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OZONE LAMINAE NEAR THE EDGE OF THE STRATOSPHERIC POLAR VORTEX.

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ABSTRACT.

Analysis of ozonesonde data collected at high northern latitudes in winter and spring shows that laminae of enhanced and depleted ozone are associated with the polar vortex. In January and February, they are most common at all latitudes in the potential temperature range 370-430K, but are abundant up to 500K between 60° and 70° N. In March and April they occur most frequently northward of 75° N, and are abundant up to 520K, whereas they are largely confined to the range 320-440K at lower latitudes. Analysis of ozone lidar data obtained during AASE-I depicts clearly the extrusion of laminae of enhanced ozone concentration from the polar regions in the altitude range 13-15 km. These extrusions form a class of laminae which transport ozone equatorward in the lowest levels of the stratosphere.

1. INTRODUCTION.

Reid and Vaughan (1991) showed that laminae in ozonesonde profiles are most prolific at polar latitudes in winter and spring over the altitude range 12 - 18km. In addition, their mean magnitude (or difference in ozone partial pressure across the edge of the layer) is greatest and their mean depth (vertical scale) least at high latitudes, suggesting a polar site for their formation. In this paper we present evidence which links the genesis of laminae to the boundary of the polar vortex, using lidar and ozonesonde data acquired during AASE, as well as further results from the WMO archive.

2. EVIDENCE FROM OZONESONDE PROFILES.

Reid and Vaughan (1991) defined a lamina in the ozone partial pressure profile as an anomaly over a vertical depth of 200m - 2.5 km, with magnitude at least 20 nbar. Both positive and negative anomalies were classified as laminae. This analysis has been extended in the present paper for the potential temperature range 300 - 620K, using data from the ozonesonde stations listed in Table 1. For most of these stations 17-25 years of data were available, but for stations between 60° N and 72° N there was only one year's data. The results may therefore be unrepresentative of the long-term mean in this latitude range. However, preliminary data from 1992 (a year of copious laminae) reveal the same distribution pattern as shown below, lending support to the conclusions drawn.

Station	Latitude, °N	No. of sondes	
Alert	82.3	56	
Resolute	74.4	74	
Scoresbysund	70.5	20	(1989 only)
Sodankyla	67.2	13	(1990 only)
Angmagssalik	65.6	19	(1989 only)
Lerwick	60.1	32	(1989 only)
Churchill	58.4	71	
Edmonton	53.3	102	
Goose	53.2	134	
Hohenpeissenberg	47.5	423	
Cagliari	39.2	37	
Wallops	37.5	77	

Table 1. Locations of ozonesonde stations used in this study.

Results for lamina frequency in January and February are shown in fig. 1. Poleward of 75° N and equatorward of 60° N laminae are mostly confined below 440K, with maximum occurrence near 400K. Between 60° and 75° N - typically the location of the vortex boundary and therefore beneath the stratospheric polar jet - laminae are observed to much higher levels. This distribution was confirmed by ozonesonde data acquired during 1989, for which potential vorticity (PV) values were also available (Newman et al 1989). A clear boundary occurs in the distribution of laminae: for large values of the 400K PV they were only found below $\theta \sim 410$K. Under such conditions the air above 410K is within the vortex, thus laminae are either absent or very rare in the north polar vortex.

The distribution in spring is quite different. Laminae are now most prevalent at very high latitudes (fig.2) and are found up to 500K. There is again a belt near 400K where laminae are most prolific southward of 75°N, but there is no maximum in occurrence between 60° and 70°. The laminae are also narrower at almost all latitudes and heights than in winter, especially at the highest latitudes. We conclude from this analysis that the processes responsible for generating laminae are not exclusively winter phenomena, but must also be active in spring.

