Anomalous long-lived trace-gas evolution during the 2019 Antarctic SSW in the Context of the 16-year Aura MLS record

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JPL — NASA — NOAA — CIRES

The Anomalous 2019 Ozone Hole

While the rare southern hemisphere (SH) sudden stratospheric warming (SSW) in early Sep 2019 was considered "minor" because 10 hPa zonal mean zonal winds did not reverse direction, the abrupt drop in zonal wind was as large as that in 2002 during the only "major" SH SSW on record (Fig. 1a–c). This SSW had a profound effect on the 2019 ozone hole (Fig. 1d). Wargan et al (2020) examined these effects in fields from a data assimilation using Aura Microwave Limb Sounder (MLS) constituent measurements, comparing 2019 to 2018 (a fairly typical SH winter).

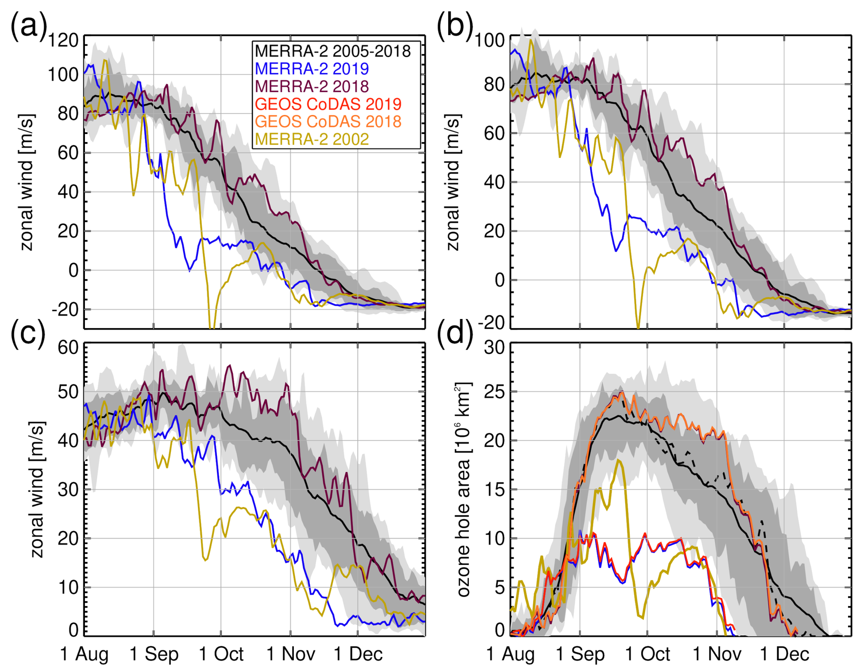

Figure 1: MERRA-2 60°S zonal mean winds in 2018 (dark magenta), 2019 (blue), and 2002 (yellow) at (a, b, and c) 5, 10, and 70 hPa. (d) Mean (solid black) and median (dashed black) ozone hole area from MERRA-2 between 2005 and 2018, ozone hole area from MERRA-2 and GEOS CoDAS for 2018 and 2019, and from MERRA-2 for 2002. Dark and light gray shading shows 60th and 95th percentiles for 2005–2018.

The evolution of vortex-averaged N_2O (Fig. 2) indicates stronger descent in 2019 than in 2018, consistent with higher temperatures arising from the SSW. Ozone mixing ratio contours flattened out earlier in 2019, indicating cessation of chemical loss (Fig. 3). However, before mid-September, ozone decreased faster in 2019 than in 2018. The early vortex breakup in 2019 is also apparent in Figures 2 & 3.

