Lower stratospheric polar temperatures in re-analyses, and their tropospheric precursors

Yvan J. ORSOLINI (1), Alexei KARPECHKO (2) and Grigory NIKULIN (3)

(1)Norwegian Institute for Air Research, Instituttveien 18, Kjeller, Norway (orsolini@nilu,no),
(2) University of East Anglia,
(3)Swedish Meteorological and Hydrological Institute, Sweden.

1. INTRODUCTION

In the northern hemisphere, large-scale waves originating in the troposphere strongly condition the wintertime circulation of the polar stratosphere. The late-winter temperatures in the lower polar stratosphere have been shown to correlate with the cumulated zonally-averaged meridional eddy heat flux at the base of the stratosphere, cumulated over winter [e.g. Karpetchko and Nikulin, 2004]. The highly variable wave amplitudes and fluxes in the troposphere, and the varying conditions under which they can propagate both vertically and meridionally in the stratosphere contribute to the high inter-annual and intra-seasonal variability of the northern hemisphere polar temperatures and vortex.

A measure of the coldness of the winter stratosphere that is widely used in ozone research is the polar stratospheric cloud (PSC) potential [Pawson and Naujokat, 1999]. PSCs are central to halogen-induced ozone loss processes, as the heterogeneous chemistry that ultimately leads to ozone destruction in winter and spring, occurs on the surface of PSCs. The PSC potential can be measured as the three-dimensional extent, or volume, of the stratospheric region where such PSCs can form, at temperatures below a threshold of, typically, 190-195K, at altitude range of 14 to 28 km and over areas typically covering a few percent of the hemisphere. The PSC potential is highly variable from year to year. The seasonally averaged PSC volume is tightly connected to ozone loss for that winter [Rex et al, 2004].

The reported correlation between zonally-averaged meridional eddy heat fluxes and the polar temperatures falls short of identifying the responsible meteorological phenomena in the troposphere, nor especially their geographical origin. Here, we are examining the nature of *tropospheric* perturbations that lead to, or coincide with, occurrences of an extremely cold stratosphere with a very high PSC potential, and possibly large ozone depletion.

2. COLD STRATOSPHERIC MONTHS WITH HIGH PSC POTENTIAL

To characterize the polar stratospheric temperatures in winter, we calculated the PSC volume, PSC_v, for all winter (DJF) months in the ERA-40 period (1959-2002), 132 months in total, and corroborated our results with NCEP and FUB. We choose a threshold of 50 millions of cubic kilometres, above which PSC_v is considered to be anomalously high. The threshold is exceeded in 16 monthly occurrences, corresponding to the 12% percentile. Monthly-mean meteorological fields were derived from ERA-40, including three-dimensional wave activity fluxes, or Plumb vector [Plumb, 1985], commonly used to diagnose the propagation of planetary stationary waves.

There are significant discrepancies between ERA-40 and other re-analyses regarding lower stratospheric temperatures at high northern latitudes [Manney et al., 2005]. While, the ERA-40 data shows consistently colder temperatures and larger PSC area at 50mb prior to 1990, compared to other datasets such as NCEP or CPC re-analyses, the patterns of inter-annual variability are very similar to other data sets.

3. THE 500-mb TROPOSPHERIC CIRCULATION DURING COLD STRATOSPHERIC WINTERS

We calculated the lagged composites of 500mb geopotential height anomalies (i.e. departures from the winter climatology) during the 16 months when the stratosphere was anomalously cold, with PSC_v in excess of 50 (Fig. 1). The zero-lag composite indicates several high-latitude tropospheric features of comparable amplitude coincident with the cold stratosphere: a deepened Icelandic Low over the North Atlantic, part of a meridional dipole that is characteristic of a positive North Atlantic Oscillation (NAO) phase, a north-south elongated negative anomaly straddling Alaska and extending toward the Pole, and a positive anomaly over Northwest Siberia, which may be indicative of an intensified, poleward-extended Siberian High.

