P2.14

DIAGNOSIS OF THE ORIGIN AND DYNAMICAL INFLUENCE OF UPPER-TROPOSPHERIC NEGATIVE PV ANOMALIES

Mark A. Liniger* and Huw C. Davies
Institute for Atmospheric Science, ETH Zurich, Switzerland

1. INTRODUCTION

Poleward incursions of tropospheric air in stratospheric elevations take the form of ridges and cut-offs. These can be identified as negative PV anomalies. Previous studies have considered different aspects of these anomalies. Theoretical studies (Wirth 2001, Muraki and Hakim 2001) have emphasized the positive-negative asymmetry of the anomalies. Diagnostic-observational studies (Wernli 1997, Pomroy and Thorpe 2000) have proposed the role of moist ascending airstreams, also referred to as warm conveyor belts (WCB). It is also recognized in idealized simulations (Zierl and Wirth 1997) and case studies (O'Connor et al. 1999) that these anomalies can be related to troposphere-stratosphere exchange (TSE).

Also, the correlation of negative PV anomalies to negative anomalies of total column ozone (Vaughan and Price 1991) underlines the relevance of the radiation properties of upper tropospheric levels in the mid latitudes.

The present study discusses these negative PV anomalies. A description of the data set and methods in section 2, a case study in section 3 and the rudiments of a climatology are given in section 4.

2. DATASET AND METHOD

This study is based on northern-hemispheric ECMWF reanalysis data from 1979 to 1988 that is available with 1° spatial and 6 hours temporal resolution. A climatology of negative tropopause-level PV anomalies in this period is developed as follows. First for every month, the potential temperature surface is evaluated that cuts the tropopause (taken here as the PV = 2 pvu surface) at 45°N in the monthly, zonal mean. This value varies between 313K in February and 337K in August.

Second, Ertel PV is interpolated on these isentropes and a PV anomaly is defined as a deviation of at least 2 pvu from the ten-years monthly mean. For the ten-years monthly mean, a Gaussian filter with a half-width of 3° has been applied.

In a separate but related climatology, the same isentropes are used as starting surfaces for the calculation of three-dimensional trajectories (Wernli and Davies 1997). Backward trajectories are initiated 4 times per month (7th, 14th, 21st and 28th) and forward trajectories twice per month (7th and 21st). The trajectories are evaluated for the entire hemisphere on a regular grid (grid spacing of 0.5°). For technical reasons, the trajectory positions and the traced PV values are retained only once a day.

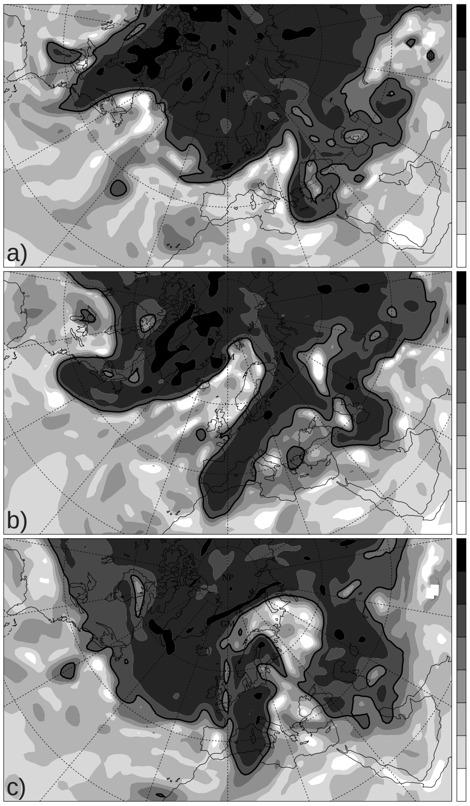

Figure 1: PV distribution on 318 K (shaded, in pvu) on 00 UTC, 18 Dec (a), 00 UTC, 21 Dec (b), and 06 UTC, 23 Dec 1979 (c).

3. CASE STUDY

To demonstrate the raison d'être for the climatology we first present a case study of the formation and decay of one particular upper-tropospheric negative anomaly The selected case on 18 - 23 Dec 1979 features a strong poleward incursion of tropospheric air north of Europe with neighboring areas of positive PV.

3.1 *Eulerian development*

The negative anomaly develops on the 18th (Fig. 1a) and it evolves poleward, extends over Greenland and propagates slowly eastwards until the 21th. Contemporaneously, the stratospheric air east of the anomaly advects southwards to form a long broad PV streamer extending south to 30°N (Fig. 1b). This stage is selected for the Lagrangian investigation (see below).

