**The Anomalous 2019 Ozone Hole**

While the rare southern hemisphere (SH) sudden stratospheric warming (SSW) as early Sep 2019 was considered “minor” because 104°F zonal mean winds did not reverse direction, the abrupt drop in zonal wind was as large as that in 2002 during the only major SH SSW record (Fig. 1a-c). This SSW had a profound effect on the 2019 ozone hole (Fig. 1d). Wargan et al (2020) documented these effects in light of data assimilation using Aura Microwave Limb Sounder (MLS) constituent measurements, comparing 2019 to 2018 (a fairly typical winter).

**Vortex Variations & Anomalous 2019 Ozone Hole**

The evolution of vortex-averaged N\textsubscript{2}O\textsubscript{5} (Fig. 2) indicate stronger descent in 2019 than in 2018, consistent with higher temperatures arising from the SSW. Ozone mixing ratios flattened out earlier in 2019, indicating cessation of chemical loss (Fig. 3). However, before mid-September, ozone decay was faster in 2019 than in 2018. The early vortex breakup in 2019 is also apparent in Figures 2 & 3.

**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.**

**Summary / Further Work**

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

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

**Figure 1:** MEIRA-2.4 km mean winds in 2018 (dark magenta), 2019 (blue), and 2020 (red) at (a), (b), and (c) as a % of the 2018 average; contours show the enhanced descent in the middle stratosphere. Horizontal lines are at 520 and 800 K.

**Table 1:** Anomalies from climatology in PV gradients (top) and effective diffusivity (bottom) at 520 K as a function of EqL in 2019 and 2020.

**Figure 7:** Vortex-averaged MLS Anomalies in PV gradients for SH winters of 2019 and 2020, (top) N\textsubscript{2}O\textsubscript{5} and (bottom) H\textsubscript{2}O. Dark red horizontal lines indicate beginning of SSW in 2019. Horizontal lines are at 520 and 800 K.

**Figure 8:** As in Figure 7 but for CO.

**Figure 9:** As in Figure 8 but for O3.

**Figure 10:** As in Figure 6 but for CO at 1200 K.

**Figure 11:** As in Figure 6 but for CD at 1200 K.

**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 line indicates beginning of SSW in 2019. Horizontal lines are at 600 and 1200 K.

**In the upper stratosphere and lower stratosphere (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 anomalous values lasted for both high and low latitudes.**

**Early vortex breakup in 2019 is clearly seen through out the stratosphere.**

**Similar to 800 K, 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 EqL past the outer vortex are particularly inclined at that time. As at lower levels, mixing was reduced in 2020 because the vortex persisted later than usual.**

**Contact email: manney@nwra.com**