Stratospheric Meteorological Conditions for the 3-12 Nov 1994 ATMOS/ATLAS-3 measurements

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Introduction

The Atmospheric Trace Molecule Spectroscopy (ATMOS) instrument measured a large complement of stratospheric trace gas concentrations during the ATLAS-3 mission, 3-12 Nov 1994. Southern hemisphere (SH) measurements were made at high latitudes (~64°-73°S), in and around the polar vortex. Northern hemisphere (NH) measurements ranged from the tropics to mid-latitudes (~5°-50°N) [*Gunson et al., 1996]*. Knowledge of meteorological conditions prior to and during this period is essential to analysis of the ATMOS/ATLAS-3 data. We summarize here the meteorological conditions before and during ATLAS-3.

We use geopotential heights, temperatures and horizontal winds from the United Kingdom Meteorological Office (UKMO) stratosphere-troposphere data assimilation system [*Swinbank and O'Neill,* 1994]. Potential vorticity (PV) is calculated from the UKMO data; PV is scaled in "vorticity units" [e.g., *Manney et al.,* 1994] to give a similar range of values at all levels. Scaled PV (sPV) is given in units of 10^{-4} s^{-1}. In the SH, we change the sign of sPV for plotting, so large positive values are shown in the vortex interior. Strong horizontal sPV gradients on isentropic (constant potential temperature, θ) surfaces represent a barrier to transport, and can be used to identify the approximate size, shape, location and evolution of the polar vortex.

An indication of the extent of the polar vortex in both hemispheres during the ATLAS-3 mission is given in Fig. 1, which shows sPV and its gradient as a function of θ and equivalent latitude (EqL) [e.g., *Butchart and Remsberg,* 1986] on 6 Nov 1994. EqL is the latitude that would enclose the same area as each sPV contour for which it is evaluated; sPV plotted in this vortex-centered coordinate thus gives a measure of the size of the vortex, independent of whether it may be distorted or shifted off the pole. In the SH, strong sPV gradients associated with the polar vortex extend from below 375 K up to about 1000 K; above this level gradients are much weaker, but some inclination of a vortex remnant is seen up to about 1300 K. The vortex is still large and strong below about 600 K, with both size and strength decreasing rapidly with height above that level. In the NH, a region of strong sPV gradients associated with the developing polar vortex is apparent above about 550 K.

Southern Hemisphere

Fig. 2 shows area integrals [*Butchart and Remsberg*, 1 986] of sPV as a function of EqL during S11 late winter/spring 1994, with the ATLAS-3 period indicated. The upper stratospheric vortex has already broken down (Fig. 1), and the middle stratospheric vortex (Fig. 2a) is being substantially eroded, with rapid weakening of sPV gradients during ATLAS-3. The lower stratospheric vortex (Fig, 211) remains strong, with sPV gradients weakening rapidly after nlid-November. This evolution is typical of the SH, and very similar to that in the previous two SH winters [e.g., *Manney et al.,* 1994]. As noted by *Manney et al.* [1 994], at the lowest levels (~375-420 K), the vortex remains strong into December.

SH winter lower stratospheric temperatures arc typically low enough to form both type 1 and type 11 polar stratospheric clouds (PSCs) for several months, with important consequences for ozone depletion, dehydration and denitrification in the SH vortex. The 1994 SH winter was fairly typical in this respect, and very similar to the 1992 S11 winter [*Manney and Zurek,* 1993]. Temperatures first dropped below 195 K (a convenient approximation to the type I PSC threshold) around 10 May and below 188 K (approximately the type 11 PSC threshold) around 5 Jun. In late J ul y, temperatures less than 195 K extended from ~1 00-7 hPa and temperatures less than 188 K from ~90-1 O hPa. Cold regions appear first near 20 hPa, ancl persist latest near 100-50 hPa. in late winter 1994, Fig. 3 shows temperatures below 188 K until late Scp, and below 195 K as late as 2 Nov. The persistent region of temperatures below 195 K disappeared around 20 Ott, but a slight cooling produced a small region of temperatures below 195 K over the Palmer peninsula between 28 Ott and 2 Nov. The S11 ATLAS-3 measurements were thus made 35-45 days after the last occurrence of typical type II PSC temperatures, and only a few days after the last occurrence of typical type I PSC temperatures.

