Supplement to 'Estimates of Tropospheric Ozone from Nimbus 7 LIMS and TOMS Datasets'

By Ellis Remsberg

Effects of Residual Cirrus and Temperature Biases on Ozone Distributions from the V6 Level 3 Dataset

Residual cirrus contamination effects are present in both the V6 Level 2 profiles and in the Level 3 (map coefficient) product used for this study. As an example, Figure S1 is a map of the distribution of V6 ozone at the 68-hPa level on 15 March 1979, as those effects appear as sporadic excesses of tropical ozone. Those excesses appear to extend over large longitude intervals because there are wave coefficients for only one to two zonal waves. V6 nitric acid has weaker excesses at 68 hPa at the same locations as shown in Figure S2. The LIMS nitric acid channel is centered in the atmospheric window region near 11 μm, and its forward model is optically thin compared to that for ozone. Thus, the nitric acid profiles serve as separate although less sensitive indicators of the presence of residual cirrus.

Temperature biases are evaluated for a test day, 26 January 1979. Figure S3 shows the bias profile for the latitude range of 40°S to 20°S. It is of order -0.7 K from 30 to 50 hPa compared to MERRA data (c.f., Fig. 2 for 20°S to 20°N of the parent manuscript). Retrieved V6 ozone is very sensitive to temperature bias in the lower stratosphere, such that a -0.7 K bias leads to an ozone error of order +15%. The V6 temperatures also have larger negative values below the 100-hPa level, and its associated retrieved V6 ozone is not accurate. On the other hand, mean temperature biases from 20°N to 40°N (not shown) are only of order -0.2 K from 30 to 50 hPa.

Figure S4 is for ozone from 40°S to 20°S, and the mean differences (bottom left) are negative at 10 hPa, tending to zero at about 50 hPa. The temperature bias of Fig. S3 changes to +1.4 K at 100 hPa and leads to zero values of retrieved V6 ozone in Fig. S4. Standard deviations about the zonal mean are small at 50 hPa and of the order 0.2 ppmv for MERRA and 0.3 ppmv for V6 ozone (Fig. S4--top right). It is noted also that MERRA ozone perturbations from a SBUV control run are constrained somewhat in the tropics, but less so at middle latitudes.

What are the distributions of SCO and TRCO on 26 January? First, Figure S5 is the plot of TOMS ozone for that day, where the broad, white swath near 50°E is the region where TOMS made no measurements that day. Figure S6 is the distribution of V6 SCO, and it shows relatively large values of 240 DU in the latitude band of 40 to 50°S and minimum values of order 210 DU in the tropics. Figure S7 is the associated distribution of TRCO values, where the red dot is the location of Santiago, Chile, or along the elevated Andes range of South America. The latitude zone of 30 to 50°S has large variations of -60 to 120 DU. A part of the largest positive TRCO values may be where the tropopause was below the 100-hPa level and where a fraction of those

TRCO values may be between 100 hPa and the tropopause or in the lowermost stratosphere. The negative values occur at longitudes where ozone at higher southern latitudes is normally low (see February average in Ziemke et al. 2006), and where there may have been transport of low ozone to lower latitudes in late January. Figure S8 shows zonal eddy geopotential height contours at 100 hPa on 26 January. The circulation near 50°S, 30°W longitude appears to be moving low ozone from high to middle southern latitudes on 26 January.

There are significant zonal wave variations in temperature of order 4 to 5 K in the lowermost stratosphere at SH middle latitudes (see Fig. S3 at upper right), and the V6 temperatures in some narrow latitude zones may have biases that vary from positive to even more negative than -0.7 K between 40°S and 20°S. The V6 Level 3 zonal wave temperature coefficients have a relatively poor fit to the Level 2 profile data (rms deviations of 2.5 to 4 K at 36°S) at the levels of 21 to 100 hPa. In other words, the Level 3 algorithm smooths the amplitudes of the zonal wave coefficients (see next paragraphs). Figure S9 is a plot of the V6 temperature distribution at 46 hPa, showing that there are strong meridional temperature gradients at about 35°S and at 25°N. Fig. S9 also shows zonal wave-4 to wave-5 features at the SH middle latitudes, characteristic of baroclinic, medium wave forcing effects from below during summer.

A small part of the zonal ozone variations at middle latitudes (±20° to 40°) is because of the along site temperature gradient corrections. That prospect is illustrated more clearly with Figure S10, which is the zonal mean, latitude versus pressure plot of V6 temperatures for 26 January. Note that there are strong meridional gradients at about 30°S and 25°N and from about 50 to 100 hPa. Those two latitudes are where corrections for horizontal temperature gradients are important for accurate retrievals of both temperature and ozone (Remsberg et al., 2007). Estimates of temperature gradients for the processing of the V6 profiles were obtained from analyses on pressure surfaces of the V5 temperature fields. However, the V5 profile retrievals were carried out only at every 4° of latitude along orbits, such that its meridional gradients are limited by that coarse latitude spacing. In other words, the V5 temperature fields underestimate the actual meridional gradients for retrievals of V6 temperature and ozone profiles, which were processed at every 1.6° of latitude. Figure S11 is a further example, showing a zonal mean cross section of the V6 minus V5 temperatures for 26 January. There are differences of up to -4 K at about 30°S and 20°N, where the corrections for temperature gradients are important. Even so, the comparisons with MERRA in Fig. S3 indicate that the V6 algorithm yields the more accurate zonal mean temperatures from 30 to 50 hPa.

Figures S12 and S13 display V6 zonal average, ascending minus descending, orbital temperature and ozone. Those differences are positive for both parameters, +1 K and +10 to 15%, respectively, in the lower stratosphere at SH middle latitudes. Conversely, their differences are both negative by about the same amounts at NH middle latitudes. The signs of the gradient corrections depend on the orientation of the LIMS view path with respect to the isolines of

temperature in Fig. S9. The orientations of the along-path temperature gradients in the lower stratosphere for ascending versus descending orbital views determines the signs of the differences in both temperature and ozone—positive at SH and negative at NH middle latitudes.

A sequential estimation (SE) algorithm was used to obtain the V6 Level 3 zonal mean and zonal wave coefficients from time series of the ascending and descending profile data points at a given pressure and latitude. The SE fitting process attempts to follow the true amplitudes of zonal waves, where the fitting is controlled by the estimated precisions of the input data. As an example, Figure S14 shows the distribution of ozone at 46 hPa for 26 January for comparison with that of temperature (Fig. S9). Figure S15 is the analogous ozone distribution at 68 hPa, and where climatological ozone between ±20° varies from 0.68 to 0.55 ppmv. How well do their zonal variations follow the Level 2 profile data? Table 1 gives ozone profile values at 30°S at both 46 and 68 hPa for comparisons with Figs. S14 and S15. In general, the SE algorithm follows the profile points, although the.SE results tend not to follow the data extremes.

Examples of a rather poor fit of the SE coefficients to the profile data occur at 36°S and 46 hPa for both temperature and ozone, which have rms differences of 3.5 K and 0.94 ppmv (39%), respectively. The corresponding rms differences at 68 hPa are 3.8 K and 0.36 ppmv (55%). Those rather poor fits also occur where the temperature gradient corrections are underestimated and where the zonal averages of ascending minus descending orbital differences are as shown in Figs. S12 and S13. In summary, the SE algorithm smooths the true zonal wave amplitudes in the lower stratosphere. Larger amplitudes would give more pronounced zonal variations in SCO, but then to a reduction of the wave amplitudes of TRCO, i.e., the negative TRCO values would become less negative, and the positive values would become less positive.