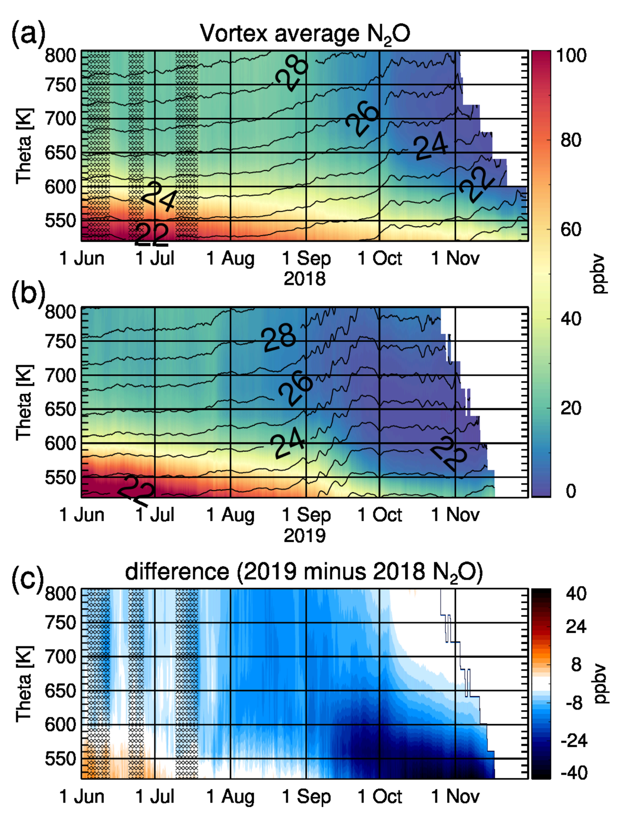

Figure 2: (a) and (b) Vortex-averaged N_2O mixing ratio for 2018 and 2019, respectively; contours show vortex-averaged geopotential height (km). (c) 2019 minus 2018 difference. Periods in 2018 with no MLS data are hatched.

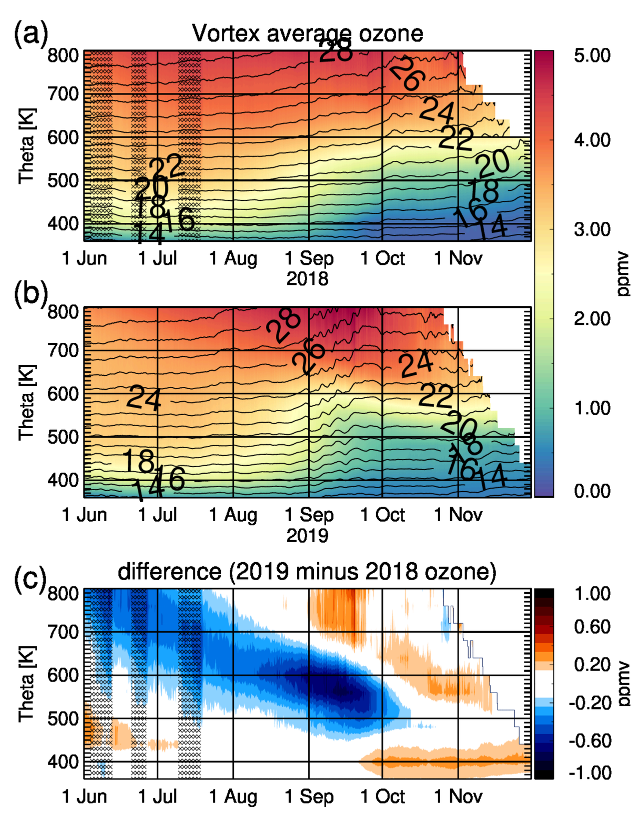

Figure 3: As in Figure 2, but for ozone.

- The ozone hole area in September and October 2019 was 5–10×10^6 km^2, compared to 20–25×10^6 km^2 in 2018.
- Wargan et al (2020) show that a combination of chemistry and diabatic descent resulted in a similar amount of ozone depletion from 360 to 600 K in both years.