---

[*] *Corresponding author address*: Mark A. Liniger, Institute for Atmospheric Science, Swiss Federal Institute of Technology, Hoenggerberg HPP, 8093 Zurich, Switzerland, e-mail: mark@atmos.umnw.ethz.ch

On the 23rd, the incursion almost cuts off over Scandinavia (Fig. 1c). Subsequently, portions of the anomaly are disconnected, advect eastwards and dissolve within the stratosphere. The major part of the anomaly however reconnects to the tropospheric pool.

3.2 Origin of low PV air

Backward trajectories are initiated as air emanating from the -2 pvu anomaly region (see Fig. 2) on 21 Dec. Subsets of the trajectories are selected based upon their height and latitude on the 17 Dec. The resulting three groups are evident in Fig. 3a and their characteristics are displayed in Fig. 3b and c.

- A boundary layer group (BL) originate over the Atlantic. The 950 trajectories are selected by pressure values above 900 hPa.

  The position of BL trajectories with pressure values above 900 hPa are depicted geographically in Fig. 2. The air has a sub-tropical source in a region of high sea surface temperatures.

  The fast and strong ascent and the PV variation with high standard deviation of these trajectories are indicative of diabatic effects south of Greenland.

- An upper-level group (U) located close to the jet-stream that end in the northern part of the anomaly. These 600 trajectories have their origin to the west of 140°W.

- A mid-tropospheric remnant group (M) of 2300 trajectories that undergo weak ascent from around 500 hPa and end in the southern part of the anomaly.

The results suggest that the main sources of the negative anomaly are located in lower and mid-tropospheric levels, with a significant portion from the boundary layer involving strong ascent and diabatic effects in the form of precipitation.

3.3 Destination of air

A similar examination was undertaken for forward trajectories (Fig. 2).

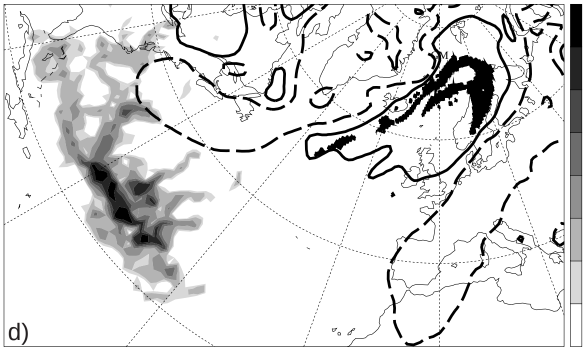

Figure 2: Boundary layer trajectory positions (shaded) which will rise during the next 5 days into the negative PV anomaly (solid contours for negative values, -2 and 1 pvu) ending in the black area on 00 UTC, 21 Dec.

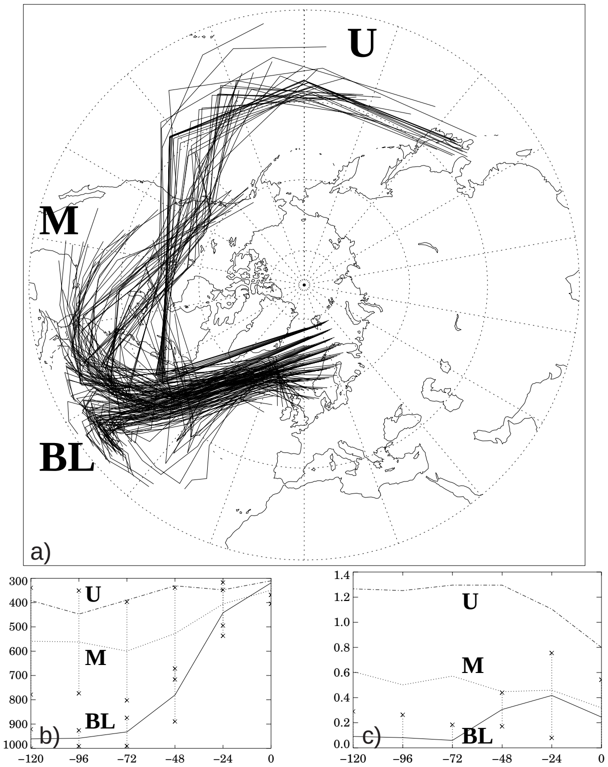

Figure 3: (a): Backward trajectories ending in the negative PV anomaly on 00 UTC, 21 Dec (a). For better clarity, every 25th trajectory is plotted only. Labels BL, M and U correspond to selected groups (see text). (b resp. c): Averaged traced pressure and PV with some error bars along BL, M and U.