Temperature biases are weaker and zonal wave variations are of smaller amplitude in the tropical lower stratosphere in November 1978. As an example, Figure S16 shows V6 minus V5 temperatures for 8 November, when the largest differences occur between ±20° of latitude rather than extending to the subtropics as on 26 January (Fig. S11). There is also a narrowing of the latitude range of minimum temperatures in November (not shown) compared with that for January (Fig. S10) that occurs because vertical transport in the tropics is weaker in November. At any rate, climatological ozone values are relied upon at 68 and 100 hPa and between about ±20° latitude to avoid residual cirrus effects in analyses of V6 SCO. Thus, it is posited that the associated daily distributions of TRCO are representative of the spatial variations of tropical tropospheric ozone during November 1978.

Figure S17 is the distribution of TRCO for 8 November but based on integrating SCO from 147 to 0.68 hPa. One can see that the elevated ozone at about 20°S, 0° longitude is nearly unchanged from that in Figure 12 of the parent manuscript; it indicates ozone from lower in the troposphere.

Figure credits: Figures S10-S13 and S16 are screen shots of images viewable at https://lims.gats-inc.com/ and by clicking on Browse Images, Version 06, Day 026 or Day 312, and then on Ltx (or latitude cross section).

Table 1

Level 2 Ozone Profile Data at ~30°S and at both 46 and 68 hPa on 26 January

Lon Deg*	46 ppmv	68 ppmv	A/D #
12	2.3	1.3	A
22	1.7	0.1	D
39	2.0	0.04	A
48	2.0	0.2	D
64	1.6	0.0	A
74	2.1	1.0	D
91	2.1	0.9	A
100	2.1	0.8	D
117	2.7	1.4	A
126	2.0	0.8	D
143	2.2	1.0	A
152	2.0	0.5	D
169	2.5	1.1	A
178	1.6	0.04	D
---	---	---	---
-171	1.9	0.03	A
-156	1.9	0.04	D
-130	1.4	0.02	D
-117	1.9	0.03	A
-104	2.1	1.0	D
-91	2.2	0.7	A
-77	2.2	0.4	D
-65	2.6	0.1	A
-52	1.4	0.04	D
-40	1.5	0.02	A
-29	1.8	0.03	D
-14	2.1	0.2	A

#A (or Asc) and D (Desc) orbits.

*pos is °E, neg is °W; the line --- partitions them.

There is no profile data near 30S on the Asc orbit between -156° and -130°.

Figures

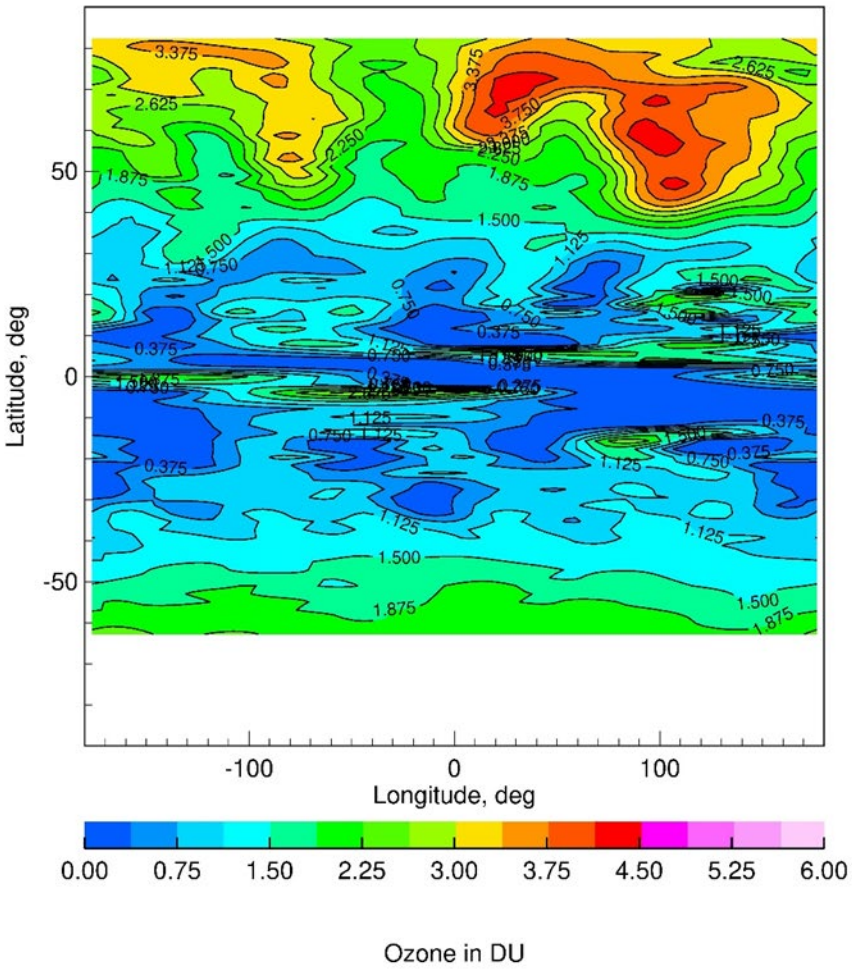

Figure S1—Cylindrical map projection of V6 ozone at 68 hPa on 15 March 1979. There are unexpected longitudinal structures in tropical ozone at this pressure level.

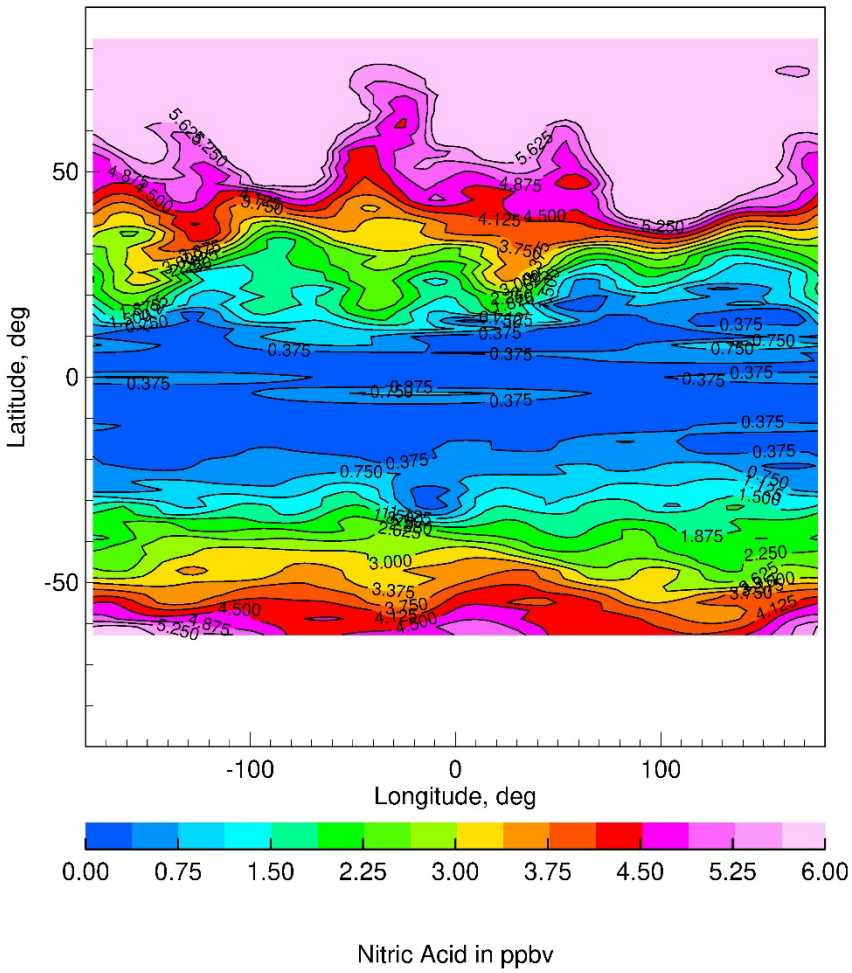

Figure S2—As in Fig. S1, but for V6 nitric acid at 68 hPa on 15 March 1979.