Wargan, K, B Weir, GL Manney, SE Cohn, & NJ Livesey, The anomalous 2019 Antarctic ozone hole in the GEOS Constituent Data Assimilation System with MLS observations. *J. Geophys. Res.*, 125, e2020JD033335, https://doi.org/10.1029/2020JD033335

Vortex Variations & Anomalous 2019 Ozone Hole

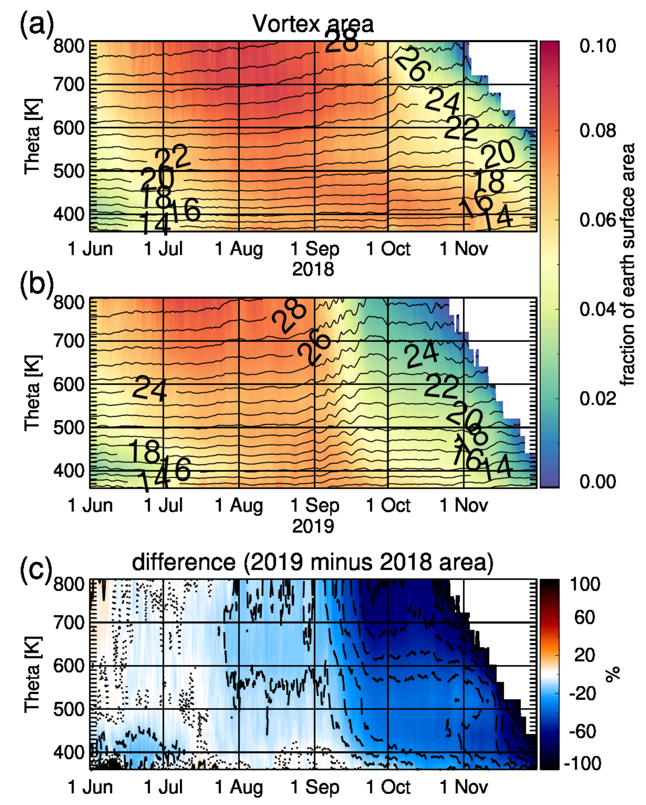

Figure 4: (a, b) Polar vortex area in 2018 and 2019, respectively, with geopotential height contours overlaid. (c) difference between (a) and (b) as a % of the 2018 average; contours are spaced by 10%, dashed lines show negative values.

During the SSW the vortex became exceptionally small, especially above about 600 K, where the area was over 60% less than typical (Fig. 4). Figure 5 shows the vortex tilt with height during the SSW (8 Sep 2019 map) and the location of the ozone hole with respect to the vortex.

