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The lower stratospheric effects of a chemistry climate model to the 11-year solar cycle

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Previous statistical analyses of observational data from 1980 to 2000 have indicated that the 11-year solar cycle causes variations of ozone concentration about 2 and 4% and temperature about 1 and 0.5 K in the upper and lower stratosphere, respectively [e.g., Soukharev and Hood, 2006]. The variation of ultraviolet (UV) radiation with the 11-year solar cycle has been suggested to affect temperature and ozone in the upper stratosphere [e.g., Chandra and McPeters, 1994; Marsh et al., 2007]. While, in the lower stratosphere the direct effect of the UV radiation change with the 11-year solar cycle is considered to be small due to the significant attenuation of UV radiation. By contrast, Kodera and Kuroda [2002] reported that for the early winter season the wave-induced circulation is affected by the solar UV radiation in the extratropics from the reanalysis data, which implied both ozone and temperature changes in the equatorial lower stratosphere through the circulation change. While, van Loon et al. [2007] showed that from the Hadley Sea Surface Temperature (SST) data set, the negative correlation between the 11-year solar cycle and the SST is seen in the central and eastern equatorial Pacific. Marsh et al. [2007] and Austin et al. [200 8] stated that the inter-annual variation of the SST simultaneous with the solar cycle can have influences the ozone concentration in the lower stratosphere through the vertical transport processes. Comparing the solar response derived from the chemistry climate model (CCM) coupled ocean-troposphere and from the CCM without the coupling, Meehl et al [2009] found that the solar response increases when the effects of ocean-troposphere coupling included in the CCM.
The solar cycle forcing and the SST variations affect to the lower stratospheric ozone solar response through the circulation change. The 3-D CCM can be able to provide better description of these dynamical processes, and it is especially important for explicit calculation of the planetary wave propagation derived in the extratropics. Therefore, it is useful to perform sensitivity experiments using a CCM to estimate these processes. Unfortunately, the CCSR/NIES CCM used in this study overestimates the effects of the volcanic aerosol, which causes unrealistically large solar response in the lower stratosphere. Thus, here we show the results which exclude the volcanic eruption.
Results from the sensitivity experiments without solar cycle forcing show no statistically significant solar responses of ozone concentration or temperature in the upper stratosphere, whereas those with solar cycle forcing show significant solar responses. These results confirm that the solar term of the ozone and temperature in the upper stratosphere is due to solar cycle forcing. The results in the lower stratosphere using the solar cycle forcing indicate that the contribution of the solar cycle forcing to the solar term is about 1% per 100 units F10.7 in ozone concentration and 0.2 K per 100 units F10.7 in temperature. The magnitudes of ozone and temperature solar responses in the lower stratosphere are smaller than the observations (about 4% in ozone and 0.5 K in temperature). It implies that the solar term in the lower stratosphere is partly related to the solar cycle forcing. Estimating the ozone transport with the solar cycle, we find that the ozone transport during the solar maximum tends to increase the ozone concentration in the lower stratosphere.

The ozone solar response in the lower stratosphere is derived in this model even if a sensitivity experiment was performed using a fixed solar forcing and observed SST forcing. Investigating of the ozone transport, we find that the ozone transport change related to the SST creates the ozone solar response in the lower stratosphere. It suggests that the effect of the ozone transport change associated with the inter-annual variability of the SST can be partly included in the solar term of ozone.

Keywords: chemistry climate model, ozone, 11-year solar cycle