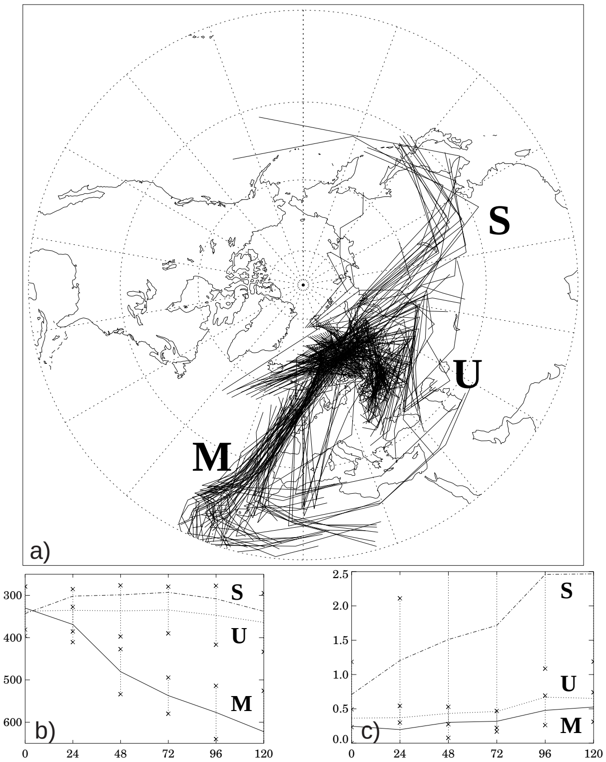

Figure 4: The same as Fig. 3 with forward trajectories starting on 00 UTC, 21 Dec.

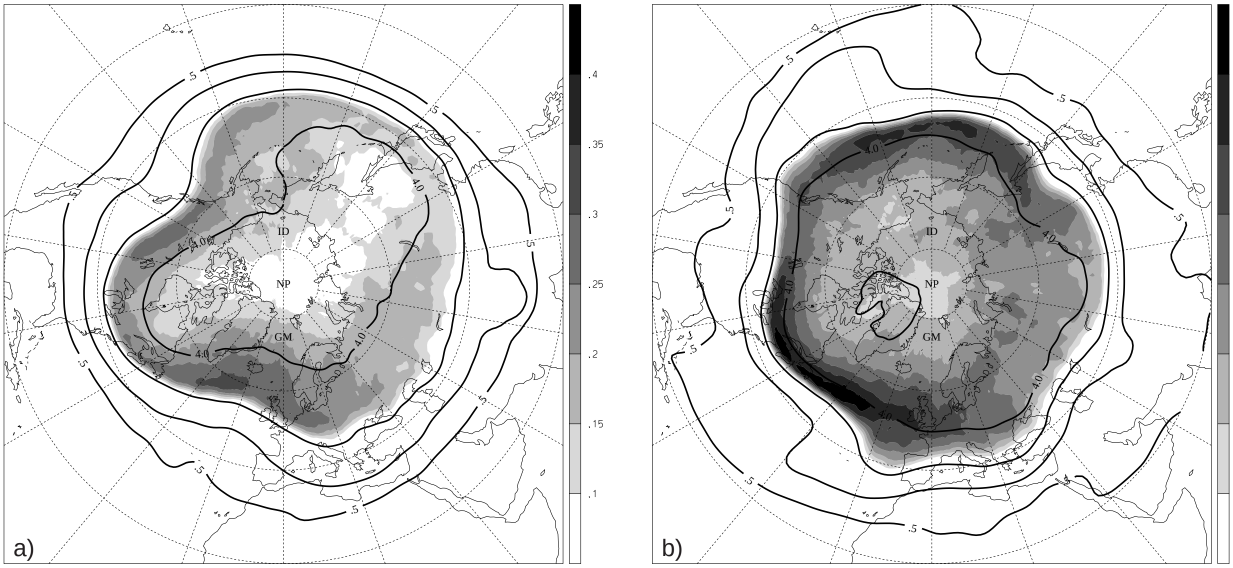

Figure 5: Frequency of occurrence of negative PV anomalies (shaded) and mean PV distribution (contour lines of 0.5, 1, 2, 4 and 6 pvu) for January (a) and July (b) from 1979 to 1988.