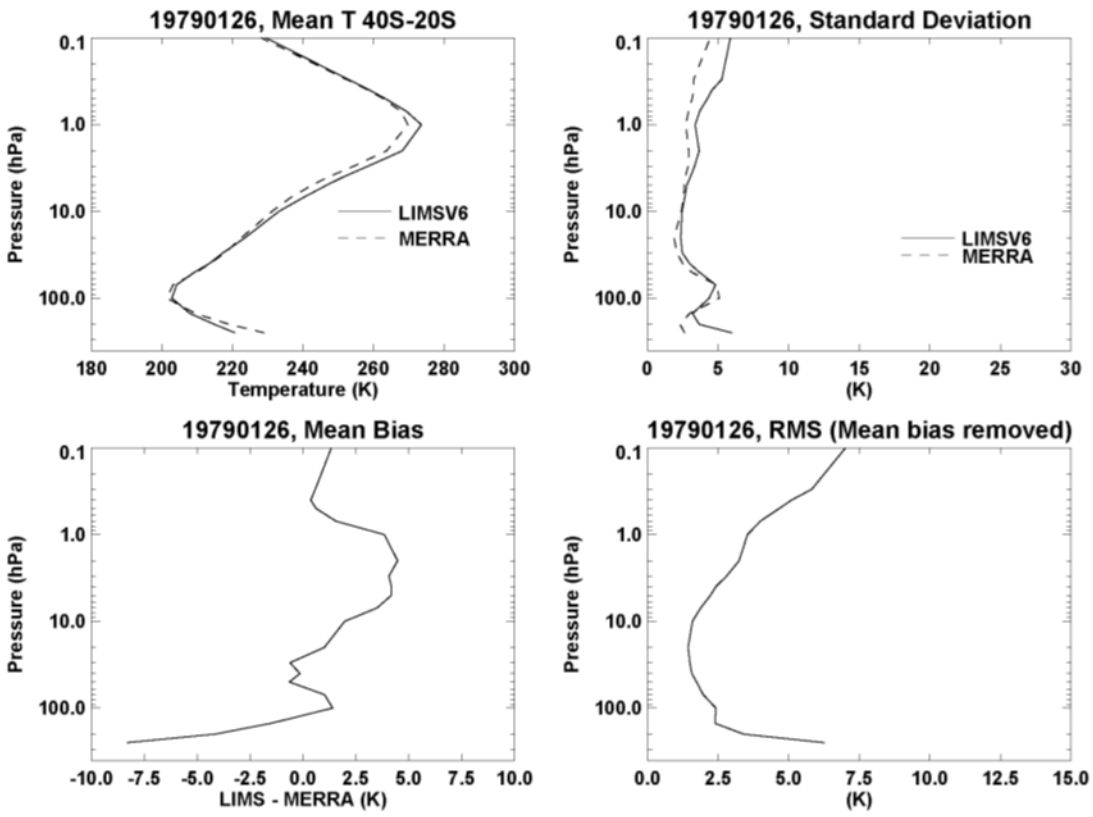

Figure S3—(top left) Temperature profiles from LIMS V6 versus MERRA for 40°S to 20°S. (bottom left) Mean bias, V6 minus MERRA, for 26 January 1979. (top right) standard deviation about the zonal mean, and (bottom right) RMS deviation with mean bias removed.

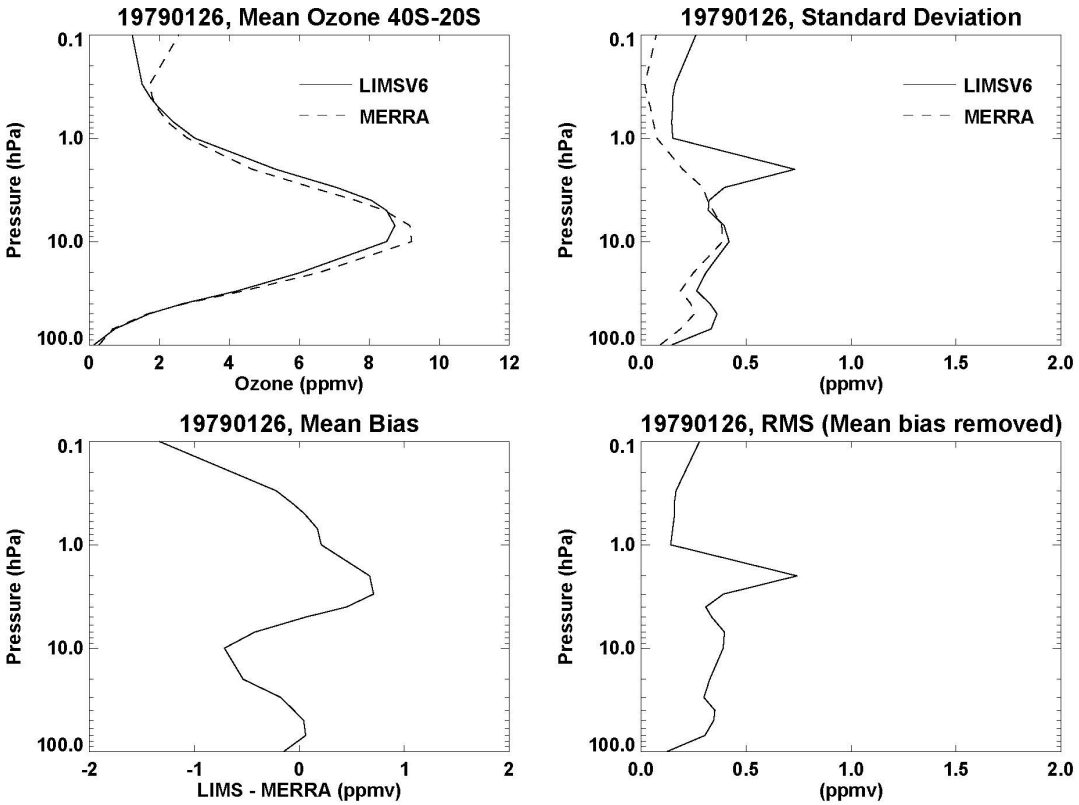

Figure S4—As in Fig. S3, but for ozone from 40°S to 20°S.

