 9 years. However, the temperature change has a large fluctuation. These fluctuations in temperature change are caused by low ozone loss around stratopause and mesopause. The ozone loss by less than approximately -1 ppmv around stratopause disturbed the temperature change in the polar middle atmosphere. In large ozone loss around stratopause, the changes in temperature and zonal wind show clear responses. The temperature increases by up to 11 K in the lower mesosphere and the zonal wind reduced by 5-21 m s^{-1} in the polar middle atmosphere. The ozone loss in the stratopause and mesopause seems important to induce the dynamic change by MEE precipitation.

2. Model simulation and Analysis

- Using SD-WACCM, focus on the chemical and dynamic impacts of MEE in terms of spatiotemporal variations of NOx, HOx, ozone, temperature, and winds in the stratosphere and mesosphere during 2005-2013 period.
- 1.9 lat x 2.5 long (144x96), L88 up to z = 140 km, transport of 58 chemical species
- Using Goddard Earth Observing System 5 (GEOS5) meteorological re-analysis data
- Nudging scheme is conducted below 50 km and fully interacts above 60 km.
- Differences of the model runs between with and without the MEE precipitation (MEE and Control runs, respectively) are calculated to see the effects of the MEE precipitation
- Control run = Effects for Aurora and SPE, MEE run = Effects for Aurora, SPE, and MEE







(from Turunen et al., 2009)