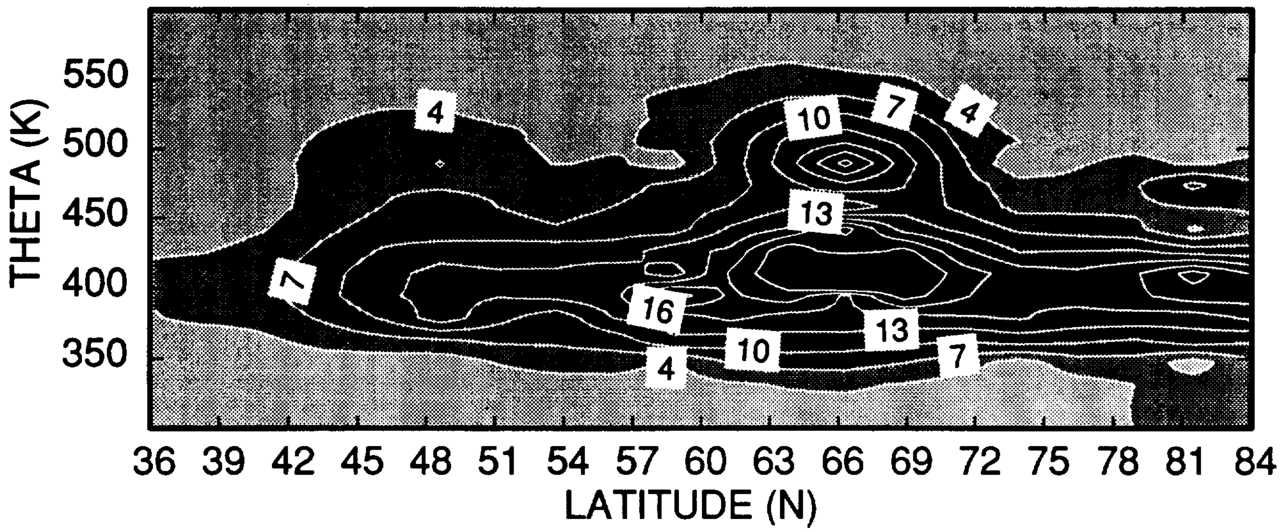

Figure 1: Frequency of occurrence of laminae as functions of latitude and potential temperature for January and February, based on the stations in Table 1. The values shown are the average number of laminae per 10K height interval at each latitude, multiplied by 100 for presentation.

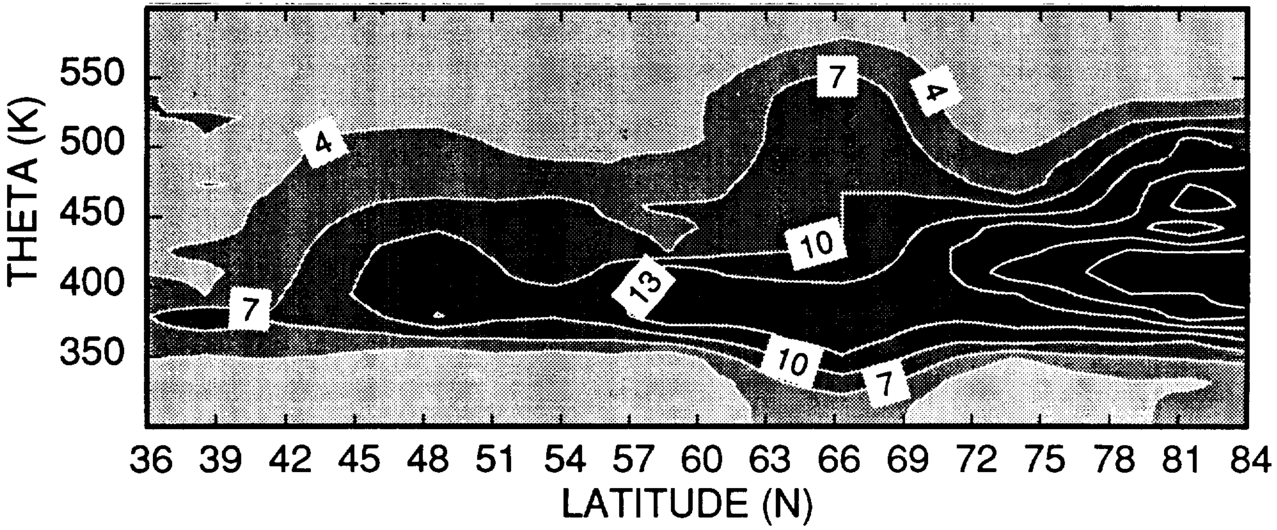

Figure 2: As for figure 1, but for the period March—April.

