The Effects of Ozone Chemistry on Winter Climate

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Land Acknowledgment: Lenni-Lenape

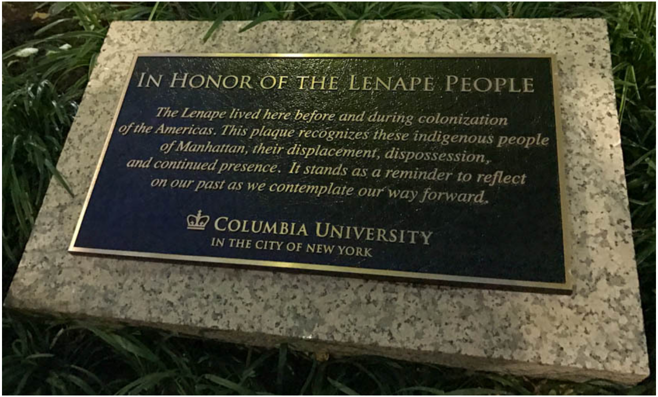

Figure: Picture by Xavier Wade for the Spectator

Why this kind of study?

We compare results from two otherwise identical models, one including a known physical process and the other not.

- Understanding relationships between different phenomena
  Ozone chemistry and extreme states of the stratospheric polar vortex
- How much does the process matter to forecasts?
  Ozone chemistry is **not** included in most models used for forecasting
- Fidelity to real system vs. computational expense

Stratospheric Polar Vortex

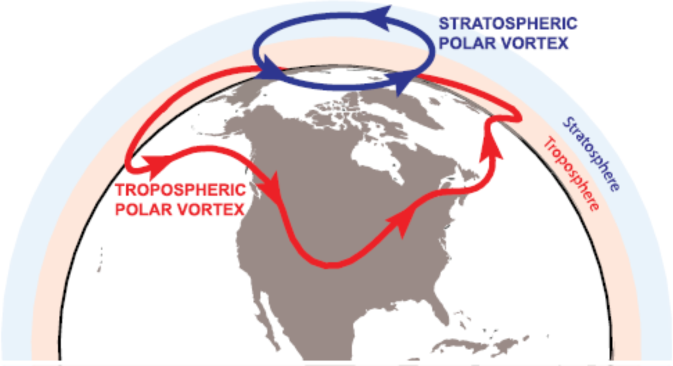

Figure: From Waugh, Sobel, Polvani 2017.

Stratospheric Polar Vortex

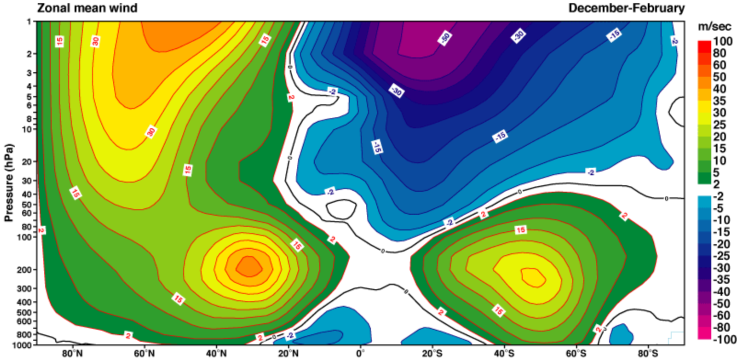

Figure: Mean east/west winds (U) averaged around latitude circles in December-February. Positive is west-to-east. Plot and data from ECMWF.

Extreme Stratospheric Events

Sudden stratospheric warming (SSW): U at 10 hPa 60° N are east-to-west.
Strong polar vortex (SPV): U at 10 hPa 60° N is west-to-east and at least 48 m/s.

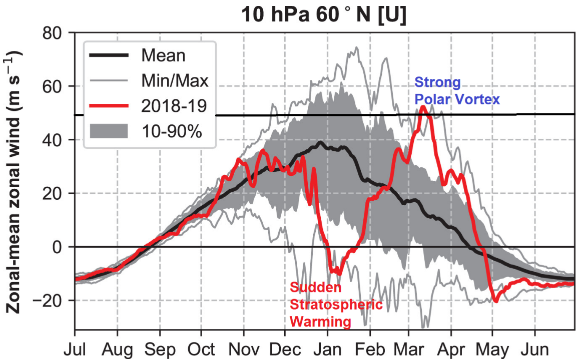

Figure: 2018-19 east/west wind at 10 hPa and 60° N. Plot modified from Butler and Lee 2019.