3. Result 1 : Chemical changes by MEE precipitation

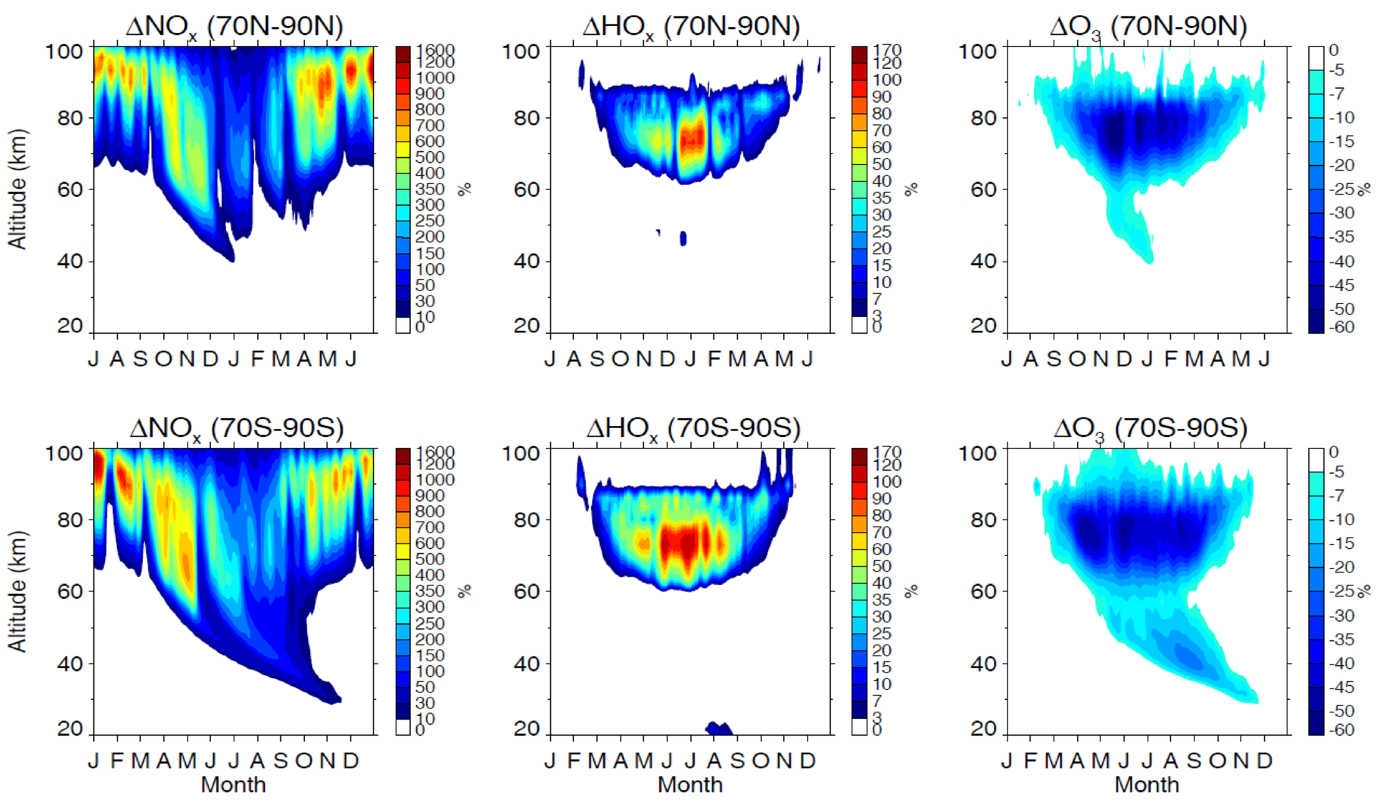


Fig 1. Composite relative changes ((MEE-Cont.)/Cont.) for zonal mean volume mixing ratios for NO_x, HO_x, and ozone in an altitude range of 20-100 km.

- NOx increases about 600% in the mesosphere and about 250% in the upper stratosphere during wintertime and reaches down to 30 km.
- HOx enhances up to 170 % and the largest enhancements are seen in an altitude range of 70-80 km in mid-winter.
- Ozone is destroyed down to 60% in the mesosphere and down to 25% in the stratosphere.