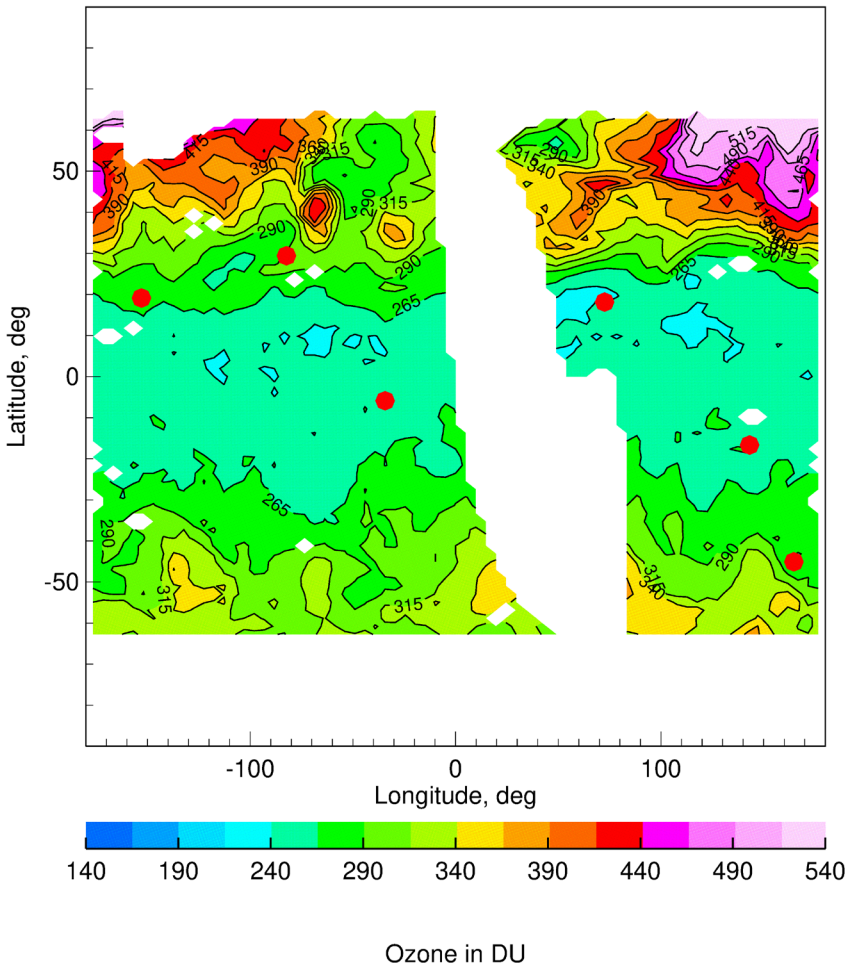

Figure S5—Distribution of TOMS ozone on 26 January 1979. White areas are where TOMS made no measurements this day.

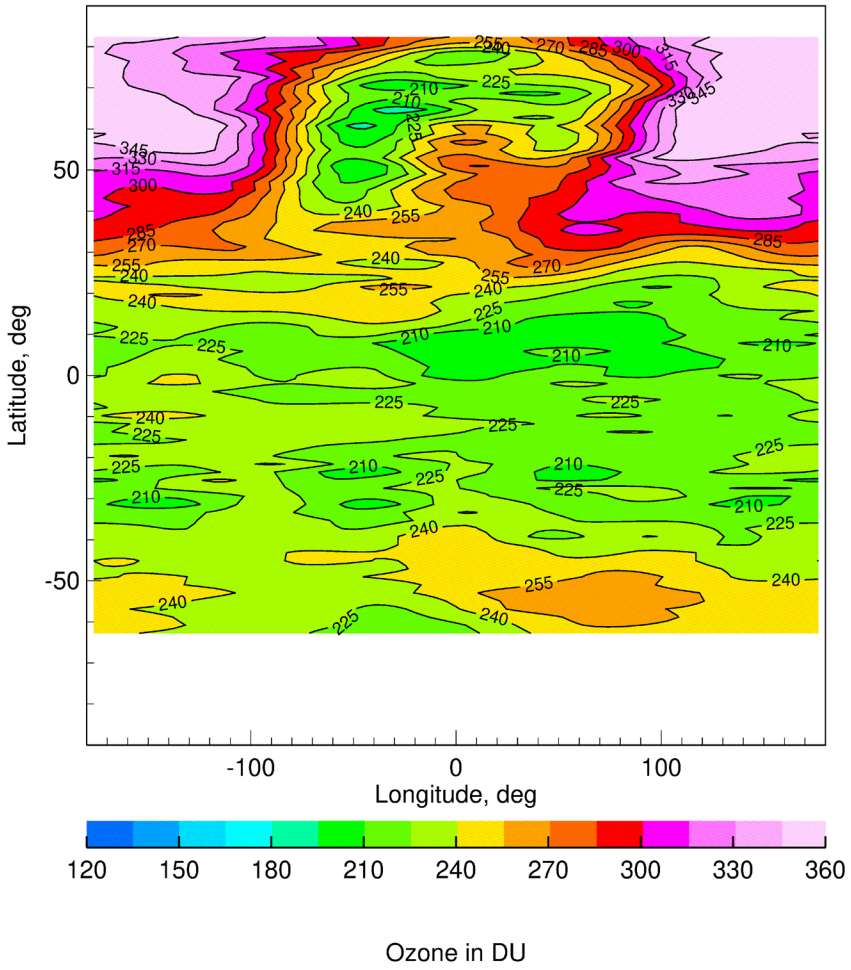

Figure S6—Distribution of SCO from 100 to 0.68 hPa on 26 January 1979.

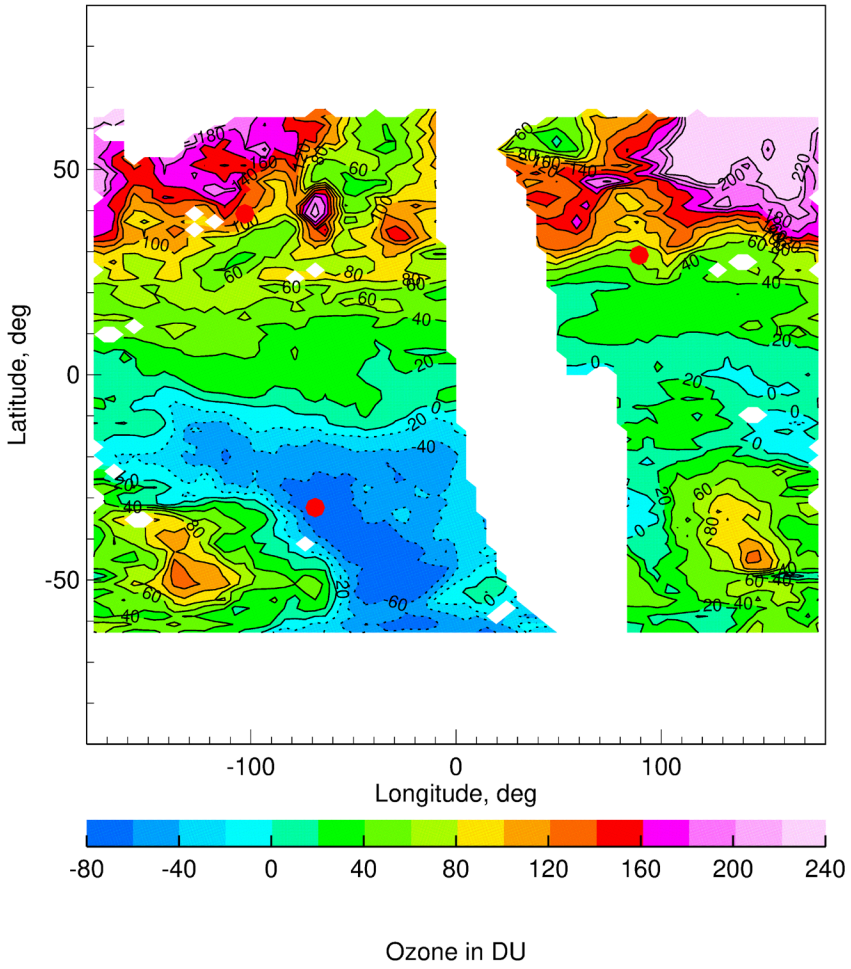

Figure S7—Distribution of TRCO values for 26 January 1979. The ozone scale is from -80 to 240 DU to accommodate negative values. Contour interval is 20 DU. Red dot at 33°S, 70°W is location of Santiago, Chile.