3. OBSERVATIONS OF OZONE LAMINAE IN LIDAR CROSS-SECTIONS.

During the Airborne Arctic Stratospheric Expedition (AASE) the NASA Langley differential absorption lidar system was mounted on the NASA Ames DC-8 aircraft for a number of flights which provided cross-sections of the polar vortex edge. A description of the experiment and sample results have been presented by Browell et al (1990). The DC-8 flew near the tropopause and measured vertical ozone profiles averaged horizontally over 60km (5 minutes flight time) and vertically over 975m below 19 km. Data shown here are those published on the AASE I CD-ROM (Browell 1990). Potential vorticity values are quoted in units of 10^{-6} K kg^{-1} m^2 s^{-1}.

A search was made in the lidar cross-sections for laminae in ozone mixing ratio. Laminae were found on almost every flight in January, but on only half of the February missions. Almost all occurred near the vortex boundary, rather than inside the vortex itself or equatorward of it. Located in the altitude range 13-18km, with a maximum frequency around 14-15km, and with magnitudes of 200 - 400 ppbv (25 - 50 nanobars) and depths of 1.0 - 1.5km, these lidar-derived features are entirely consistent with those recorded in the ozonesonde analysis.

One example of such a feature, observed by the aircraft on 19 January, is presented here. The vortex on this day was relatively undisturbed, centered roughly over the pole with shallow troughs at 75°W and 60°E and a shallow ridge over eastern Scandinavia. The path of the DC-8 on this day is shown relative to the 100 mb and 400K PV fields in fig.4. Although the aircraft flew beneath the vortex in a northward and westward direction, laminar structure was only observed on the latter portion of the flight, near to the 15 PV units contour. The