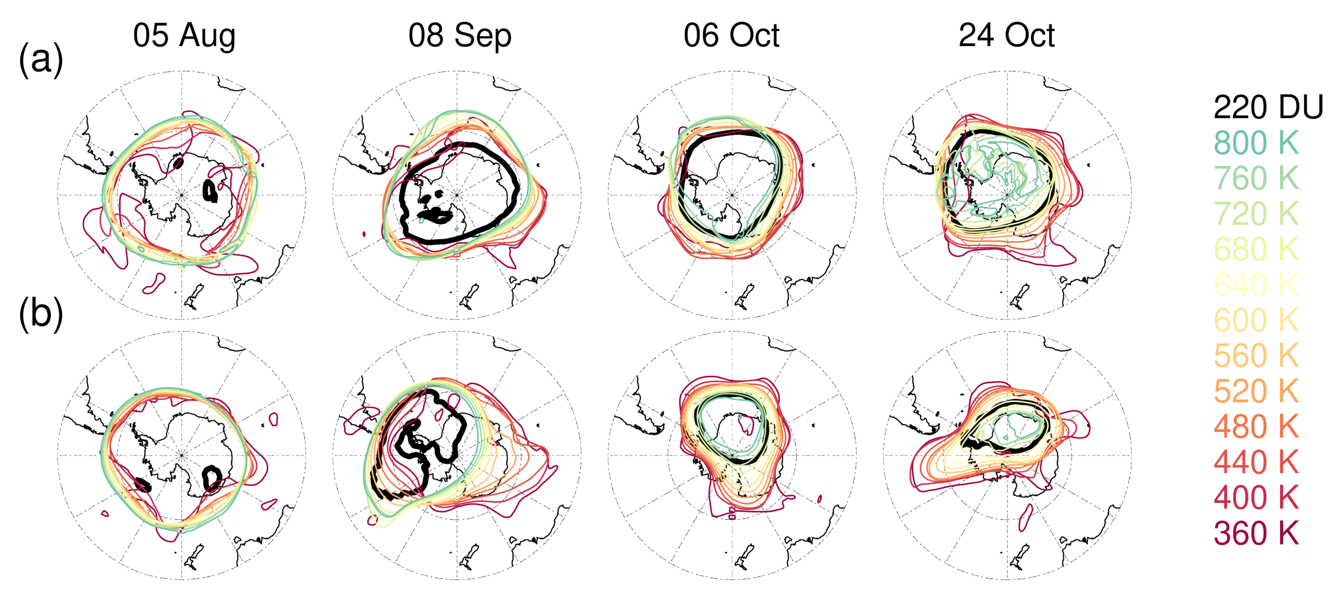

Figure 5: Positions of the polar vortex edges on isentropic surfaces from 360 to 800 K, and the edge of the ozone hole, on 5 Aug, 8 Sep, and 6 & 24 Oct in (a) 2018 and (b) 2019.

Figure 6 details the impact of the atypical vortex evolution on column ozone.

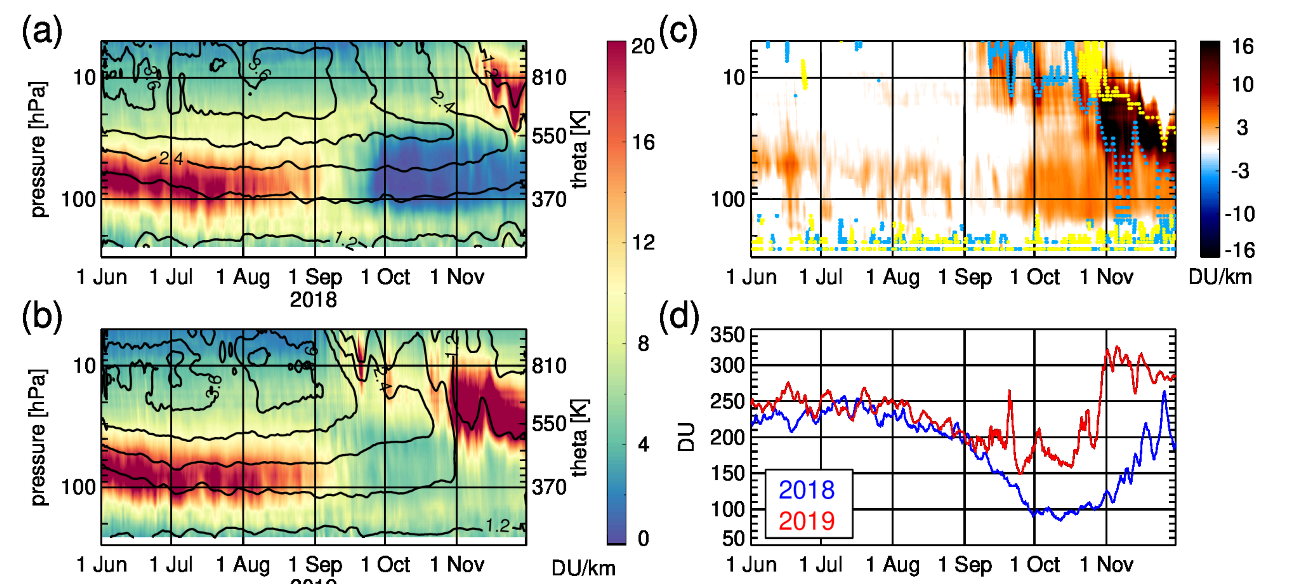

Figure 6: (a and b) 2018 and 2019 time series of 90–85°S ozone profiles in DU per km Contours show the corresponding sPV time series. (c) corresponding 2019−2018 ozone difference. Cyan and yellow dots mark when / where the polar vortex edge passed over the South Pole in 2019 and 2018, respectively. (d) 90–85°S ozone vertically integrated between 300 and 1200 K in 2018 (blue) and 2019 (red).

