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Response of the north polar vortex and its evolution to solar activity using chemistry-climate model and reanalysis data

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Variations in solar ultra violet radiation, ozone, and temperature over the equatorial upper stratosphere caused by 11-year solar cycle have been observed (e.g., Lean et al., 1997; Gray et al., 2009). In the solar maximum, these variations were related to meridional gradient of the temperature and the strong polar vortex over the Northern Hemisphere extratropics in early winter (November-December) (e.g., Kodera and Kuroda, 2002). Kodera and Kuroda (2002) suggested that the strong polar vortex could influence the Brewer Dobson (BD) circulation, affecting distributions of equatorial ozone and temperature through ozone transport and adiabatic heating. Yamashita et al. (2010) investigated the difference between solar maximum and minimum from output of CCSR/NIES CCM, and they suggested that a simulation period of about 140 years might be sufficient for detecting the responses of the circulation around the polar vortex, equatorial ozone, and temperature.

The variation in the polar vortex is related to the equatorial quasi-biennial oscillation (QBO) as well as the 11-year solar cycle (e.g., Labitzke and van Loon, 1988). Holton and Tan (1980) showed that on average, the polar vortex is strong (weak) throughout the winter when the equatorial zonal wind at 50 hPa is westerly (easterly). Thus, we suppose that effects of the solar maximum and the westerly phase of the QBO create the strong polar vortex. In fact, the strong polar vortex was seen in early winter (e.g., Gray et al., 2004). In contrast, the polar vortex tended to be weak in westerly phase during the solar maximum in late winter (January-February) (e.g., Labitzke and van Loon, 1988). The reason for the different behavior between the early winter and late winter is still unclear. In addition, it is not well understood how mechanism for the influence of QBO on the polar region changes with the solar activity.

Yamashita et al. (2011) proposed a possible explanation that the difference of wave propagation and circulation in the upper/middle stratosphere as well as lower stratosphere between the easterly and westerly phases is related to the polar vortex.

In this study, we investigated the mechanism for the QBO and solar cycle influences on the polar vortex using CCSR/NIES CCM output and JRA-25 dataset, with a focus on detailed evolution of the influence throughout the winter. Note that we performed three transient runs from 1960 to 2006, and the output for 138 winters was analyzed in order to gain sufficient data for detecting the solar response.

Four composites were compiled on the basis of both 11-year solar cycle phase and QBO phase defined at 50 hPa. The composite analysis for CCM output and JRA-25 dataset suggested that the strong (weak) polar vortex and cold (warm) temperature were seen in the westerly (easterly) phase of the QBO during solar maximum (minimum) in the lower stratosphere over the polar region around December-January, indicating the suppression (enhancement) of upward wave propagation, wave dissipation and the BD circulation in the lower stratosphere. For these cases, the responses of the QBO and solar cycle were similar and reinforced each other around the polar vortex, indicating the strong/weak polar vortex. It moved poleward and downward with the seasonal march throughout the winter. These movements were related to weak polar vortex appeared in the upper stratosphere around February in the westerly phase/solar maximum, in agreement with previous foundation by Labitzke and van Loon (1988). In contrast, the response in the westerly (easterly) phase of the QBO was canceled by the opposite signs of response during the solar minimum (maximum).

These results suggest that the effects of solar cycle and QBO on the polar vortex are explained as the reinforcement and cancellation processes occurred between the solar activity and QBO influences in early winter. Later, these effects would change with the seasonal march associated with the wave-mean flow interaction.

Keywords: middle atmosphere, 11-year solar cycle, chemistry-climate model