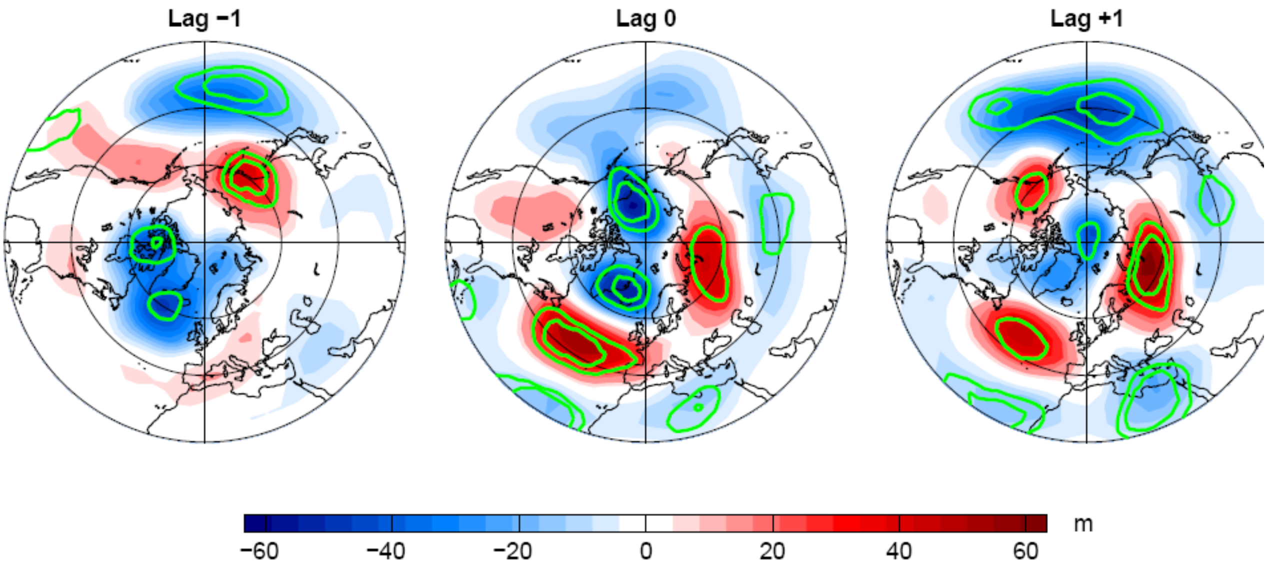

FIGURE 1: Composite of the ERA-40 500mb-geopotential departure from climatology, one month before (lag –1), during (lag 0), and one month after (lag +1) the 16 months when the PSC volume was in excess of 50. (Units are gpm). Contours indicate significance based on a Monte-Carlo approach.

Turning to the precursory (lag –1) composite, one can identify 500mb-height positive anomalies over the Far East at 60N, just west of the International Date Line (IDL), and a negative anomaly further south and closer to the IDL. On the opposite side of the hemisphere, one finds negative anomalies over the Icelandic and Northwest Atlantic sectors.

The positively lagged composite reveals that a more narrow annular negative height anomaly prevailed surrounding the North Pole. The later is accompanied by increased heights in a near-wave-3 pattern over the mid latitudes.

In Figure 2 we show the lag –1 composite of the vertical component of the Plumb vector anomaly, estimated at 100mb, for the 16 months when the stratosphere is extremely cold. The mid-latitude positive anomalies are largely found over the Pacific sector, and the negative anomalies over the polar regions, but mainly between 90E and the IDL.

The qualitative aspects of the connection of these tropospheric anomalies with the stratosphere can be understood by considering how these anomalies interact with the stationary planetary wave structure. In the Pacific sector, their positions with respect to the quasi-stationary ridge east of the IDL and the trough upstream are critical. The precursory high-latitude positive height anomaly over the Far East, at lag –1, is reminiscent of a West-Pacific pattern (Wallace and Gutzler, 1981), and weakens and extends southwards the climatogical planetary wave trough, and hence contributes to reduce the amplitude of planetary waves and their upward propagation. These conditions lead to a colder stratosphere. They are also reminiscent of intra-seasonal amplification episodes of the Siberian High, described in Takaya and Nakamura (2005), when upper-tropospheric positive height anomalies develop over the North Pacific and retrograde to the west of the IDL, leading to an inward-breaking of the polar vortex. We conjecture that the North Pacific monthly-mean anomalies could result from repeated episodes of poleward Rossby wave-breaking (Peters and Waugh, 1996).