- Vortex size (smaller in 2019) had a larger effect than chemistry. As a result of chemical depletion together with the differences in the size of the 2019 and 2018 vortices, the cumulative end of October vortex ozone loss in 2019 was 60% of that in 2018.
- Anomalous polar vortex geometry (tilting and shrinking with altitude) accounted for the entire difference in ozone hole area between 2018 and 2019 during the first half of September and over half of the difference afterward.

Results from: Wargan, et al (*J. Geophys. Res.*, 2020)

Aura MLS Climatological (and 2020) Context: Transport & Mixing

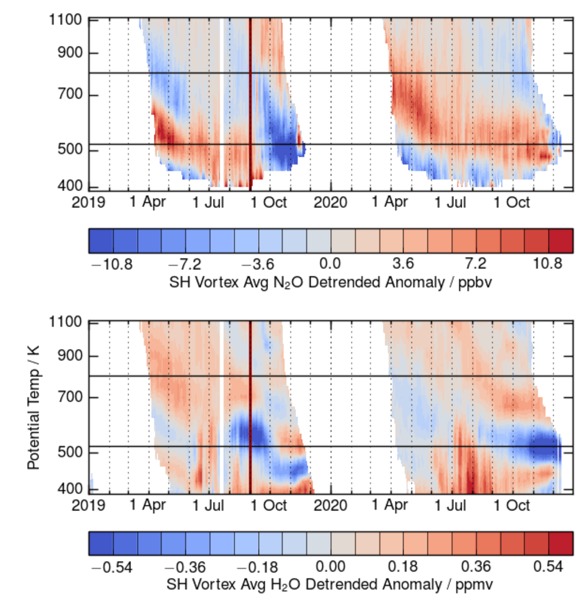

Figure 7: Vortex-averaged MLS Anomalies from climatology for SH winters of 2019 and 2020, (top) N_2O and (bottom) H_2O. Dark red line indicates beginning of SSW in 2019. Horizontal lines are at 520 and 800 K.

Anomalies from the 2005–2020 climatology highlight unusual transport in 2019. We compare here with 2020, which had the most persistent polar vortex in the 16-year Aura record. Vortex-averaged N_2O (Fig. 7 top) decreased suddenly after the SSW because of increased diabatic descent (in contrast, N_2O showed high anomalies in late winter 2020 when there was less diabatic descent). H_2O (Fig. 7 bottom) is affected by both dehydration and descent; higher values near 500 K after the SSW would be expected both from enhanced descent and less dehydration.