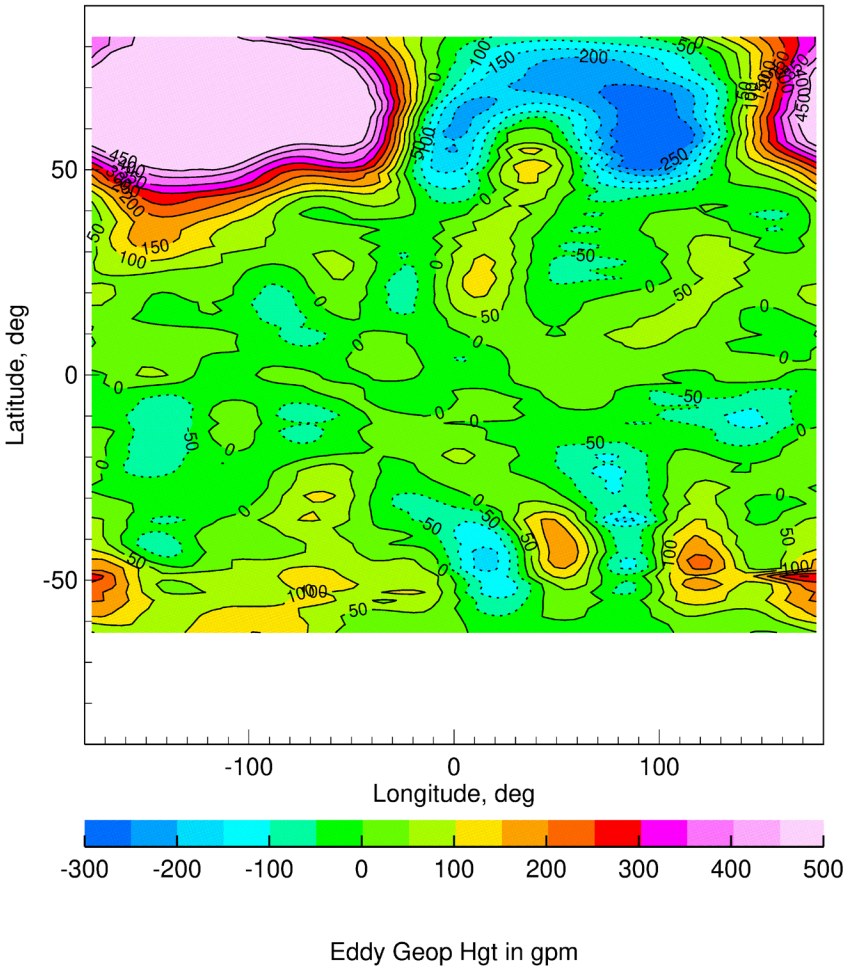

Figure S8—Contours of zonal eddy geopotential height on 26 January at 100 hPa.

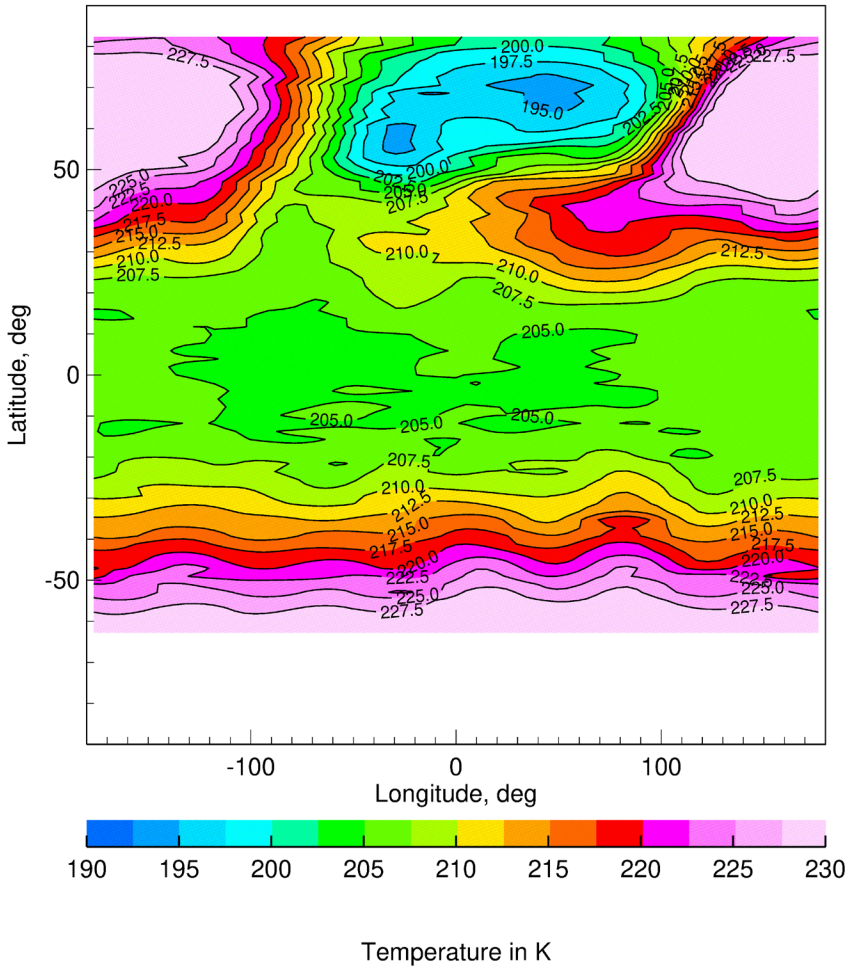

Figure S9—Distribution of V6 temperature on the 46 hPa surface for 26 January 1979. Contour interval is 2.5 K.

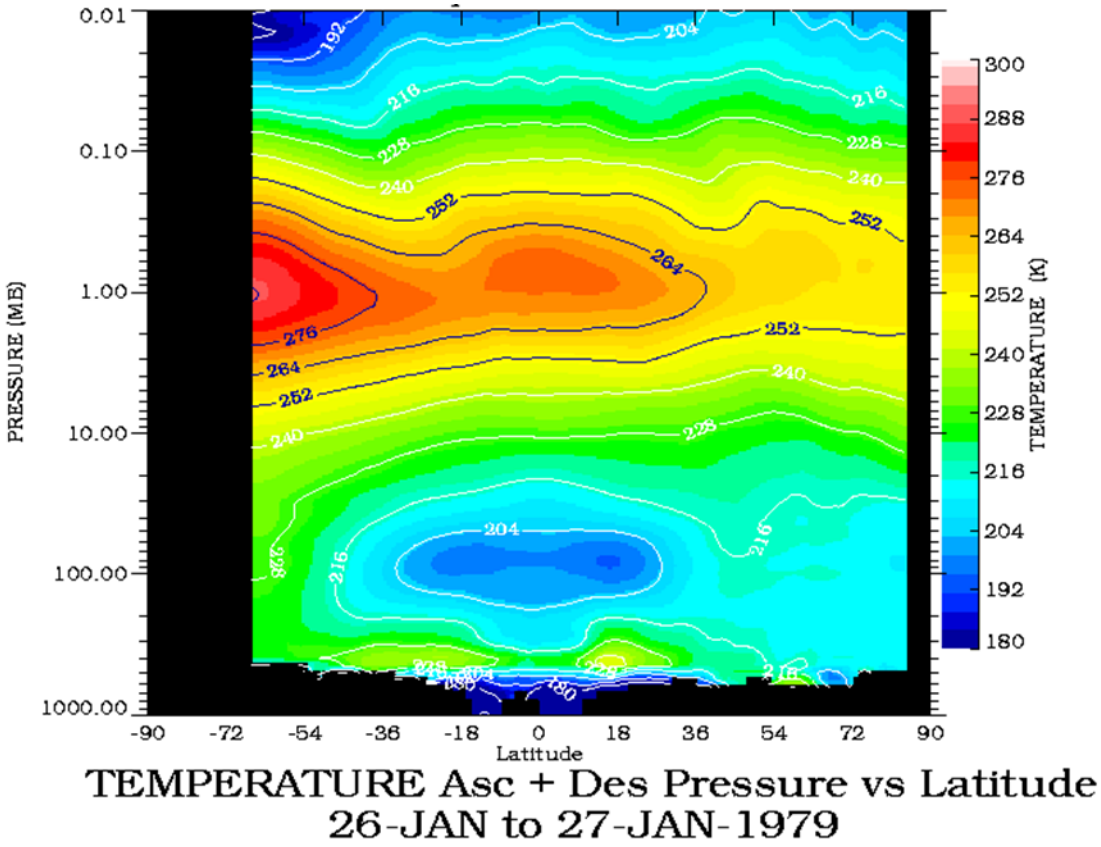

Figure S10—V6 zonal mean temperature distribution on 26 January 1979. The terms, Asc plus Des, refer to profile data taken in the alternate viewing directions of the LIMS ascending and descending orbital segments.

