Climate Patterns and the Forcing of the Polar Stratosphere in Winter

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Introduction

In the northern hemisphere, large-scale waves originating in the troposphere strongly condition the wintertime circulation of the stratosphere. The highly variable wave amplitudes and fluxes in the troposphere, and the varying upward propagation conditions (both vertical and meridional) contribute to the high inter-annual and intra-seasonal variability of the northern hemisphere polar temperatures and vortex. Rapid, wave-driven changes in the stratospheric circulation are exemplified by the phenomenon of stratospheric sudden warming (SSW). Despite several decades of research, it is still unclear which tropospheric perturbations pre-date SSWs, although blocking precursors have been noted in early case studies, and the recent comprehensive study of SSWs during the 40-year period 1959-2002 by Kindem et al. [2006] indicates that, in the mean, positive geopotential anomalies over northern Scandinavia precede SSWs.

We re-examine the nature of tropospheric perturbations that lead to a cold (warm) winter stratosphere. To systematically investigate tropospheric perturbations that we wish to link to stratospheric temperatures, we use the sectorial empirical orthogonal function (EOF) approach, that has been successfully used in seasonal forecasting studies [Pavan et al., 2000]. It relies on identifying dominant patterns of variability, or climate patterns, in given regions such as the Euro-Atlantic or the Pacific. Orsolini and Reyes [2003] used a similar approach to find the signatures of modes of tropospheric variability upon column ozone.

Polar vortex diagnostics

Polar cap temperatures and zonal winds

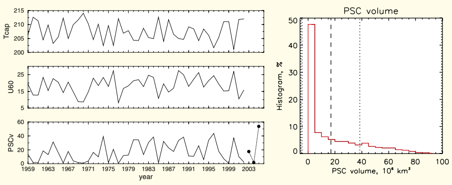
We characterize the lower and mid polar stratosphere in winter by

- 475K temperature averaged over the polar cap (latitudes above 60N), Tcap
- zonal-mean zonal wind at 60N at 475K, U60, as a measure of the polar vortex strength.

Polar stratospheric cloud volume (pscv)

A measure of the coldness of the winter stratosphere that is widely used in ozone research is the polar stratospheric cloud (PSC) potential, measuring the three-dimensional extent of the stratospheric region where PSCs can form, at temperatures below a threshold of typically 190K. When scaled by the chlorine loading, the seasonally averaged PSC volume is tightly connected to ozone loss for that year. PSCv is expressed in millions of cubic kilometers, and is highly non-Gaussian.

Data: winter (DJF) months for the ERA-40 period (1959-2002), 132 months in total.



Pacific climate patterns

Climate patterns from EOF analysis

Leading monthly-mean EOFs of the Pacific (PAC) (20N-87.5N, 110E-90W) sector were calculated form the 500-mb geopotential heights. We retain the four highest order EOFs : the Pacific-North America pattern (32%), and a series of EOFs related to North Pacific blockings: an EOF-2 resembling the West Pacific pattern (20%), an EOF-3 (9%) and an EOF-4 (7%). Pattern indices have been normalised, and when using composites we consider large positive (>0.67) or negative (<-0.67) values.

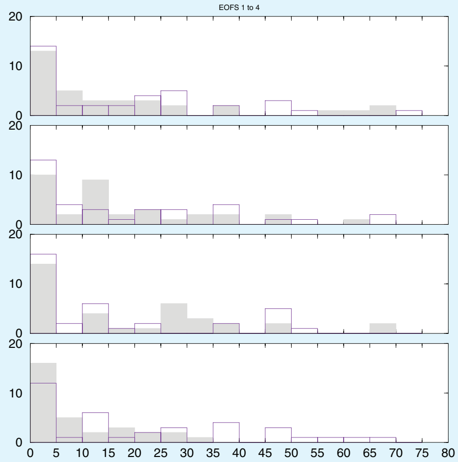
The EOF-4 and North Pacific Blocking

The EOF-4 extends the most polewards, into the high Arctic and across the North Pole toward the North Atlantic. In its positive phase, the PAC EOF-4 is associated with a blocking High over Alaska. We found that nearly 25% of all winter months (30 cases out of 132) were characterised by an anomalously high or low PAC EOF-4 index. We note that the PAC EOF-4 has the largest intensity in the stratosphere (at 50mb) of all the four patterns, with higher heights over the pole (and hence a weaker polar vortex).

We examined the number of blocked days at every longitude and at a latitude of 60N for each winter month of the ERA-15 period (1978-1993). Blocking was defined using a simple wind criterion [Pavan et al., 2000]. We composited the blocking frequency (number of blocked days per month) for large and weak indices of the PAC EOF4. In its positive phase, the pattern is associated with enhanced blocking occurrences west of the dateline, in the location of the ridge of at 500mb. In its negative phase, the blockings are shifted eastward of the dateline, but the high anomaly does not extend far polewards.