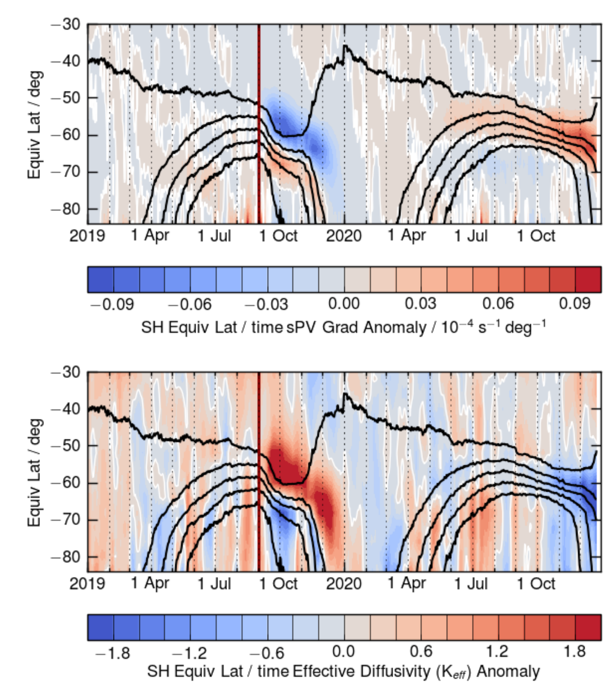

Figure 8: Anomalies from climatology in PV gradients (top) and effective diffusivity (bottom) at 520 K as a function of EqL and time in 2019 and 2020.

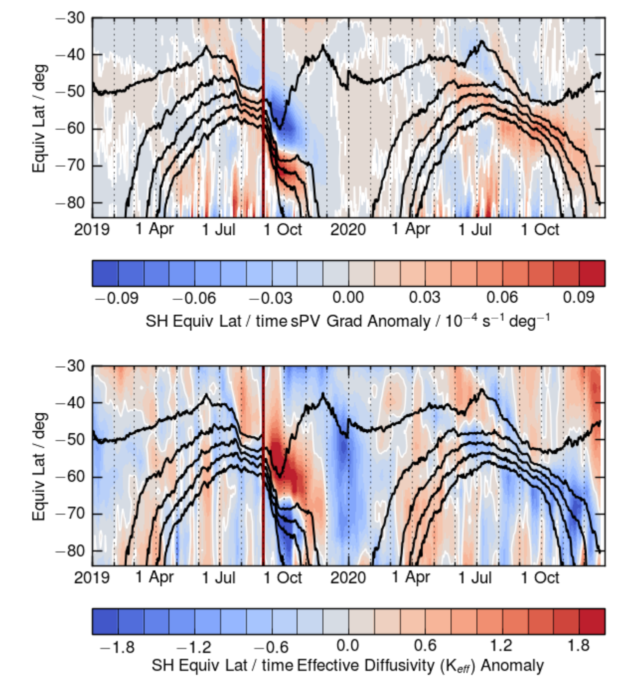

Figure 9: As in Figure 8 but for 800K.

High effective diffusivity (low PV gradient) anomalies (Figs. 8 & 9) after the SSW indicate unusually strong mixing outside the 2019 vortex, because of the unusually small vortex and the "surf-zone" of air drawn up from low latitudes. (Mixing was unusually weak in 2020 because the vortex remained large / quiescent later than usual.) Consistent with this enhanced mixing, MLS N_2O (H_2O at 800 K) (Figures 10 & 11) shows strong high (low) anomalies after the SSW. H_2O evolution at 520 K is more complex since both less dehydration and more mixing contribute.

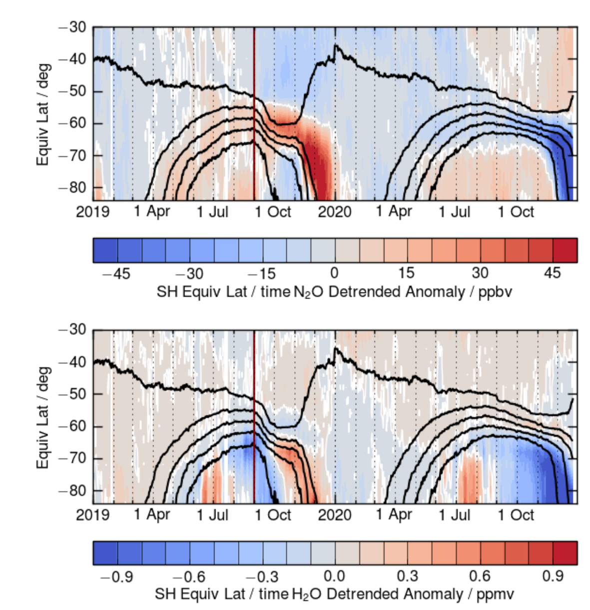

Figure 10: As in Figure 8, but for detrended anomalies in MLS N_2O and H_2O.