Surface Effects of SSWs and SPVs

SSW: typically followed by negative phase of North Atlantic Oscillation (NAO)
SPV: typically followed by positive phase of NAO

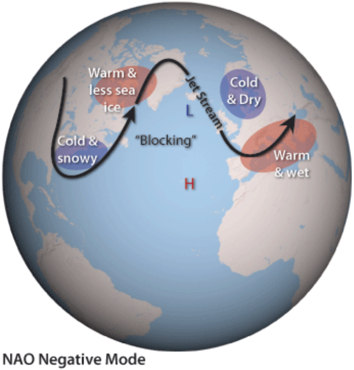

Figure: NAO negative and positive modes. Figure from NOAA.

Ozone Formation and Transport

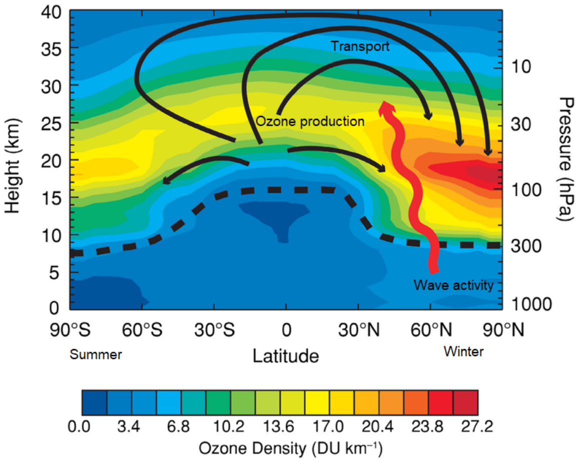

Figure: Northern Hemisphere winter ozone density and transport. Modified from Metz et al. 2005.

Ozone and SSWs/SPVs

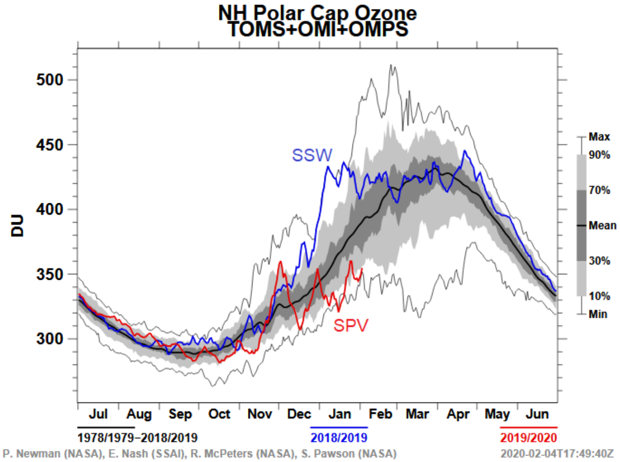

Figure: Northern Hemisphere polar cap total column ozone in climatology, 2018-19, and 2019-20. Figure from NASA OzoneWatch.

Interactive vs. Specified Climate Models

- Interactive chemistry: computes formation, destruction, transport.
- Specified chemistry models use given concentrations of constituents like ozone instead.
- Haase and Matthes 2019: interactive chemistry model has a stronger vortex, fewer SSWs, stronger SSWs.

Approach

- 200-year model integrations with same conditions in interactive (CHEM) and specified chemistry (NOCHEM) versions of one climate model (WACCM)
- Compare mean state of stratospheric polar vortex in two integrations
- Identify extreme stratospheric events in both runs
- Compare development of and response to SSWs and SPVs in CHEM and NOCHEM model versions