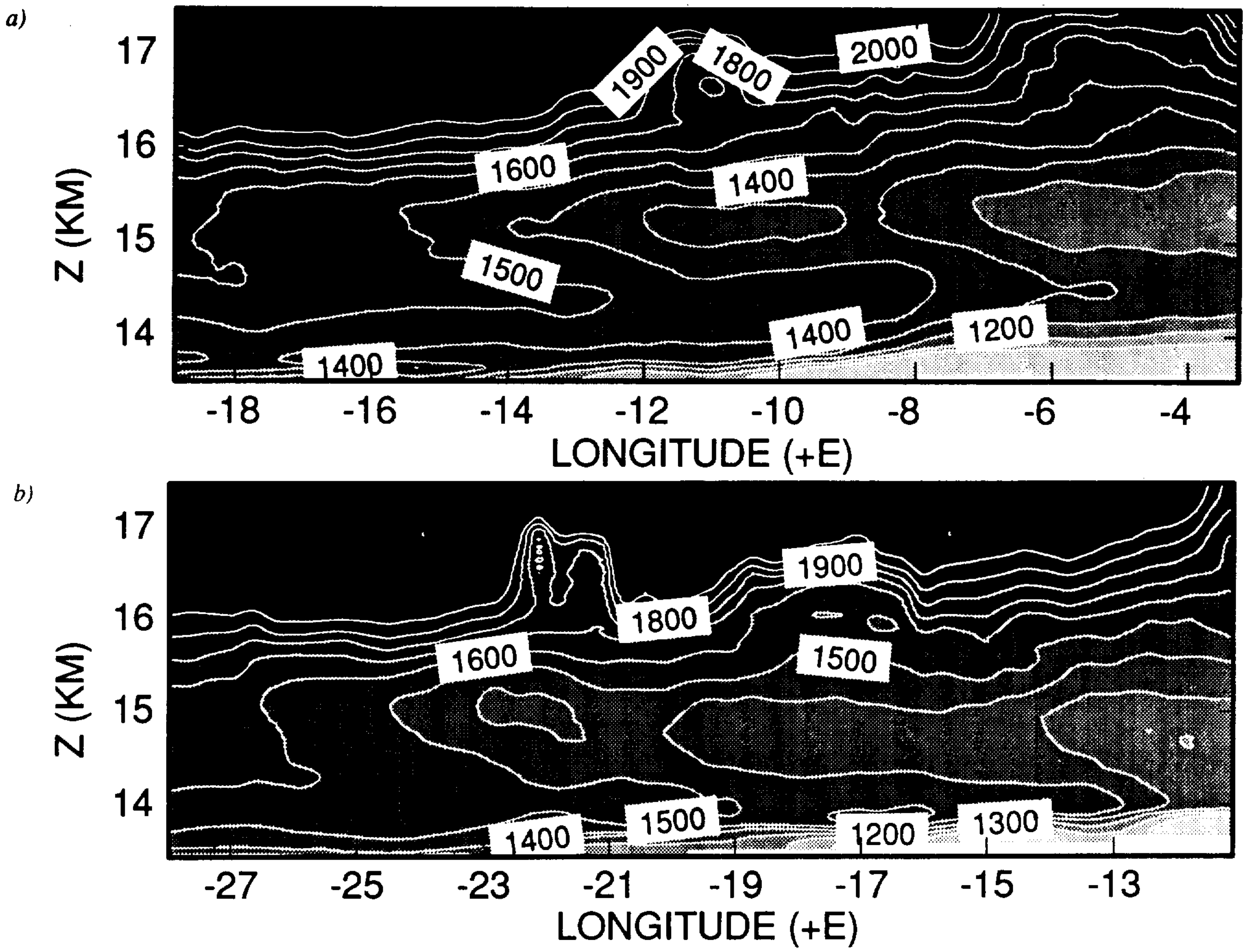

Figure 3: Ozone lidar cross-sections across the polar vortex edge, 19 Jan 1989: a) westbound leg; b) eastbound leg.

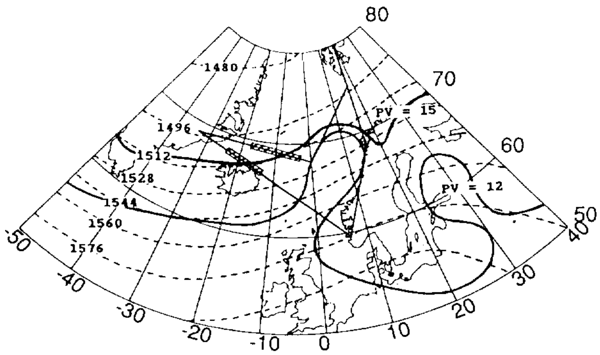

Figure 4: Path of the DC-8 on 19 Jan 1989 superimposed on the 100 mb geopotential chart for 00h on 20th. 400K PV contours for mid-day on 19th are shown as thick lines and the extent of the laminae as cross-hatched sections.

laminae are shown in figs. 3a and b, and are about 0.5-1.0 km deep and 200-300ppbv (25-35nb) in magnitude, spanning about 10 degrees in longitude (~ 500km). The laminae on the eastbound leg occurred directly upwind of those on the westbound leg, with a displacement of about 500 km. These two figures give a cross-wind dimension of about 350 km and an along-wind dimension of at least 700 km.

It should be noted that the enhanced lamina in fig. 3b is about 300 m lower than that in fig.3a. In fact, the meteorological data for this day show that air was rising as it flowed from the trough to the ridge, and it appears that both laminae occured near 382K. It is also clear from the figures that the laminae slope upwards with longitude, again consistent with rising motion.

4. DISCUSSION AND CONCLUSIONS

The AASE data support two views of ozone laminae: isentropic extrusions of elevated ozone mixing ratio from the base of the polar vortex and a less coherent structure which is more akin to blobs or patches of ozone-rich air. These cannot easily be distinguished in an ozonesonde ascent, and so both are represented in the statistical analysis of section 2. The isentropic extrusions appear to have a consistent form in the lidar data - a thin enhanced lamina in the range 360-380K, with a rather broader depleted layer in the 400-420K range. In some ways this pattern is reminiscent of the ozone partial pressure minimum at 15 km discussed by Dobson (1973): he found that this feature predominated at high latitudes in spring. Because of the vertical averaging of the lidar data the actual vertical scale of these features cannot be determined: they appear to be about 0.5-1.0 km deep, consistent with the data resolution. Much thinner laminae are resolved by high resolution ozonesonde profiles, but the dominant vertical scales in the WMO data are around 1.5 km at high latitudes. Thus, the lidar is probably just about resolving the laminar structure.