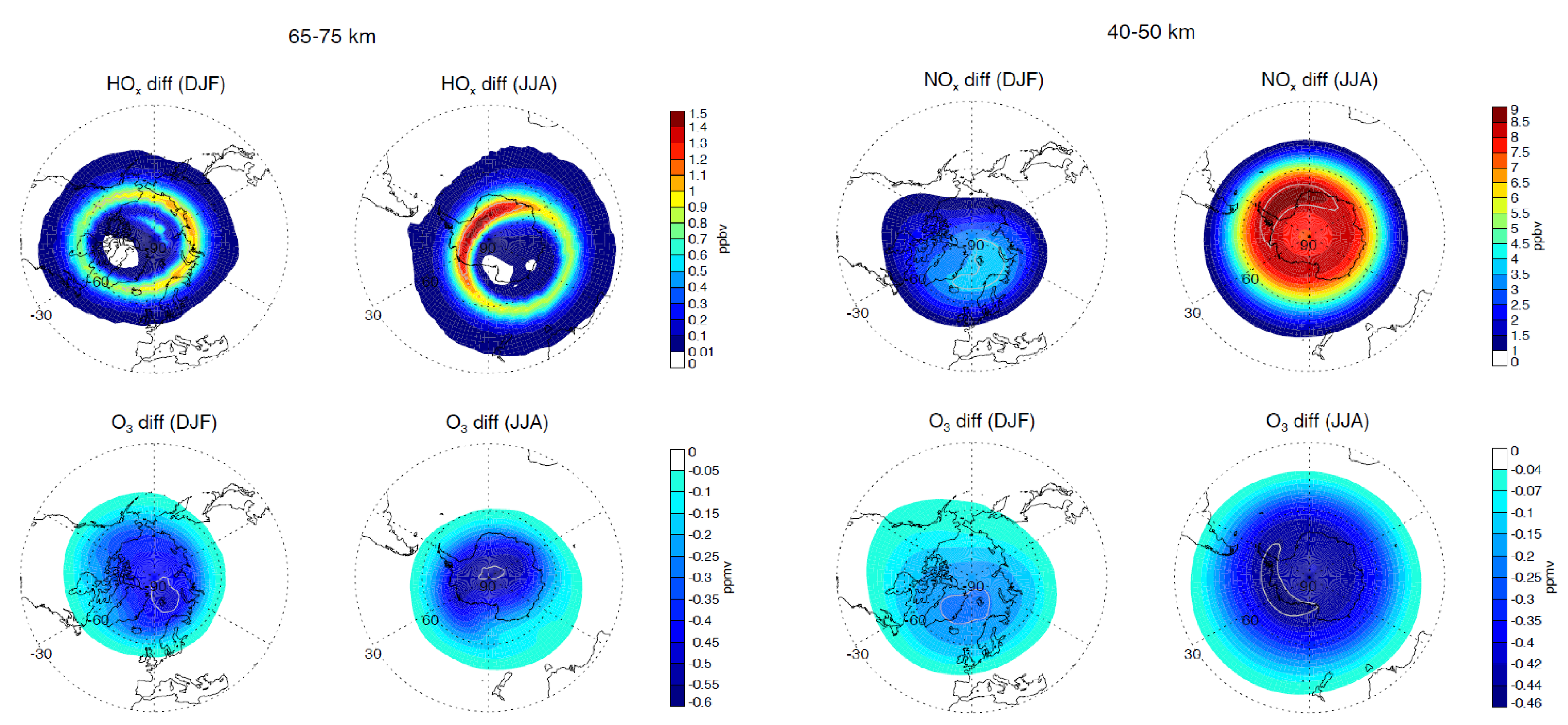


Fig 2. Composite differences (MEE-Cont.) of averaged HO_x and ozone in an altitude range of 65-75 km and of averaged NO_x and ozone in an altitude range of 40-50 km during boreal winter (DJF) and austral winter (JJA) from 2005 to 2013. The gray contours represent the 95% confidence levels, respectively.

References

Andersson, M. E., Verronen, P. T., Marsh, D. R., Seppälä, A., Päivärinta, S.-M., Rodger, C. J., and van de Kamp, M. (2018). Polar ozone response to energetic particle precipitation over decadal time scales: The role