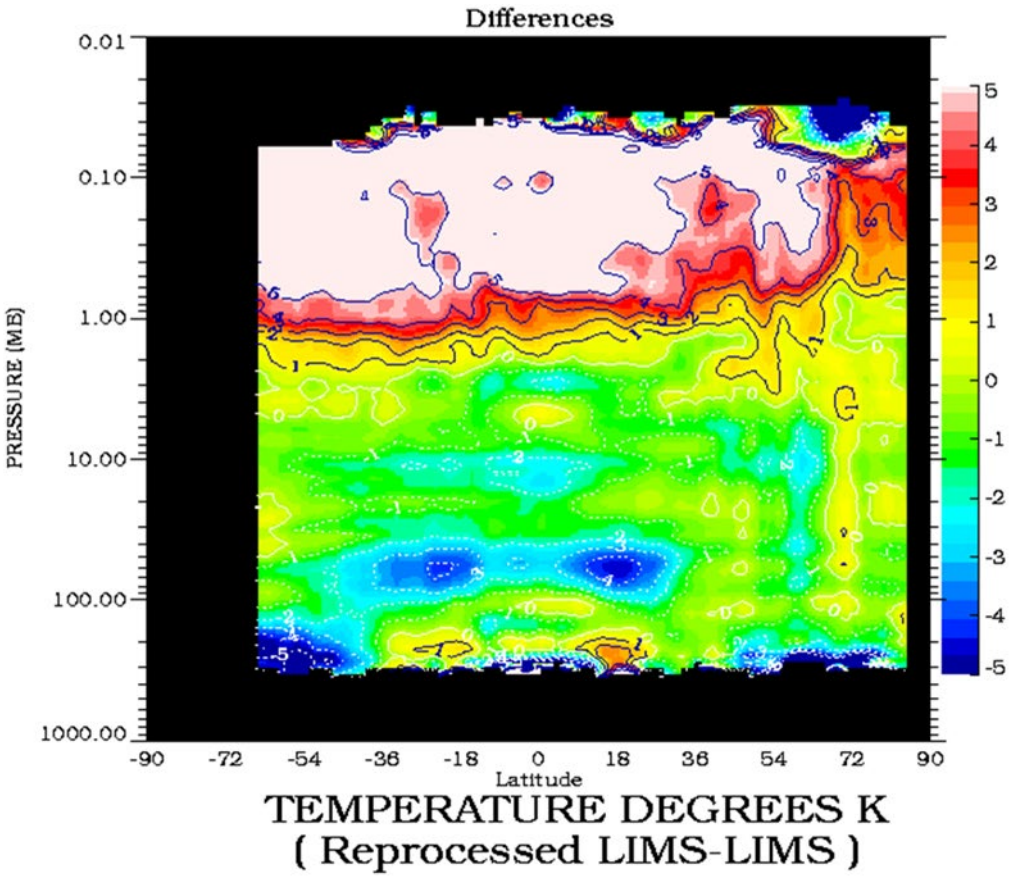

Figure S11—V6-V5 zonal average, temperature differences for 26 January 1979. The term 'Reprocessed LIMS' refers to V6 and the term 'LIMS' to V5 in the label on the abscissa.

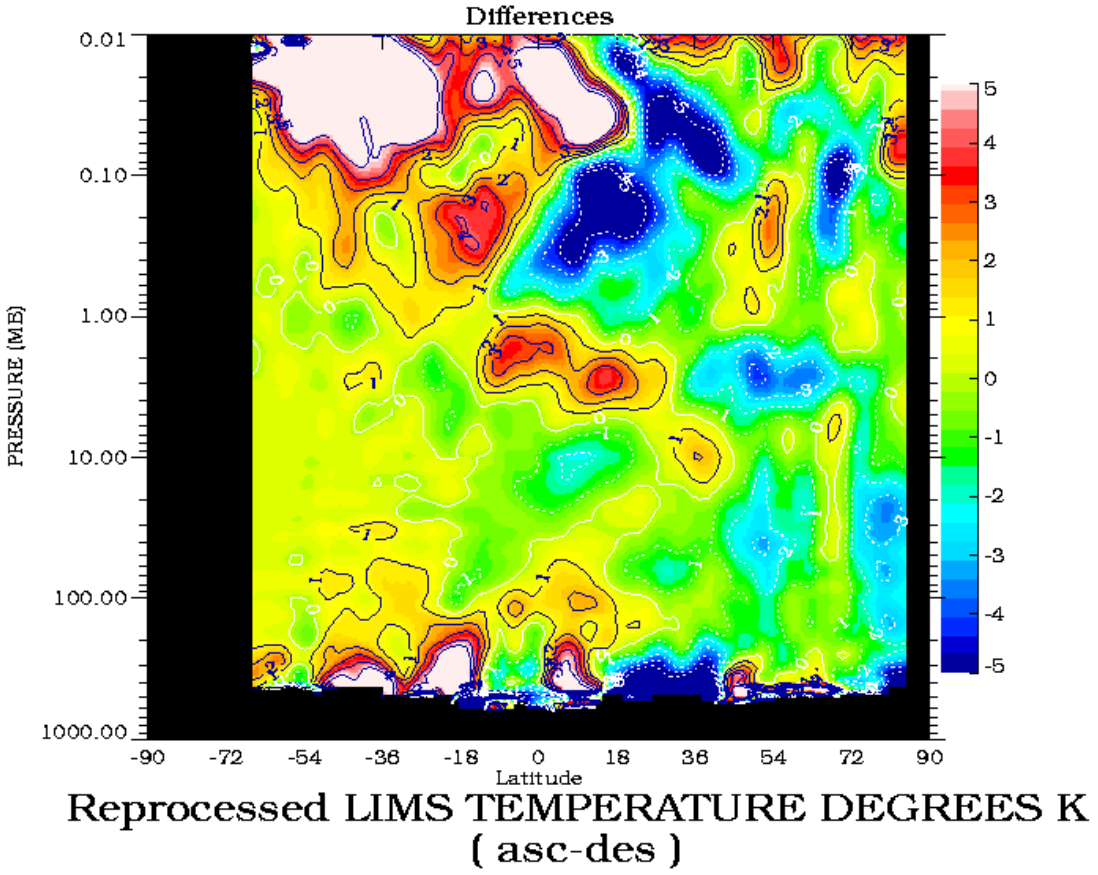

Figure S12—Zonal average of the ascending minus descending orbital temperature differences (in K) from the V6 or 'Reprocessed' LIMS profile data for 26 January.