From inspection of Fig. 4a, three groups of trajectories can again be identified. Two selection criteria yield the following groups (Fig. 4b and c):

- A mid-tropospheric group (M) that descend southwards back to the sub-tropics These have a a height below 500 hPa 3 days after their release and consist of 1300 trajectories.

  Both the low standard deviation and the low temporal variation of PV imply adiabatic advection.

- A second group (S) that are contained within small sub-anomalies after the breakup of the main anomaly (Section 3.1). 400 trajectories fulfill the selection criterium of reaching a position east of 120°E.

  The strong PV increase within the stratosphere corresponds to the dissolution of the cutoffs by radiative and diffusive processes.

- The remnant group (U) are characterized by an upper tropospheric destination, since the air is staying within the large part of the anomaly, that is reconnecting to the tropospheric pool later.

Although less than 10% of the trajectories can be associated with TSE, it is evident, that the negative PV anomaly contribute significantly to cross-tropopause transport.

4. CLIMATOLOGY

4.1 Eulerian statistics

A 10-years climatology of negative PV anomalies yields information on their preferred location and seasonal variation.

In January, local maxima are found over the mid-Atlantic and the western American continent (Fig. 5a). The Atlantic maximum is stronger and broader in latitude and is related to the Atlantic storm track. The American maximum is downstream of this sector's storm track,

The PV distribution resembles and relates to the typical stationary wave pattern: Positive troughs and strong gradients are found over Eastern America and, less pronounced, over Eastern Asia.

In July, the anomaly frequency is significantly higher and more zonally aligned (Fig. 5b). The Atlantic maximum starts in the center of the American continent and a weak extension can be identified over Scandinavia. (cf. case discussed in section 3).The Pacific maximum is shifted 60° westwards towards the Asian continent with a local minimum over western America. The higher frequency values for July correspond to different characteristics of the negative anomalies.

The PV distribution itself exhibits a weaker meridional variation. In particular the Eastern Asian trough and the negative ridges over the mid-Atlantic and eastern Pacific are not clearly identifiable anymore. Over eastern Atlantic and eastern Pacific, there is a southward expansion of the stratospheric pool.

Independent of the season, the frequency distribution is confined within the PV = 2 contour by the sparseness of anomalies of less than 0 pvu.

4.2 Boundary layer origin

The case study underlined the existence of air streams that transport boundary layer air to form upper level negative PV anomalies. Calculation of locations below 900 hPa of the backward trajectories ending in a negative PV anomaly reveals favored boundary layer regions.

In January, the distribution is linked to the storm track structure (Fig. 6a), the source regions correspond to the southern, sub-tropical edges of the storm tracks over the oceans.

In July, there are hardly any locations of boundary layer air (Fig. 6b). Deep synoptic tropospheric transport process does not appear to take place in summer with a