Fig. 4 shows the time evolution of PV in the SH on the 655 K O-surface (~20 hPa) during ATLAS-3, in relation to the ATMOS measurements. The vortex shape changes rapidly during ATLAS-3, but throughout the period it remains shifted off the pole towards ~270°E, so most of the ATMOS measurements between 180° and 360° fall within the vortex at this level; thus, cross- sections of trace species constructed from ATMOS measurements over the 10 day period, such as those shown by *Abrams et al. [1 996]* and *Rinsland et al.* [1996] provide a reasonable picture of the longitudinal variations in the observations. The measurement shown by a triangle on 6 Nov (SR29) is used by *Rinsland et al.* [1996] as an example of a profile that is well outside the vortex; at 655 K, this measurement in fact samples subtropical air that has been drawn up around the vortex. The ATMOS measurement shown by a triangle on 10 Nov (SR68) is used as an example of one that is well inside the vortex. The region of strong sPV gradients is from ~1.0 to 1.8 x $10^{-4} s^{-1}$. Fig. 5 shows sPV on several other O-surfaces on 4 Nov 1994. The vortex is shifted in the same direction at all levels, with higher levels shifted farther off the pole. The measurement shown by a triangle (SR09) is examined in detail by *Newchurch et al. [1996]* and is within the vortex at all levels, but is near the inside edge at the lowest levels shown. As was shown in Fig. 1, sPV gradients at 1100 K (and above) are weak, and only a small remnant of vortex air is seen. At 375 K, although strong sPV gradients exist (Fig. 1), there are longitudes where gradients are weak, suggesting that the average strong gradients at this level may not represent as strong a barrier to transport as that at higher levels where strong sPV gradients are continuous around the circumference of the vortex.

Although the sPV fields shown above suggest material may be drawn up from low latitudes and pulled off the vortex, the extent of this behavior is not obvious in the relatively low resolution sPV fields calculated from the UKM () data. To get a mom complete picture of the circulation outside the vortex, we use reverse trajectory calculations [*Sutton et al.,* 1994] (done on an equal area grid with 0.8° latitude spacing and 0.8° longitude spacing at the equator, and run isentropically for 10 days using UKMO winds) to generate simulated high-resolution sPV fields. Fig. 6 shows high-resolution sPV fields for 4 Nov 1994. The vortex remnant at 1100 K is still separated from the exterior flow; however, some lower sPV material characteristic of the vortex exterior is being mixed with the remaining "vortex" air. At both 1100 and 840 K, long tongues of material with s1'V typical of the vortex edge arc drawn out into low latitudes and coiled up with very low sPV air drawn in from low latitudes. These fields show that, at some locations (e.g., near 0° longitude crossing the pole) extremely strong horizontal tracer gradients would be expected, as material from low latitudes is wrapped around the vortex. Similar calculations for vertical sections show that these tongues or filaments arc relatively deep, extending down to at least 700 K.

At lower levels, narrow (and generally quite shallow) filaments arc nearly continuously drawn off the vortex edge, but arc usually wrapped around the vortex, as opposed to extending to low latitudes. Such filaments may lead to tracer measurements that appear to be inconsistent with the fields in Fig. 5. At 375 K, some material with sPV characteristic of the vortex edge appears to be entrained deep into the vortex; this supports our earlier suggestion that the barrier to transport is not as strong here.

Northern Hemisphere

Fig. 7 shows sPV fields in the NH middle and lower stratosphere on 4 Nov 1994. As was seen in Fig. 1, the vortex is strong at 840 K (and above). 465 K is below the level where the vortex has formed, and PV gradients arc weak. The vortex is shifted slightly off the pole towards 0° longitude; this is before the formation of the climatological "Aleutian high" which shifts the vortex further off the pole in that direction [e.g., *Juckes and O'Neill,* 1988], the formation of which was delayed until late Jan 1995 during this

NH winter.

Simulated high-resolution sPV fields (Fig. 8) show more clearly the material being drawn up around the vortex from low latitudes and coiling up with air from the vortex edge. As is typical in NH early winter, material is drawn in from low latitudes and off the vortex nearly continuously. This is thought to contribute to forming the main vortex/surf zone structure [e.g., *Juckes and O'Neill,* 1988] by strengthening PV and tracer gradients both along the vortex edge and in the subtropics. Fig. 8 shows that adjacent ATMOS measurements could sample very different tracer values, e.g., at 840 K, the measurement shown by a triangle (SS01, discussed in *Newchurch et al. [1 996]* and *Chang et al.* [1 996]) near 230°13 may sample air characteristic of the vortex edge, while the adjacent measurement near 21 0°E may sample tropical or subtropical air. Although the vortex is just forming at 465 K, material is also being drawn up from the tropics there, so that a measurement that samples vortex edge air at higher levels may sample subtropical air at this level (e.g., triangle). The complexity of the air motion over the Pacific and western US at this time makes it especially important to carefully interpret detailed analyses and intercomparisons [e.g., *Chang et al.,* 1996] of measurements in this region in view of the variety of meteorological conditions that may be sampled in a small region.