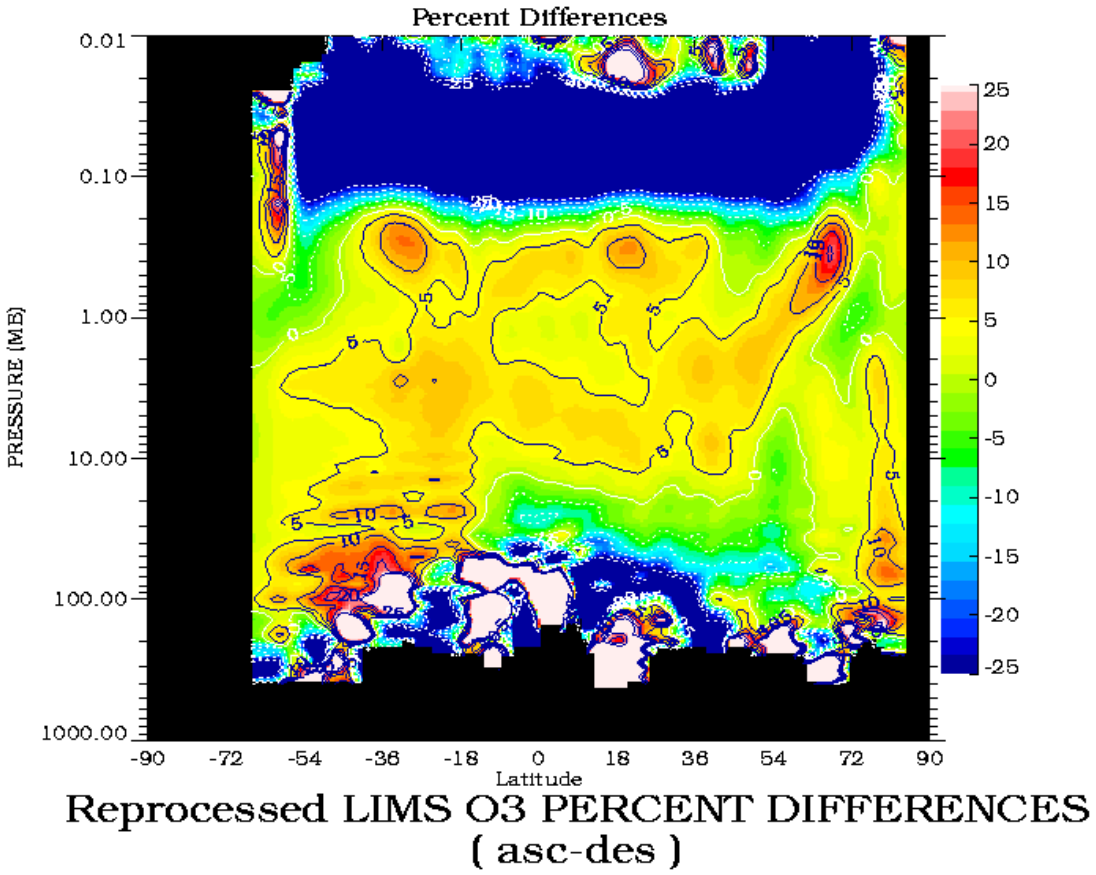

Figure S13—As in Fig. S12, but where the differences are for V6 ozone (in %).

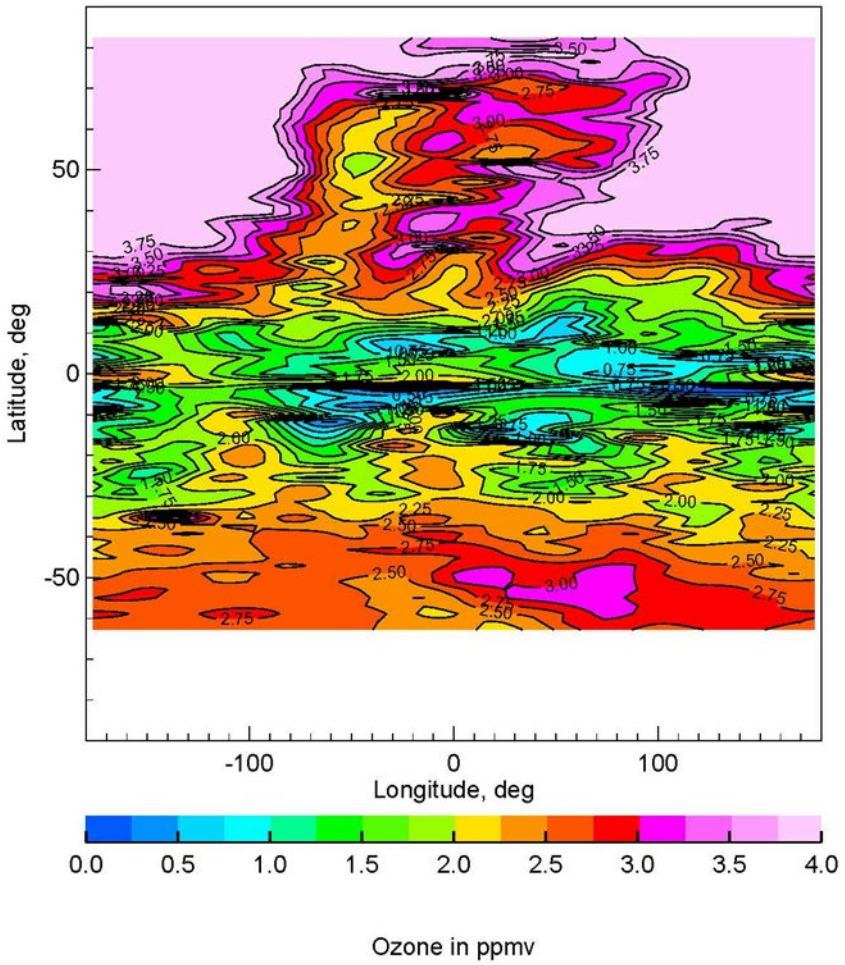

Figure S14—Distribution of V6 ozone on the 46 hPa surface for 26 January 1979.

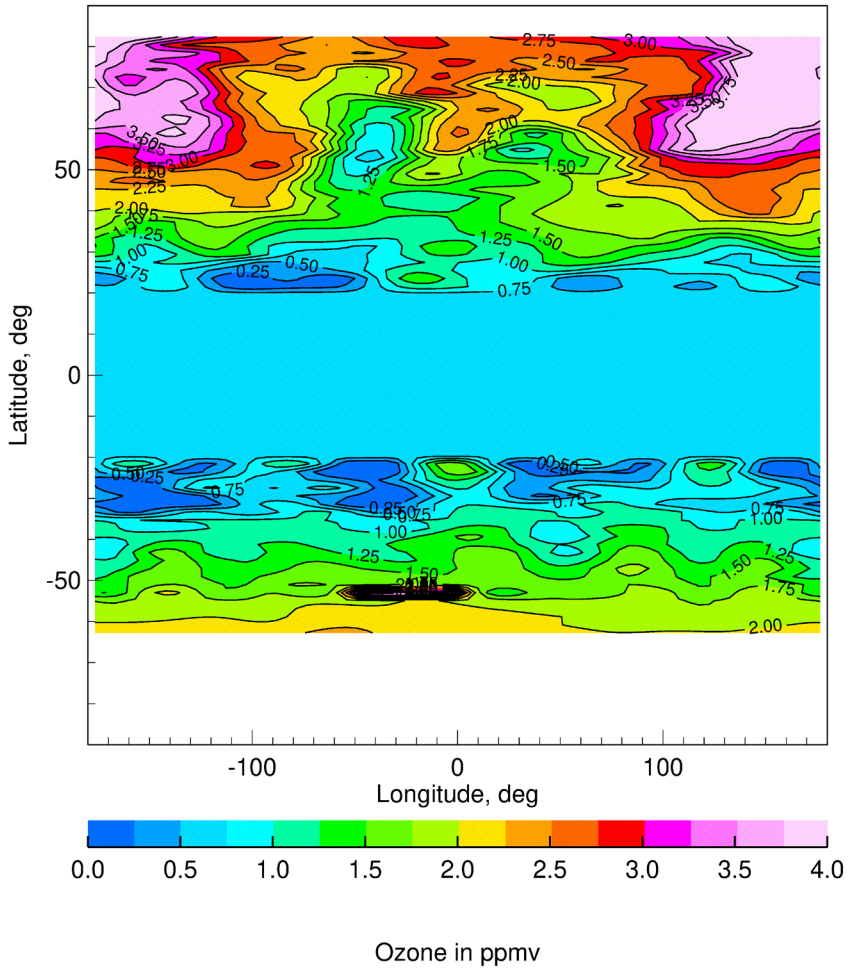

Figure S15—As in Fig. S14, but for ozone on the 68 hPa surface on 26 January 1979. LIMS values have been replaced by zonal mean climatological values in the tropics.