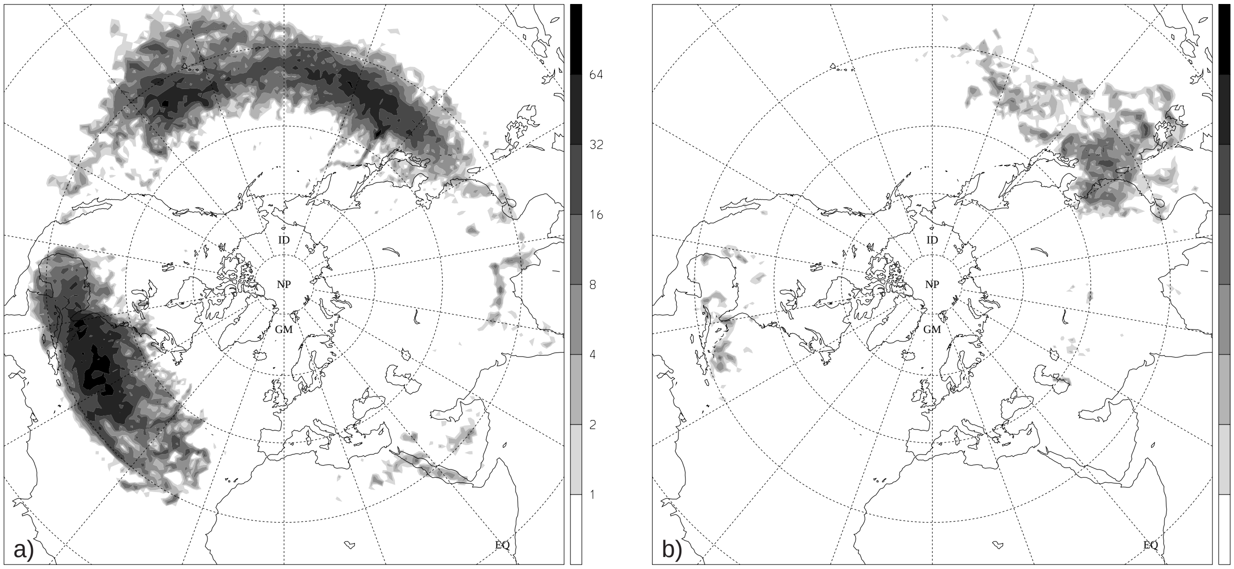

Figure 6: Locations below 900 hPa of backward trajectories ending in a negative PV anomaly for January (a) and July (b) from 1979 to 1988.

comparable strength - or - in the case of deep convection, is not accurately captured by the data.

5. DISCUSSION

The first climatology of negative PV anomalies in the upper troposphere over ten years has been presented here. A strong seasonal and geographical variation of these incursions has been detected.

In winter, their preferred region is collocated with the poleward ridges of the stationary wave pattern. The Atlantic maximum is broader in the meridional and shorter in the zonal direction than the Pacific counterpart. A link between strong ascent in WCB and negative PV anomalies is found using Lagrangian methods in a good correspondence to the one-month survey from Wernli and Davies (1997).

In summer, the anomaly frequency tends to higher values with maxima significantly shifted eastwards and to a weaker meridional variability. Hence, the negative anomalies are suspected to be weaker and broader than in winter. The vague stationary wave pattern and the absence of cross-isentropic, deep transport in July indicates that the summer variability is due to quasi-adiabatic advection by Rossby waves.

In the discussed case in December, a part of the air masses originating from the negative anomaly performs TSE, consistent to a case presented by O'Connor et al. (1999). It is expected to have more similar events in winter. But considering Bourqui (2001) TSE has a significant seasonal cycle and the insights drawn from the case study do not necessarily apply to the summer season.

The concatenation of WCB and air undergoing TSE in negative anomalies is not addressed here, but demands future attention considering its chemical and radiative relevance.

Acknowledgments: The author thanks M. Sprenger, C. Schwierz and H. Wernli for their insightful thoughts and assistance.

Further Information can be obtained at www.lapeth.ethz.ch/∼mark/research/

References

Bourqui, M. 2001. *Stratosphere - Troposphere Investigations*. PhD thesis. Swiss Federal Institute of Technology (ETH). Dissertation Nr. 14054.

Muraki, D. J., and G. J. Hakim. 2001. Balanced asymmetries of waves on the tropopause. *J. Atmos. Sci.* **58**, 237–252.

O'Connor, F. M., G. Vaughan, and H. de Backer. 1999. Observations of subtropical air in the European mid-latitude lower stratosphere. *Quart. J. Roy. Meteor. Soc.* **125**, 2965–2986.

Pomroy, H. R., and A. J. Thorpe. 2000. The evolution and dynamical role of reduced upper-tropospheric potential vorticity in intensive observing period one of FASTEX. *Mon. Wea. Rev.* **128**, 1817–1834.

Vaughan, G., and J. D. Price. 1991. On the relation between total ozone and meteorology. *Quart. J. Roy. Meteor. Soc.* **117**, 1281–1298.

Wernli, H. 1997. A Lagrangian-based analysis of extratropical cyclones. II: A detailed case-study. *Quart. J. Roy. Meteor. Soc.* **123**, 1677–1706.

Wernli, H., and H. C. Davies. 1997. A Lagrangian-based analysis of extratropical cyclones. I: The method and some applications. *Quart. J. Roy. Meteor. Soc.* **123**, 467–489.

Wirth, V. 2001. Cyclonic-anticyclonic asymmetry concerning the height of the thermal and the dynamical tropopause. *J. Atmos. Sci.* **58**, 26–37.

Zierl, B., and V. Wirth. 1997. The influence of radiation on tropopause behaviour and stratosphere-troposphere exchange in an upper tropospheric anticyclone. *J. Geophys. Res.* **102**, 23883–23894.