Summary

During ATLAS-3, the SH polar vortex was still strong at levels below about 655 K, and weakened rapidly with increasing altitude above this, with strong sPV gradients still evident below about, 1000 K and coherent vortex fragments apparent up to about 1300 K. Throughout ATLAS-3, the SH vortex was shifted off the pole toward 270° E. SH lower stratospheric temperatures below 195 K were observed a few days before ATLAS-3, which was 35-45 days after the last occurrence of temperatures less than 188 K. In the N]], the vortex was developing during ATLAS-3, and a region of strong sPV gradients was apparent above about 550 K.

Simulated high-resolution sPV fields during ATLAS-3 in both the NH and SH show that considerably more atmospheric variability than the fields calculated from UKMO analyses is expected to influence the ATMOS/ATLAS-3 measurements. This sort of structure may lead to apparent discrepancies between ATMOS tracer observations and low-resolution PV fields. These calculations also show that ATMOS may sample air with very different origins at different altitudes in the same profile, or in adjacent measurements.

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Figure 1. sPV (contours, $10^{-4} s^{-1}$) and sPV gradients (colors, $10^{-4} s^{-1}$ /°EqL) on 6 Nov 1994, as a function of EqL and θ.

Figure 2. Area integrals of sPV for 1 Sep to 30 Nov 1994 in the SH, at 840 (~10 hPa) and 465 K (~50 hPa). sPV contour interval is *0.2* x $10^{-4} s^{-1}$, bold contour is 1.4 x $10^{-4} s^{-1}$. Thin vertical lines show the ATLAS-3 period.

Figure 3. Minimum temperature poleward of 40"S, for 1 Sep to 30 Nov 1994. Dark shading is from 180-185 K and light shading from 190-195 K. Thin vertical lines show the ATLAS-3 period.

Figure 4. SH sPV at *655* K (~20 hPa) *on* each day of ATLAS-3, at 12 GMT. Black dots are locations of ATMOS measurements during each day. The projection is orthographic) with 0° at the top and 90°E to the right; thin dashed lines are 30° and 60° S. Contour interval is 0.2 x $10^{-4} s^{-1}$, with light shading from 1.2 to 1.4 x $10^{-4} s^{-1}$ and dark shading from 0.6 to 0.8 x $10^{-4} s^{-1}$.

Figure 5. SH sPV maps at 1100, 840, 465, and 375 K on 6 Nov 1994. Layout is as in Fig. 4.

Figure 6. High-resolution sPV fields from 10 day reverse trajectory calculations, for 4 Nov 1994 in the SH, at 1100, 840, 465 and 375 K. Layout is as in Fig. 4.

Figure 7. As in Fig. 5, but in the NH at 840 and 465 K. 0° longitude is at tile bottom

Figure 8. As in Fig. 6, but, in the NH at 840 and 585 K. Layout is as in Fig. 7.

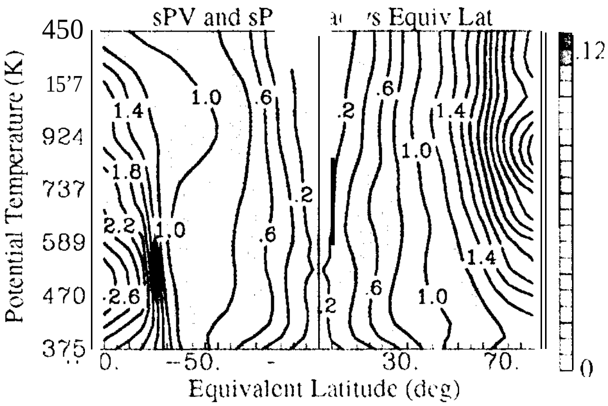
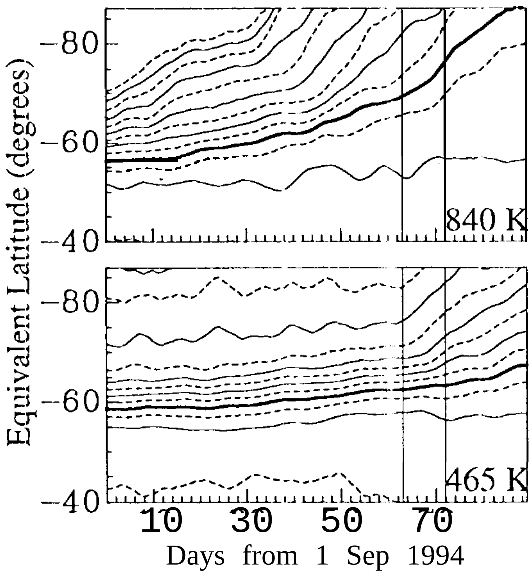