Histogram of PSCv

We examined changes in the distribution (histogram) of PSCv, when Pacific patterns were in either phases. Surprisingly, only PAC EOF-4 induced a notable change. In its negative phase, the PSCv distribution extends toward much larger values than in the positive phase, when no values larger than 35 were found. The EOF4, with its Alaskan blocking and its pronounced ridge extending to the pole, is associated with lesser potential occurrences of PSCs. This is fully consistent with U60 and Tcap, histograms. Only the PAC EOF-4 induced noticeable change: weaker winds and higher temperatures in the positive phase are consistent with the lessened PSCv.

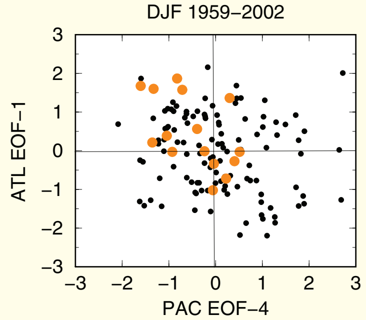


Histogram of PSCv composited against the positive phase (grey shade) and the negative phase (purple) of each PACIFC EOFs. EOF1 at top, EOF4 at bottom.

Cold months with extreme PSCv

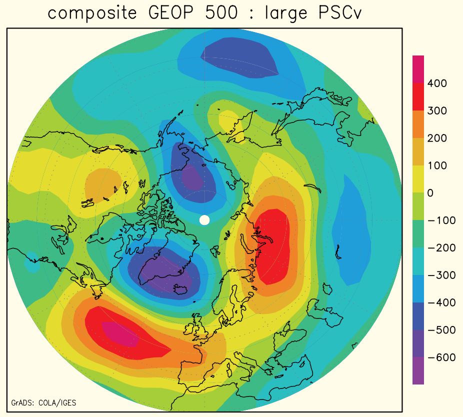
Joint occurrences of Pacific Blocking (EOF4) and NAO

Scatter plot of the indices of the PAC EOF-4 and the NAO for all the 132 (DJF) months of the ERA-40 record. Months with extremely large PSCv, in excess of 40, are highlighted (orange circles). These particular months (15 in total) tend to cluster in the quadrant where PAC EOF-4 is negative and the NAO is positive.

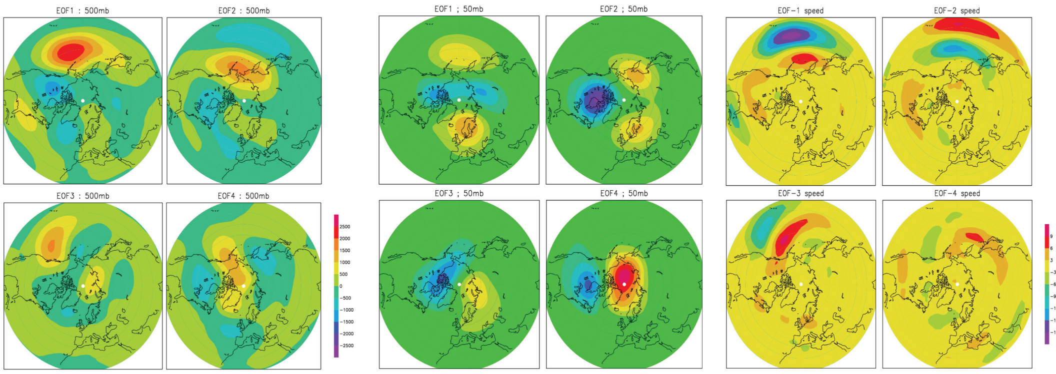


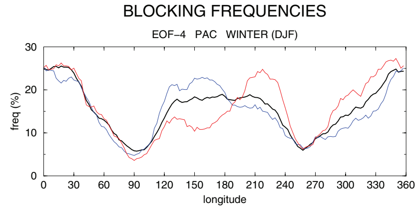
Composite for "Cold Months" (PSCV>40)

The composite of 500mb geopotential height for all the 15 months during which PSCv was in excess of 40 shows a clear positive NAO signature, with an enhanced Icelandic low. It also shows negative geopotential anomalies in the North Pacific, with a trough extending to the Pole, as in the negative phase of PAC EOF-4.



Leading PACIFIC EOFS at 500mb and 50mb, and horizontal wind speed composited at 500mb





References

Pavan, V., S. Tibaldi and C. Brankovic, *Seasonal prediction of blocking frequency : results from winter ensemble experiments*, Q. J. R. Meteorol. Soc., 126, 2125-2142, 2000b

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Conclusions

- North Pacific blockings are important to "rock" the stratosphere.
- Cold winter months, large PSC volume and potential ozone loss, are characterised by the absence of north Pacific blockings east of the dateline, and by a positive NAO.