of medium-energy electrons. Journal of Geophysical Research: Atmospheres, 123, 607–622. https://doi.org/10.1002/2017JD027605.

Arsenovic P., Rozanov E., Stenke A., Funke B., Wissing J. M., Mursula K., Tummon F. Peter T. (2016). The influence of Middle Range Energy Electrons on atmospheric chemistry and regional climate. Journal of Atmospheric and Solar-Terrestrial Physics, 149, 180–190. http://dx.doi.org/10.1016/j.jastp.2016.04.008.

4. Result 2 : Dynamic changes by MEE precipitation

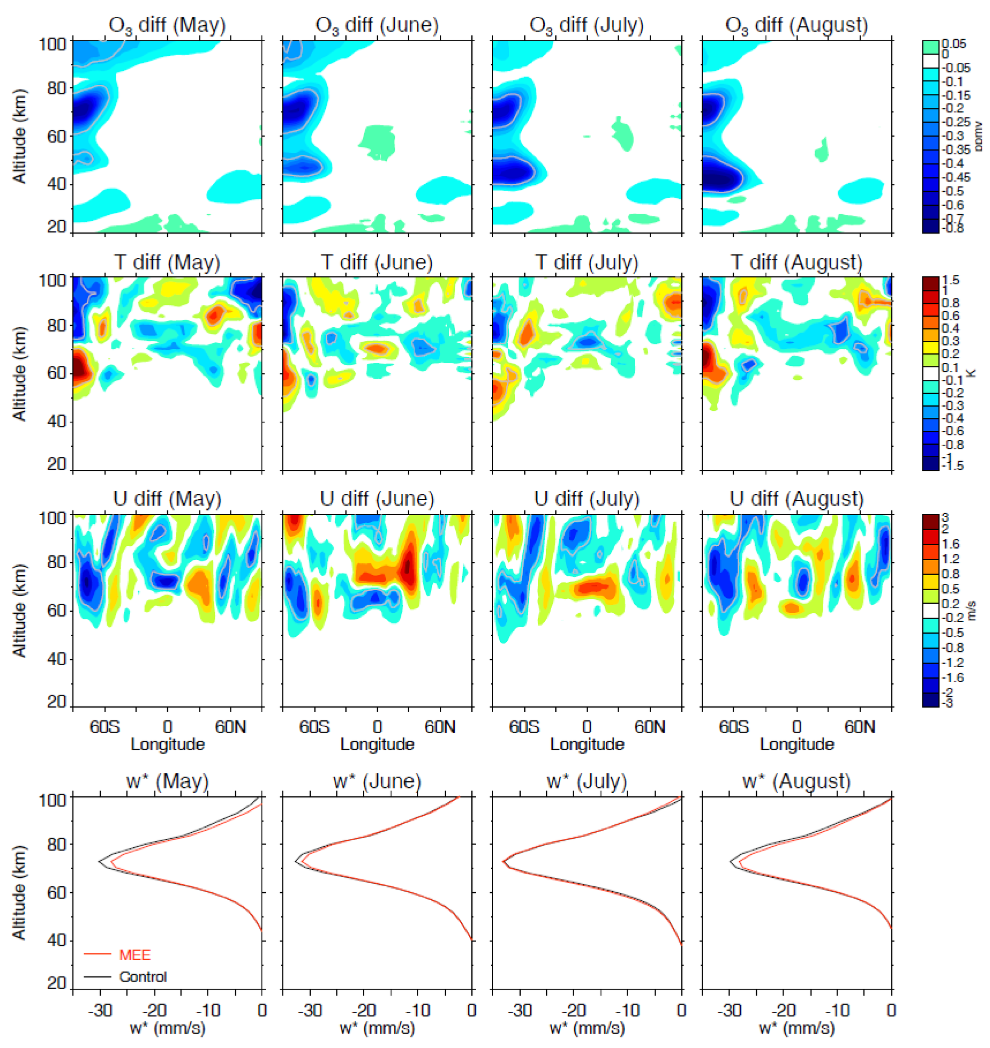
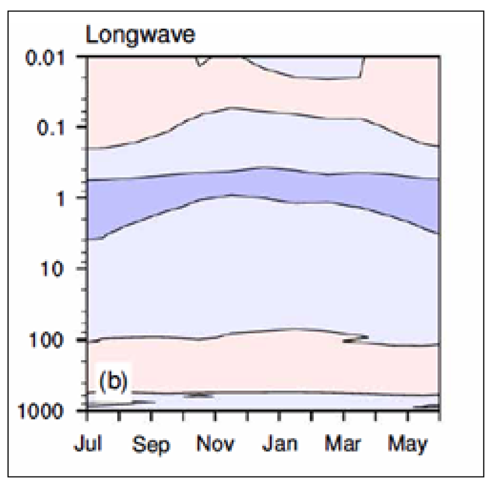


