Enhanced transport and mixing of Arctic ozone during SSWs

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Response of Arctic ozone to sudden stratospheric warmings

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Composite of Arctic ozone anomalies

6 SSWs in MLS
23 SSWs in ERAI
152 SSWs in WACCM
The zonal-mean ozone continuity equation

\[
\partial_t \bar{O}_3 = \bar{S}^* - a^{-1} \bar{v}^* \partial_\phi \bar{O}_3 - \bar{Q}^* \partial_\theta \bar{O}_3 + \bar{\sigma}_\theta^{-1} \left[ (a \cos \phi)^{-1} \partial_\phi \left( M_\phi \cos \phi \right) + \partial_\theta M_\theta \right]
\]

\begin{align*}
\text{Zonal-mean ozone tendency} &= \text{Chemical production minus loss} + \text{Mean advection} + \text{Eddy transport} \\
M = (0, M_\phi, M_\theta) &= (0, -\bar{\sigma}_\theta v O_3^I, -\bar{\sigma}_\theta Q O_3^I)
\end{align*}
What drives the ozone changes during SSWs?

70°-90°N [ppbv / day]

O3 tendency during the onset of SSWs is dominated by isentropic eddy transport.

In the aftermath of SSWs, reduced isentropic advection (↓wave activity) and vertical advection contribute to O3 recovery, with chemical tendency partially counteracting in upper levels.
Irreversible mixing of ozone

\[ \partial_t O_3,\phi_e = -a^{-1} \partial_{\phi_e} \left[ \kappa_e^{\text{eff}} \left( a \cdot \cos \phi_e \right)^{-1} \partial_{\phi_e} \left( \cos \phi_e \cdot O_3,\phi_e \right) \right] + \text{(diabatic and chemical terms)} \]

Mixing-induced O3 tendency

**Eddy transport of ozone (polar cap)**

Although zonal-mean isentropic eddy transport is often referred to as mixing, the initial increase in isentropic eddy transport has a strong reversible component.
Arctic ozone and PJO sudden warmings

- Ozone anomalies during PJO-SSWs (left column) persist much longer after SSWs than non-PJO-SSW (right column).

- Anomalies appear later in equivalent latitude (EqL) than in geographical, which confirms that the initial increase in Arctic ozone over the pole has a strong reversible component (→ the vortex changing shape and position right before SSWs).

PJO (polar night-jet oscillation) sudden warmings are deep SSWs whose temperature and wind anomalies reach the lower stratosphere, where they persist longer than non-PJO SSWs (Hitchcock et al 2013).
Long-lasting total column anomalies of ozone during and after SSWs!
Conclusions

Isentropic eddy transport of O3 (reversible process)

Competing effects of vertical advection and isentropic irreversible mixing

The chemical O3 tendencies simulated in WACCM tend to counteract the dynamically induced changes of ozone

SSW that occur during PJO events (sufficiently deep SSWs) have a stronger and more persistent response of ozone (details in the paper).

REFERENCES:

- de la Cámara, Abalos, Hitchcock (2018 JGR) Changes in stratospheric transport and mixing during SSWs
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