Climatological differences in CHEM and NOCHEM

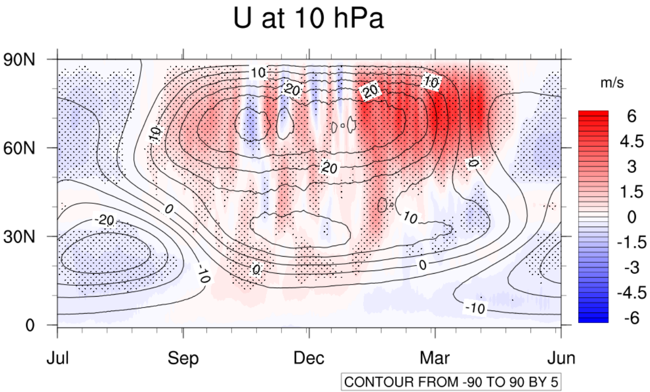

Figure: East/west wind averaged around latitude circles at 10 hPa from July to June. Color shows CHEM-NOCHEM difference. Contours show NOCHEM state.

SSW and SPV Frequency

	2000 NOCHEM	2000 CHEM
Total Winters	200	200
Dec-Feb SSW events	75	67
Dec-Feb SPV events	58	74

Table: Summary of sudden stratospheric warming (SSW) and strong polar vortex (SPV) events in CHEM and NOCHEM.

Surface Response to December-February SSWs

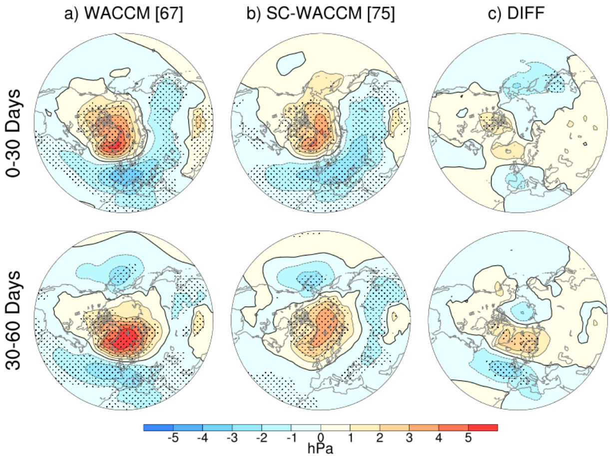

Figure: Sea level pressure anomalies following December-February SSWs in CHEM and NOCHEM.

Ozone Response to December-February SSWs

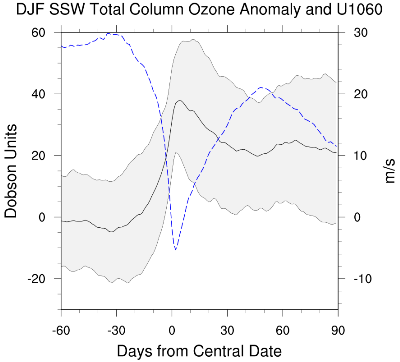

Figure: Ozone (black, one standard deviation in gray) and average east/west wind at 10 hPa and 60° N (blue) at lags -60 to +90 days around SSW central date.

Surface Response to December-February SPVs

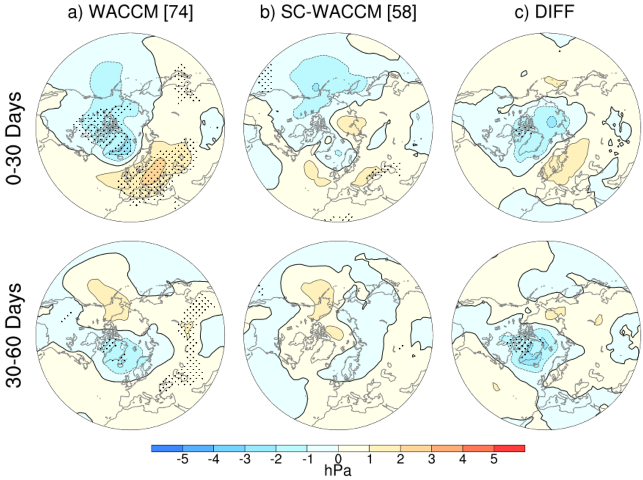

Figure: Sea level pressure anomalies following December-February SPVs in CHEM and NOCHEM.

Conclusions

- Interactive ozone chemistry leads to a stronger and longer-lasting polar vortex in the model.
- More SPVs with interactive chemistry. Fewer SSWs, but not significant.
- SSWs are stronger and have a larger, longer surface effect with interactive chemistry.
- Little difference in surface effects of midwinter SPVs.