Fig 3. Monthly differences of the zonal mean ozone, temperature, zonal wind, and vertical wind between control and MEE runs from May to August in the southern winter during 2005-2013



- Ozone loss in secondary ozone layer (90-105 km) decreases; the ozone loss in tertiary ozone layer (65-80 km) seems steady; but the upper stratospheric ozone loss gradually increases and the peak altitude slightly decreases from May to August.
- Temperature changes show clear warming at the altitude of 50-70 km and cooling at higher altitude.
- Reduction of the zonal wind shows clearly in the whole polar mesosphere.
- Downward motion in MEE run is generally smaller than in control run except for July.

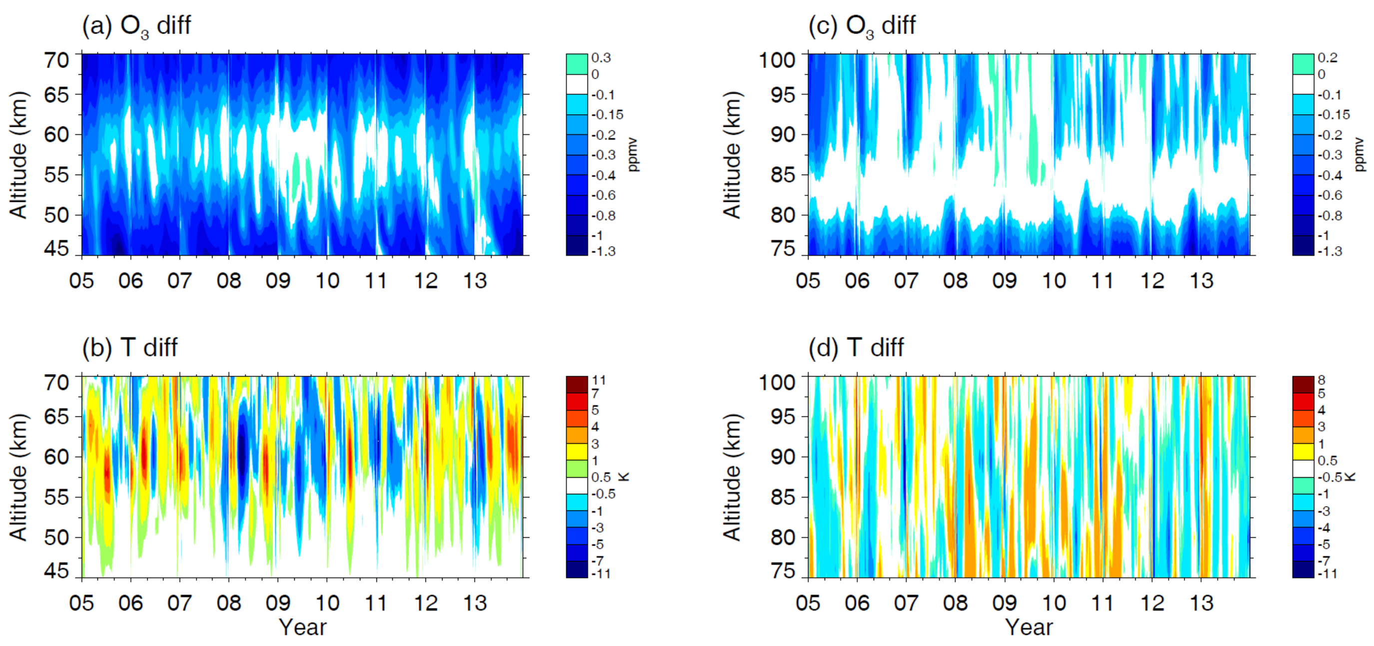


Fig 4. Temperature and ozone loss differences between MEE and control runs in an altitude range of 45-70 km and 75-100km in latitude range of 70S-90S during JJA from 2005 to 2013.

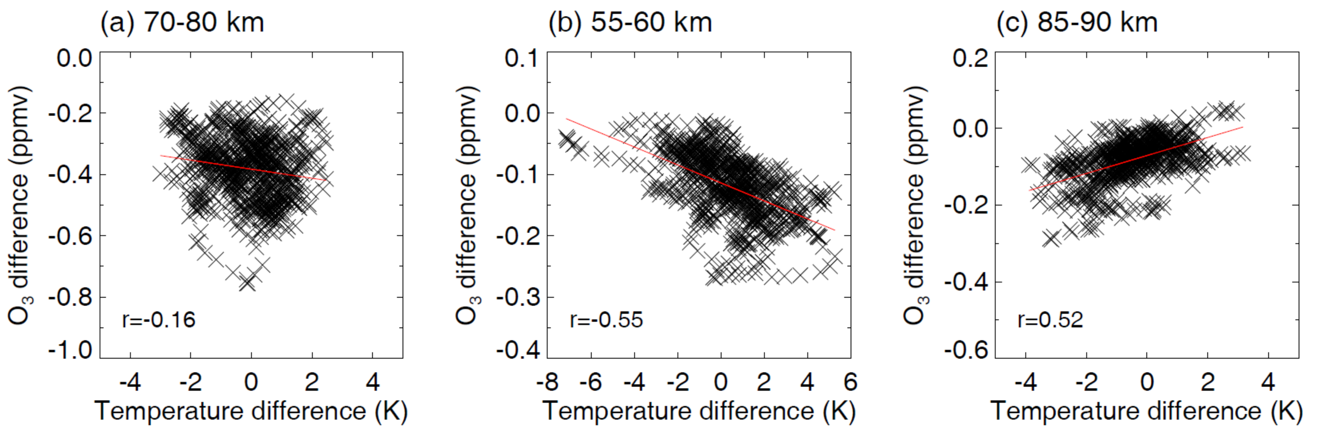


Fig 5. Correlations between temperature change and ozone loss at the altitude range of 70-80 km, 55-60 km, and 85-90 km.

- The ozone loss by MEE precipitation occurred most significant in 70-80 km, however, the relationship between temperature change and ozone loss has a low correlation, which correlation coefficient is -0.16.
- On the other hand, the relationships around stratopause and mesopause can be considered moderately correlated, which correlation coefficient is -0.55 and 0.52.
- This may mean that the ozone loss in the altitudes of largest radiative control by ozone can be important in the effect on the dynamic change by EPP.

5. Conclusions

We investigated the chemical and dynamical effects driven by the MEE precipitation in the polar winter during the period of 2005-2013 by using SD-WACCM. We found the significant enhancements of NOx and HOx and the reduction of stratospheric and mesospheric ozone by MEE effect. The MEE-induced ozone loss leads to warming in the upper stratosphere and lower mesosphere during polar winter and leads to cooling above the lower mesosphere. Also, the downward motion generally weakens when the temperature change due to ozone loss is significant. The ozone loss around stratopause and mesopause seems important on temperature change by MEE precipitation. During large MEE precipitation, the temperature increased by up to 11 K in the lower mesosphere and zonal wind decreased by down to 21 m s^{-1}. These dynamic changes by the MEE effect may influence on climate during large MEE precipitation.

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