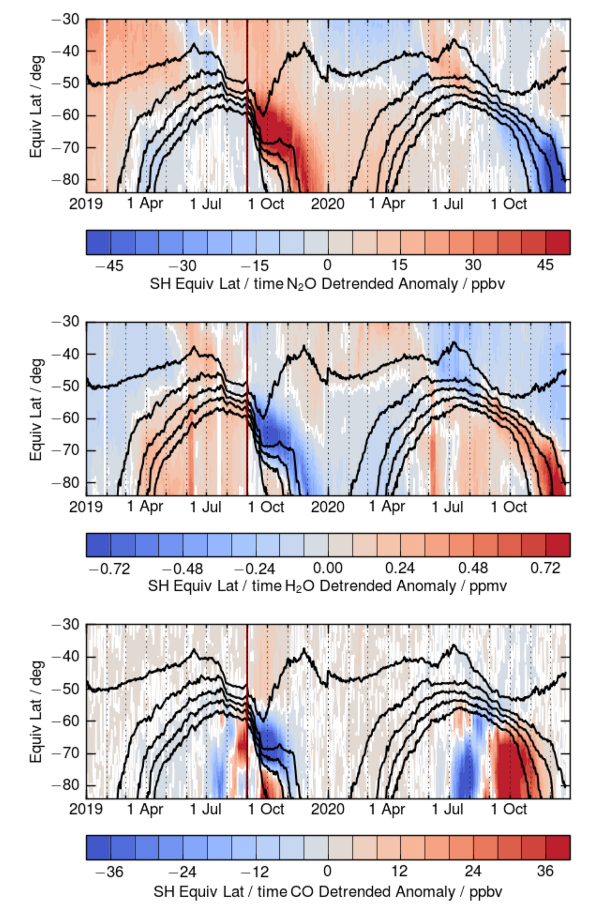

Figure 11: As in Figure 10, but at 800 K, and showing CO in the bottom panel.

In the upper stratosphere and lower mesosphere (USLM), CO is a particularly good tracer of vortex transport. Vortex-averaged CO and CO anomalies (Fig. 12) show the enhanced descent in the middle to lower stratosphere previously mentioned.

In the USLM, large interannual variations lead to both strong high and low anomalies in each winter. Early vortex breakup in 2019 is clearly seen throughout the stratosphere.

Similar to 800K, high effective diffusivity (low PV gradient) anomalies at 1200K(Fig. 13) are seen after the SSW, indicating unusually strong mixing in this region, related to both enhanced mixing out of the vortex, and the fact that EqLs just outside the vortex are typically inside it at that time. As at lower levels, mixing was reduced in 2020 because the vortex persisted later than usual.