sPV and sP
's Equiv Lat
450
15'7
924
737
589
470
375
Potential Temperature (K)
1.4
1.8
2.2
2.6
1.0
.6
.2
1.0
.6
.2
.6
.2
1.4
1.0
1.4
.6
1.0
.2
0.
--50.
30.
70.
Equivalent Latitude (deg)
.12
0

Fig. 1



Equivalent Latitude (degrees)
-80
-60
-40
840 K
-80
-60
-40
465 K
10
30
50
70
Days from 1 Sep 1994

Fig. 2

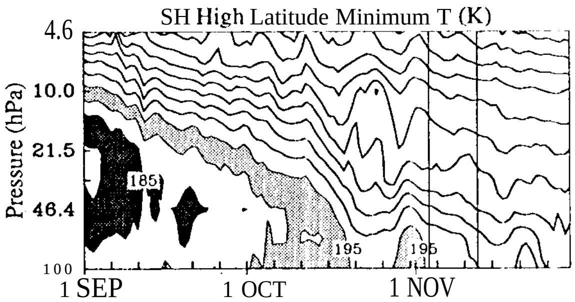

SH High Latitude Minimum T (K)
4.6
10.0
21.5
46.4
100
Pressure (hPa)
185
195
195
1 SEP
1 OCT
1 NOV

Fig. 3

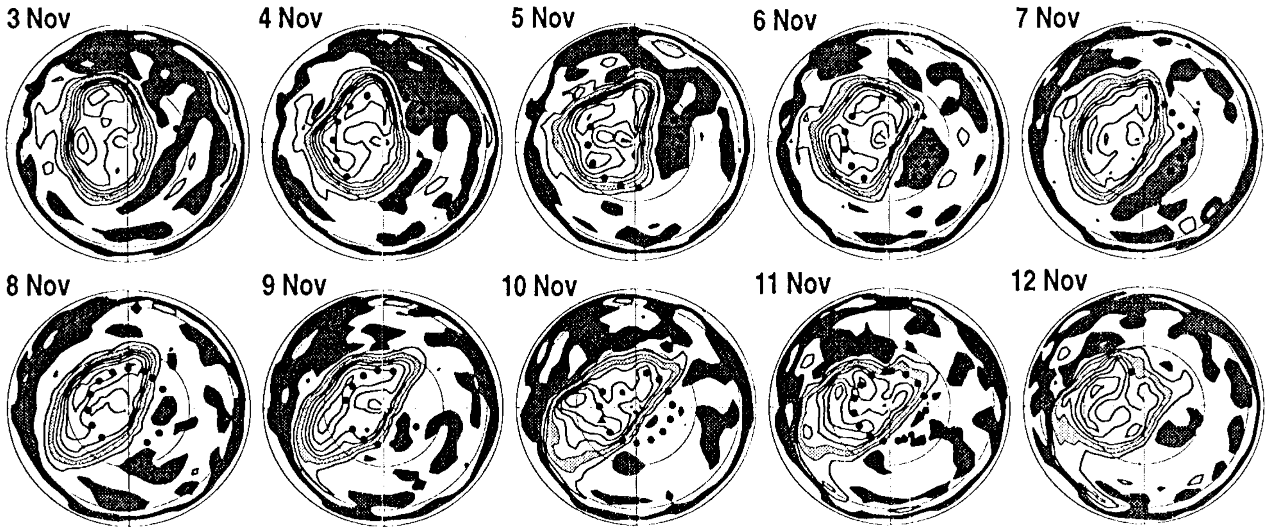
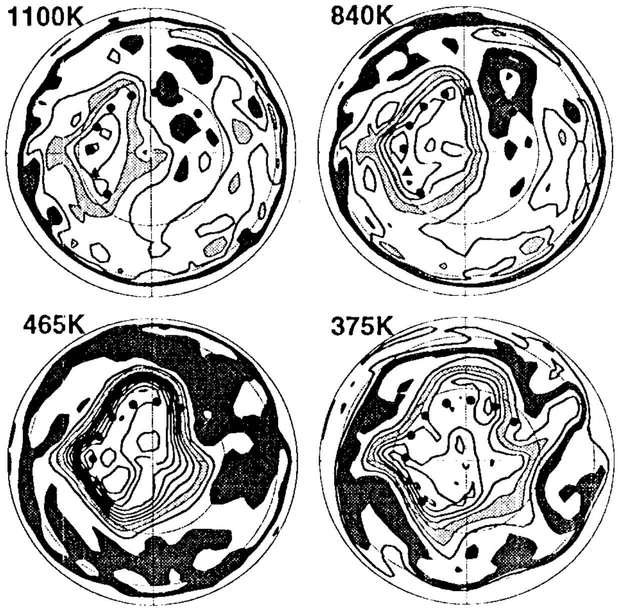