The lidar cross-sections clearly show that subsidence of air in the polar regions continues well below the nominal vortex base of 400K : elevated ozone mixing ratios beneath the vortex are observed at all heights (as shown most clearly in fig.3). The belt of high laminar frequency shown between 370 and 430K in figs. 1 and 2 identify this altitude range as a region of horizontal mixing. Whatever the mechanism for this mixing, this branch of the stratospheric circulation is of crucial importance in the atmosphere: it is only by the pronounced subsidence near the winter poles that ozone (and other stratospheric tracers) can reach the tropopause and be expelled from the stratosphere. Thus, the subsidence and subsequent mixing to midlatitudes control the rate of transfer of stratospheric ozone into the troposphere.

Tuck et al (1992) postulate that the stripping of air off the vortex edge near 475K transfers to lower latitudes air that has been chemically processed in PSCs. Active chlorine in these air parcels could destroy some of the ozone, explaining the downward trend seen in total ozone in northern midlatitudes in winter and spring. For exchange below 420K to contribute to this loss, diabatic cooling rates in the lower stratosphere must be such that air exposed to PSCs has time to descend to 420K during the rest of the winter. PSCs were present in the vortex from about 22 November onwards (Tuck et al 1992), and an average diabatic descent rate of < 2.6 km per month during the AASE experiment (2 Jan - 15 Feb) was estimated by Schoeberl et al (1991) based on tracer measurements and radiative calculations. It would then appear that PSC-processed air would have had time to sink to the lowest part of the vortex, where the exchange is most active. The diabatic descent rate is of course very uncertain, but it should be greater in the early part of the winter because the vortex was warmer.

The discussion so far has focussed on the polar vortex as a source of laminae. The WMO analysis in section 2 show that laminae are equally prolific, equally large and if anything narrower in vertical scale during spring than in winter. Clearly, some (at least) of the processes which generate laminae must be active at that time. Air in the polar vortex does not mix with midlatitude air immediately following the final warming, and the spring laminae probably represent the mixing of the two air masses by synoptic-scale motions. The question then arises of the fate of PSC-processed air within the vortex, and the speed with which active chlorine is returned to inactive forms compared with the time scale for ozone destruction (if any) in the comparatively warm spring lower stratosphere.

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REFERENCES

Browell, E. V., C. F. Butler, S. Ismail, M. A. Fenn, S. A. Kooi, A. F. Carter, A. F. Tuck, O. B. Toon, M. H. Proffitt, M. Loewenstein, M. R. Schoeberl, I. Isaksen and G. Braathen. Airborne lidar observations in the wintertime arctic stratosphere. Geophys Res. Lett., **17**, 325-8, 1990.

Browell, E. V. Airborne UV DIAL lidar ozone and aerosol data obtained during the 1988-89 Airborne Arctic Stratospheric Expedition (AASE), in NASA/NOAA AASE CD-ROM Data Archive, 1990.

Dobson, G.M.B. The laminated structure of the ozone in the atmosphere. Q. J. Roy. Met. Soc., **99**, 599-607, 1973.

Newman, P. A., L. R. Lait, M. R. Schoeberl, R. M. Nagatani and A. J. Krueger. Meteorological atlas of the northern hemisphere lower stratosphere for January and February 1989 during the airborne Arctic stratospheric expedition. NASA technical memorandum 4145.

Reid, S.J. and G. Vaughan. Lamination in ozone profiles in the lower stratosphere. Q. J. Roy. Met. Soc., **117**, 825-844, 1991.

Schoeberl, M. R., M. H. Proffitt, K. K. Kelly, L. R. Lait, P. A. Newman, J. E. Rosenfield, M. Loewenstein, J. R. Podolske, S. E. Strahan and K. R. Chan. Stratospheric constituent trends from AASE data. Geophys. Res. Lett., **17**, 469-72, 1990.

Tuck, A. F., T. Davies, S. J. Hovde, M. Noguer-Alba, D. W. Fahey, S. R. Kawa, K. K. Kelly, D. M. Murphy, M. H. Proffitt, J. J. Margitan, M. Loewenstein, J. R. Podolske, S. E. Strahan, and K. R. Chan, PSC-processed air and potential vorticity in the northern hemisphere lower stratosphere at mid-latitudes during winter. J. Geophys. Res., **97**, 7883-7904, 1992.