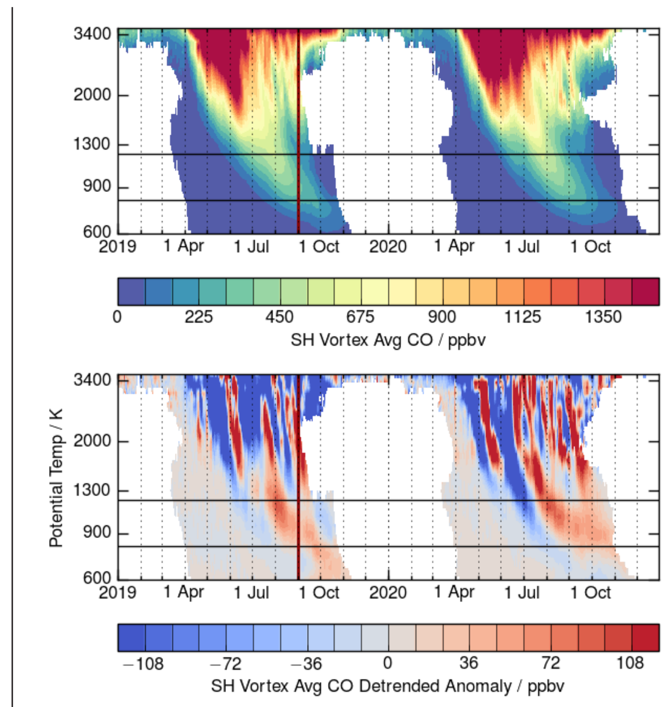

Figure 12: Vortex-averaged MLS CO (top) and CO Anomalies (bottom) from climatology for SH winters of 2019 and 2020, in the middle stratosphere through lower mesosphere. Vertical dark red lines indicate beginning of SSW in 2019. Horizontal lines are at 800 and 1200 K.

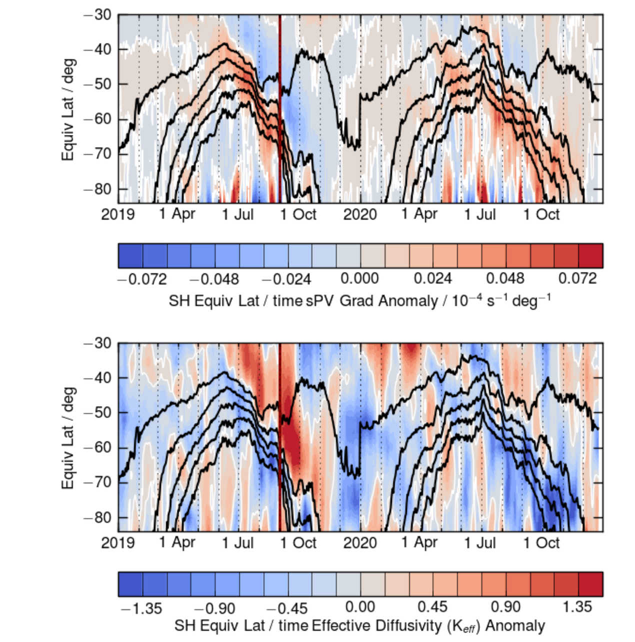

Figure 13: As in Figure 8 but for 1200K.

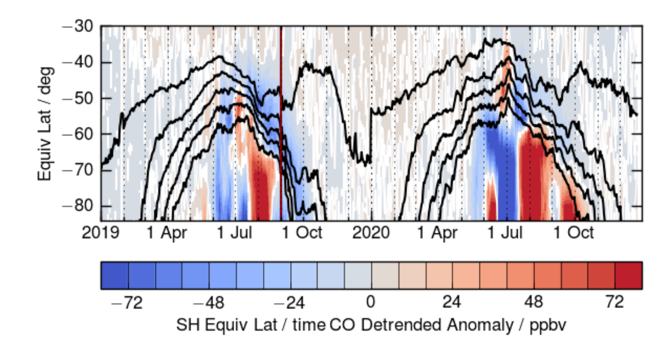

Figure 14: As in Figure 10, but for CO at 1200 K.

Summary / Further Work

The the early September 2019 SH SSW had a profound impact on stratospheric vortex structure and evolution. This anomalous vortex evolution led to, via both dynamical and chemical processes, an ozone hole area around half of that in a typical year and minimum column ozone values over 1.5 times higher than usual.

Preliminary results show the large impact of the unusual vortex structure and early vortex breakup following the SSW on transport throughout the stratosphere and lower mesosphere. Strong mixing in the surf zone outside the vortex edge in 2019 during / following the SSW is contrasted with low anomalies in mixing in 2020 because of the exceptionally persistent polar vortex in that year. The contrast between these two winters emphasizes that, while the SH shows much less interannual variability than the NH, dynamical variability still contributes substantially to stratospheric composition in the Antarctic.

Additional analysis of Antarctic trace gas transport in 2019 and 2020 will provide more quantitative details of the relationships between vortex structure and evolution and anomalous trace gas distributions.

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