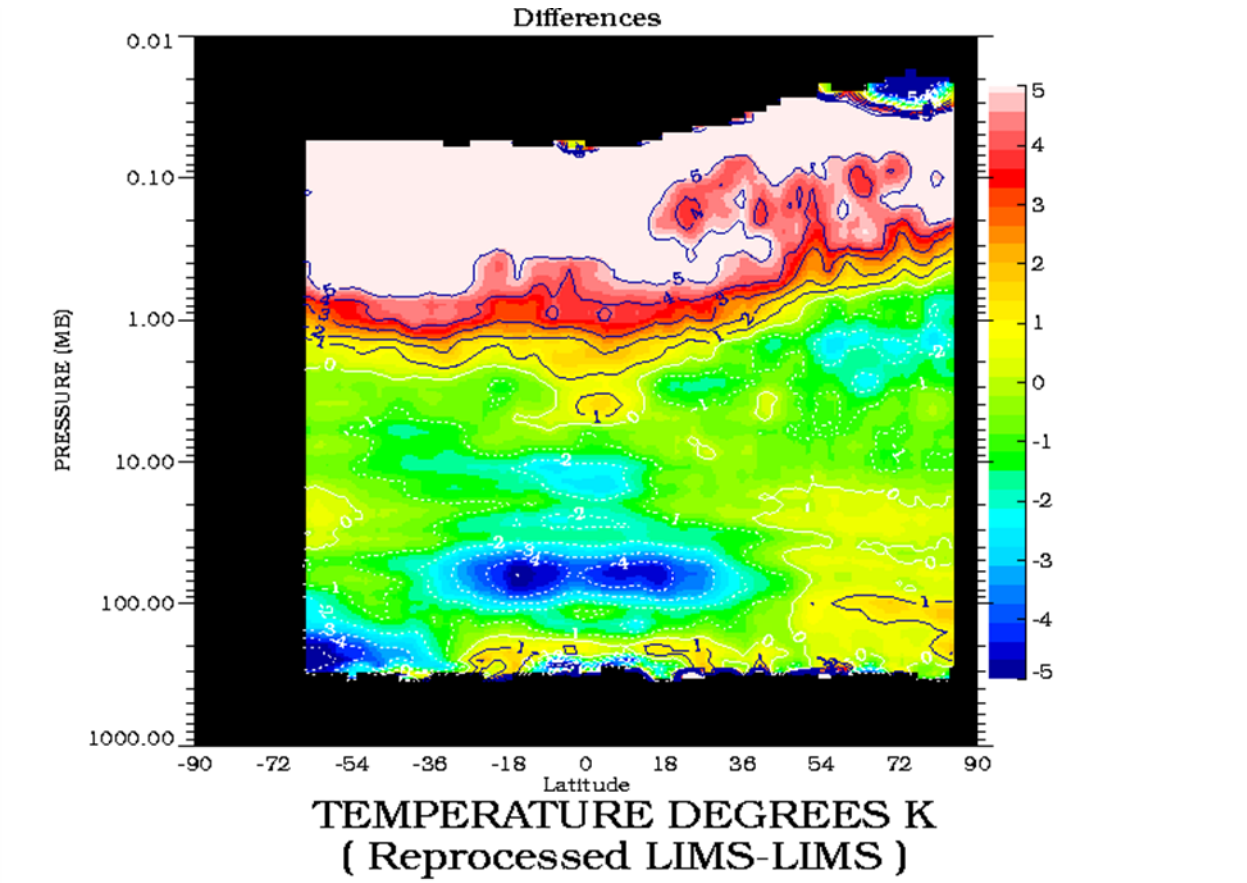

Figure S16—As in Fig. S11, but for 8 November 1978.

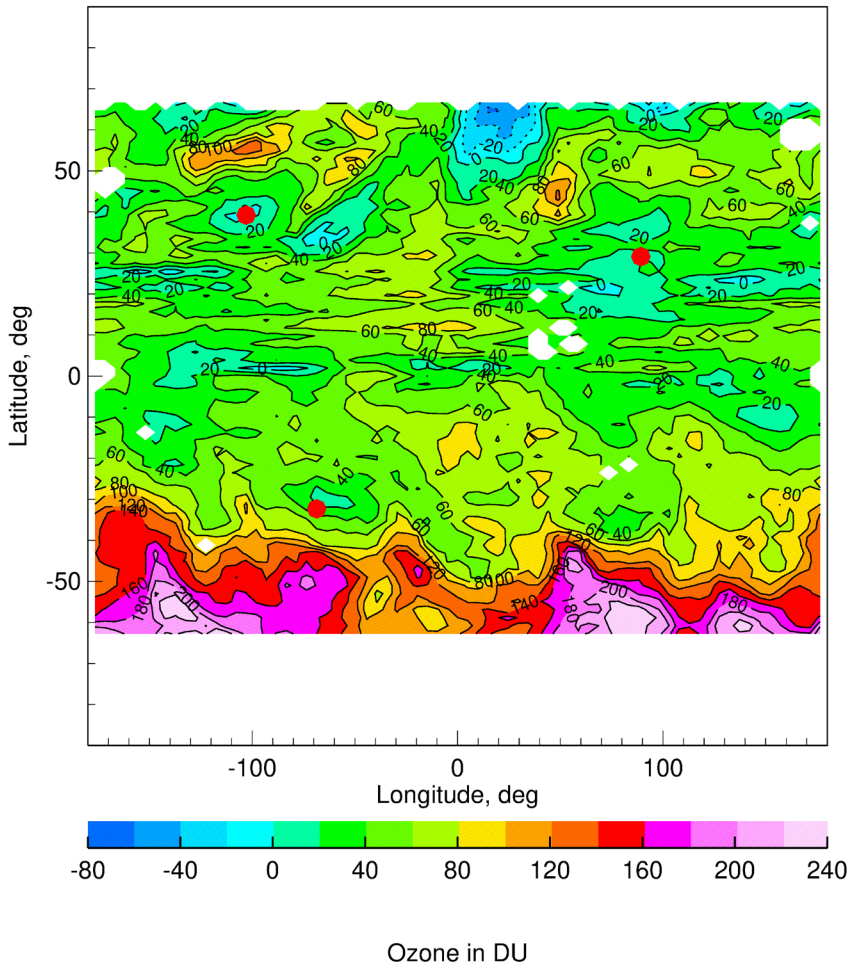

Figure S17—TRCO distribution for 8 November but based on integrating SCO from 147 to 0.68 hPa and for comparison with Figure 12 of the parent manuscript.