Stratospheric and tropospheric variability around the North Pole associated with the solar cycle

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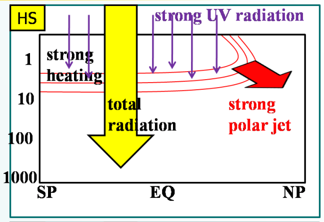
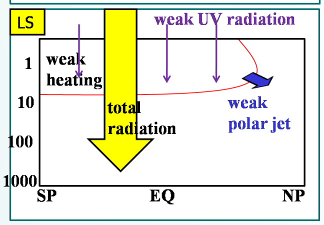
Introduction

The prominent variability from climatology in the northern hemisphere winter is known as a north-south dipole structure of pressure between the North Pole and mid-latitude (e.g. Zonal Index, North Atlantic Oscillation (NAO), and Arctic Oscillation (AO) [e.g. Walker and Bliss, 1932; Rossby et al., 1939; Namias, 1950; Thompson and Wallace, 1998, 1999]). Thompson and Wallace [1998, 1999] defined the AO as the primary mode of an empirical orthogonal function (EOF-1) for sea level pressure (SLP) anomaly over 20-90^{o}N. The AO is also extracted from the zonal mean geopotential height anomaly over 40-90^{o}N, 1000-200hPa [Ogi et al., 2004]. The AO is not "periodic oscillation", so the AO is sometimes called Northern Hemisphere annular mode (NAM). (hereafter AO/NAM)

In the observational study, vertical connection of the AO/NAM between the stratosphere and troposphere is different with solar cycle [Kodera and Kuroda, 2005]. The strength of the winter mean polar vortex may be different between high solar (HS) and low solar (LS) period with the change of ozone heating. The dynamical difference in lower layer by the solar difference of the polar vortex only affects to the vertical connection of the AO/NAM?, or chemical interaction affects to the vertical connection? Since, we want to know the solar change of the chemical interaction of ozone (transport, chemical reaction and radiation of ozone), we use the AGCM include the chemical interaction with ozone (Chemistry Climate Model; CCM). To investigate the effect of the chemical interaction, we remove the chemical interaction from the CCM, and this model is compared to the original CCM.





Analysis Method

- We perform the EOF decomposition for HS, LS individually.
- Zonal mean and Monthly mean geopotential height field
- The analysis domain is 40-90^o N, 10-200 hPa.
- We derive the principal component timeseries of the EOF-1.
- We call this index Stratospheric NAM (S-NAM) index.
- E-P flux is used for assessing the wave forcing.

Model Description for CCM

- CCSR/NIES Chemistry Climate Model (CCM): T42L34 (model top: 80 km)
- REF1 scenario of CCM Validation (CCMVal-REF1) [Eyring et al., 2006]
- Solar cycle forcing (as F10.7), volcanic aerosol with SAGE-I, II, SAM-II
- QBO is nudging to observational data [Giorgetta and Bengtsson, 1999]
- sea surface temperature: HadISST1 (UK Met. Office)
- density of greenhouse gas: IPCC-A1B scenario

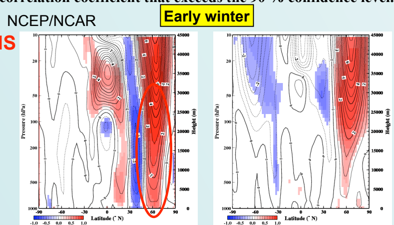
Zonal Wind regressed to the S-NAM index

Contour is the regression coefficient, and shading indicates the correlation coefficient that exceeds the 90 % confidence level.

NCEP/NCAR

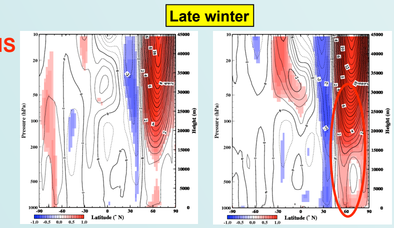
Early winter

HS LS



Late winter

HS LS



In the early/late winter during the HS/LS, the anomaly of mid-latitude extends stratosphere to the troposphere. Other periods, the downward extension is weak.

E-P flux regressed to the S-NAM

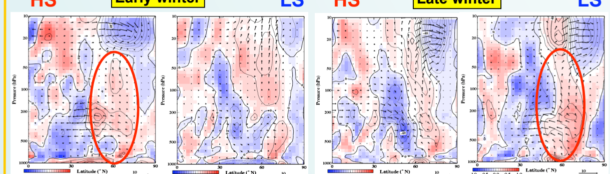
$$F = \left(-\overline{u_a v_a},\ fR\frac{\overline{v_a T_a}}{S}\right)$$

wave forcing $\nabla \bullet F$

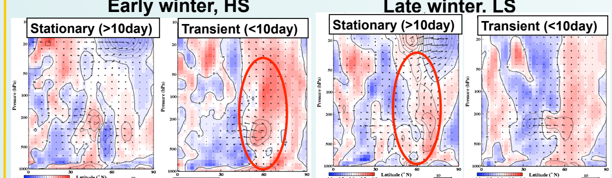
The wave forcing term (contour, shading), E-P flux (arrow) regressed to the S-NAM index are shown.

Total component (transient + stationary) of the E-P flux

HS Early winter LS HS Late winter LS



Early winter, HS Late winter, LS

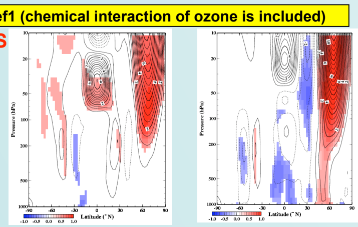


In the early winter during the HS, the transient component is important in the troposphere. In the late winter during the LS, the vertical connection is mainly due to the stationary component.

CCM results (late winter)

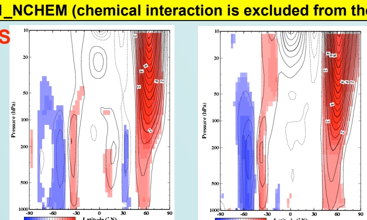
ref1 (chemical interaction of ozone is included)

HS LS



ref1_NCHEM (chemical interaction is excluded from the CCM)

HS LS



In the late winter, the solar difference is not shown in the ref1_NCHEM experiment.

Conclusion

- The vertical connection of the AO/NAM is analyzed with observational data.
- In the HS during early winter, the anomaly of high-latitude extends stratosphere to the troposphere, while downward propagation is weak in the LS. In early winter during HS, the transient wave plays important roll for the downward propagation.
- In late winter, the downward extension is strong during LS and weak during HS. This difference between the solar phases is corresponding to the difference of the stationary wave forcing in the troposphere.
- The CCM output is used for analyzing the vertical connection of the AO/NAM. In the late winter, the downward extension is strong in LS and weak in HS, which is similar to the observation.
- The sensitivity run excluded the chemical interaction of ozone shows the no solar difference in late winter. Thus, the chemical interaction may affect to the vertical connection of the AO/NAM.

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