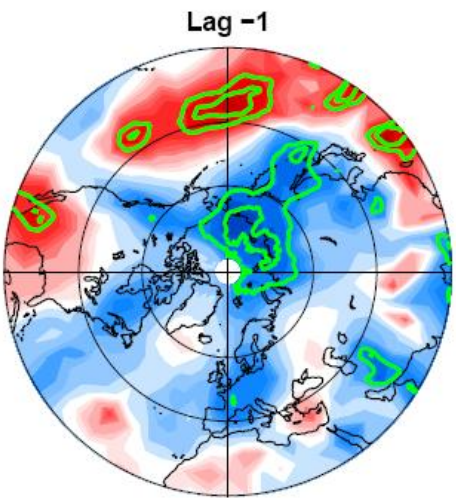

FIGURE 2: Similar composite at lag –1 (i.e. precursory) of the ERA-40 vertical components of the Plumb vector at 100mb.

The lag +1 composite is very similar to composites of anomalously strong stratospheric vortex events in Limpasuvan et al. (2005). Based on the later study, it could arguably be understood as a downward influence of the cold, polar stratosphere, i.e. an enhanced positive phase of the annular mode (Baldwin and Dunkerton, 1999).

Acknowledgements : Y.O. has been supported by the Norwegian Research Council NORKLIMA programme, and by the EU Scout project. The lead author would like to thank Prof. H. Nakamura, and Drs. K. Takaya and M. Honda for useful suggestions.

REFERENCES

Baldwin, M.P. and T.J. Dunkerton, Propagation of the Arctic Oscillation from the stratosphere to the troposphere, J. Geophys. Res., 104, 30937-30946, 1999.

Karpetchko, A., and G. Nikulin, Influence of early winter upward wave activity flux on midwinter circulation in the stratosphere and troposphere, J. Clim., 17, 4443-4452, 2004.

Limpasuvan, V. et al., 2005. Stratosphere-troposphere evolution during polar vortex intensification, J. Geophys. Res., 110, D24101.

Manney, G. L., J. L. Sabutis, S. Pawson, M. L. Santee, B. Naujokat, R. Swinbank, M. EManney, G. L., K. Krüger, J. L. Sabutis, S. A. Sena, and S. Pawson (2005), The remarkable 2003–2004 winter and other recent warm winters in the Arctic stratosphere since the late 1990s, J. Geophys. Res., 110, D04107, doi:10.1029/2004JD005367

Pawson, S., and B. Naujokat, The cold winters of the middle 1990s in the northern lower stratosphere, J. Geophys. Res., 104, 14,209 – 14,222, 1999

Peters D. and D. W. Waugh, Influence of the barotropic shear on the poleward advection of upper-tropospheric air, J. Atmos. Sci., 53, 3013-3031, 1996.

Plumb, R.A., On the three-dimensional propagation of stationary waves, *J. Atmos. Sci*., 42, 217-229, 1985.

Rex, M., R.J. Salawitch, P. von der Gathen, N.R.P. Harris, M.P. Chipperfield, and B. Naujokat, Arctic ozone loss and climate change, *Geophys. Res. Lett., 31*, L04116, doi: 10.1029/2003GL018844, 2004.

Takaya, K. and H. Nakamura, Geographical dependence of upper-level blocking formation associated with intraseasonal amplification of the Siberian High, J. Atmos. Sci., 62, 4441-4449, 2005.

Wallace, J.M. and D.S. Gutzler, 1981, Teleconnections in the geopotential height field during the Northern Hemisphere winter, *Mon. Wea. Rev.*, 109, 784-812.