Fig. 4



UKMO sPV 4 Nov 1994 SH

Fig. 5

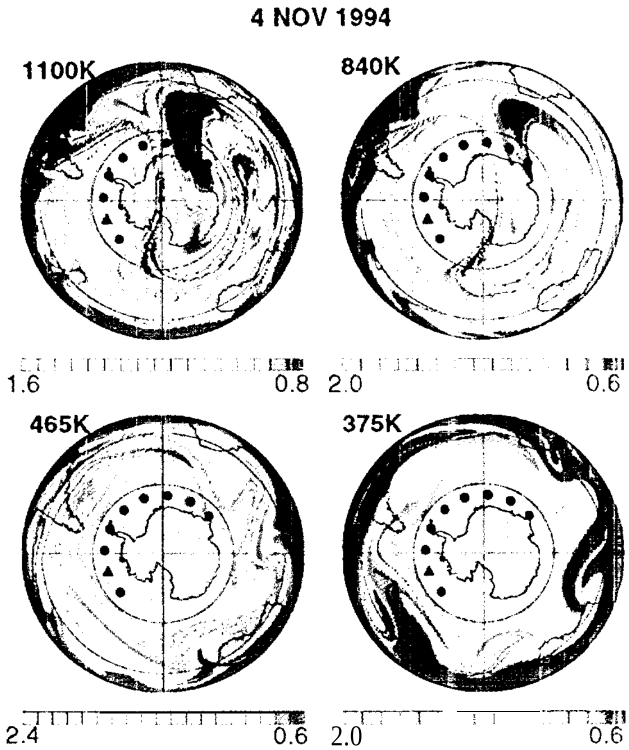
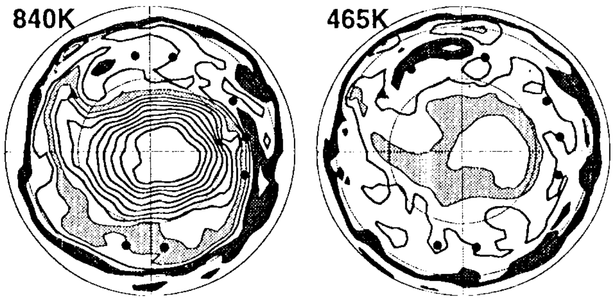


Fig. 6



UKMO sPV 4 Nov 1994 NH

Fig. 7

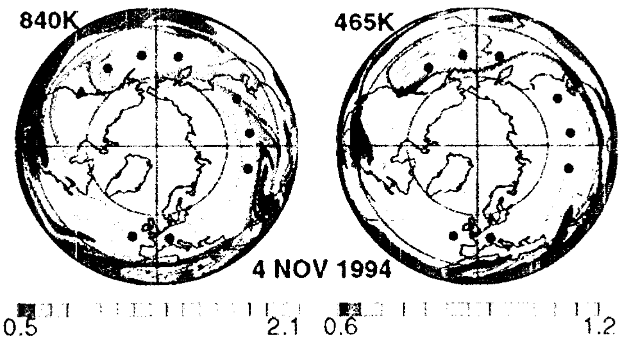


Fig. 8