Stronger Response to Ozone Depletion Simulated in Models with Interactive Ozone

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Summary

Represeting the stratospheric ozone depletion is crucial for simulating the climate changes in the historical period.[1] Yet, most climate models do not embody the full interaction between ozone and the climate system and prescribe monthly mean ozone concentration instead. A few studies [2-4] have shown that models with interactive ozone schemes produce stronger response to ozone depletion than the models prescribing ozone, and the difference is usually attributed to the amount of ozone changes. Here, we investigate the effect of different ozone schemes in GFDL AM4 model. We compared the simulations prescribing monthly zonal mean ozone against those with either full ozone chemistry or simplified linear chemistry. While the changes in the ozone concentration are almost identical among the three simulations, stronger stratospheric cooling are seen in those with interactive ozone compared to the prescribed one. The temperature difference does not arise from ozone's radiative effects, but from the dynamical response to ozone depletion. The wave-driven stratospheric overturning circulation strengthens in response to ozone depletion, leading to a dynamical heating in the polar region that partly compensates the radiative cooling. With interactive ozone, the covariance between ozone and temperature variations leads to a weaker radiative damping of the waves, as the SW heating of ozone compensates the LW cooling. This then leads to weaker changes in the circulation, weaker dynamical heating in the polar lower stratosphere, and hence stronger net cooling.

Model and Experiments

GFDL AM4: 63 levels with model top at 1 Pa.

Time-slice simulations: 70 years of 2010-climo simulations with ozone at the year 2010 level or the 1960 level.

Ozone treatment:

CNTL prescribe monthly zonal mean ozone from FullChem.

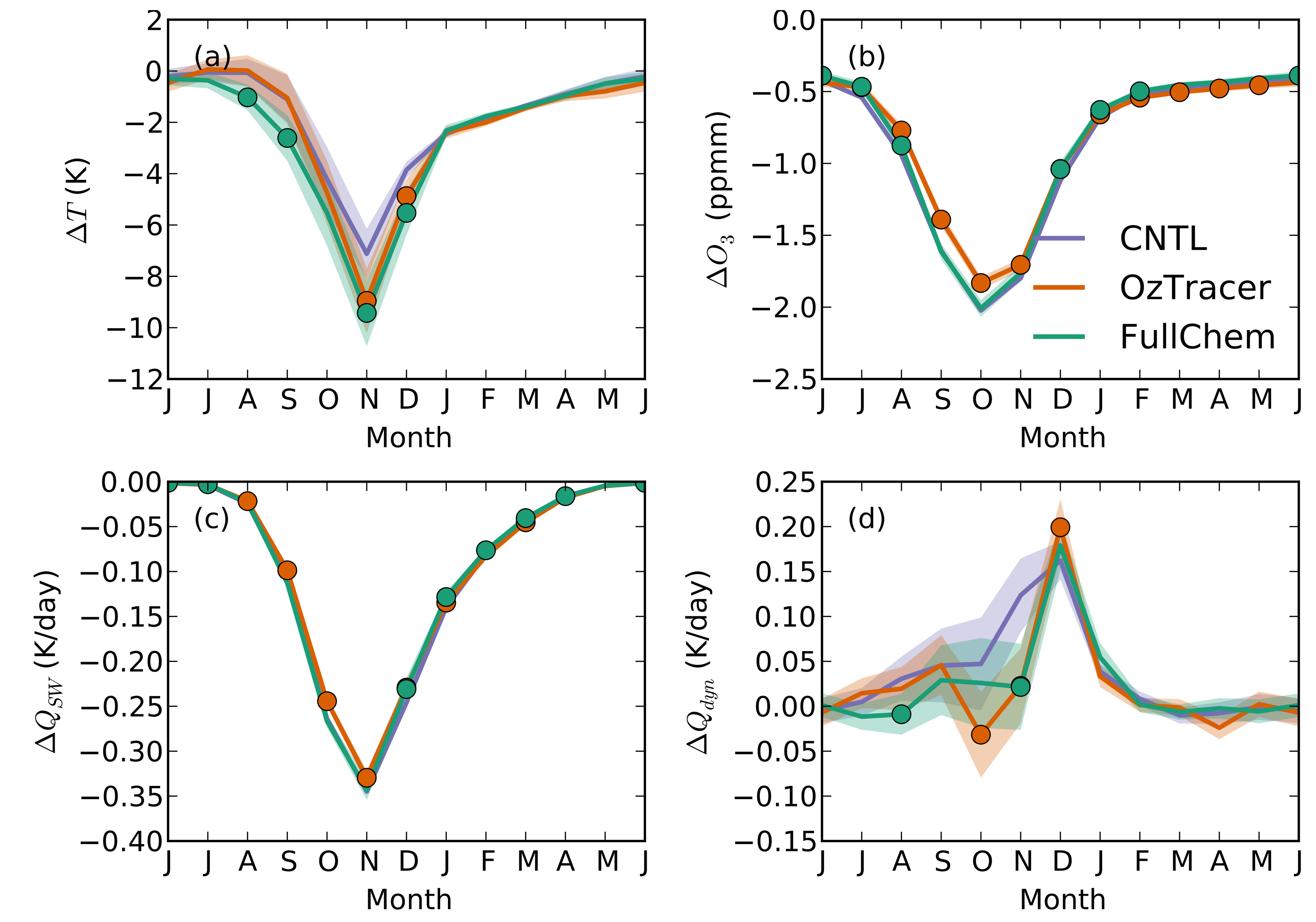
FullChem prognostic ozone produced by a fully interactive stratospheric and tropospheric chemistry scheme.

OzTracer The dynamical tendency remains prognostic, and t he chemical tendency is replaced by:

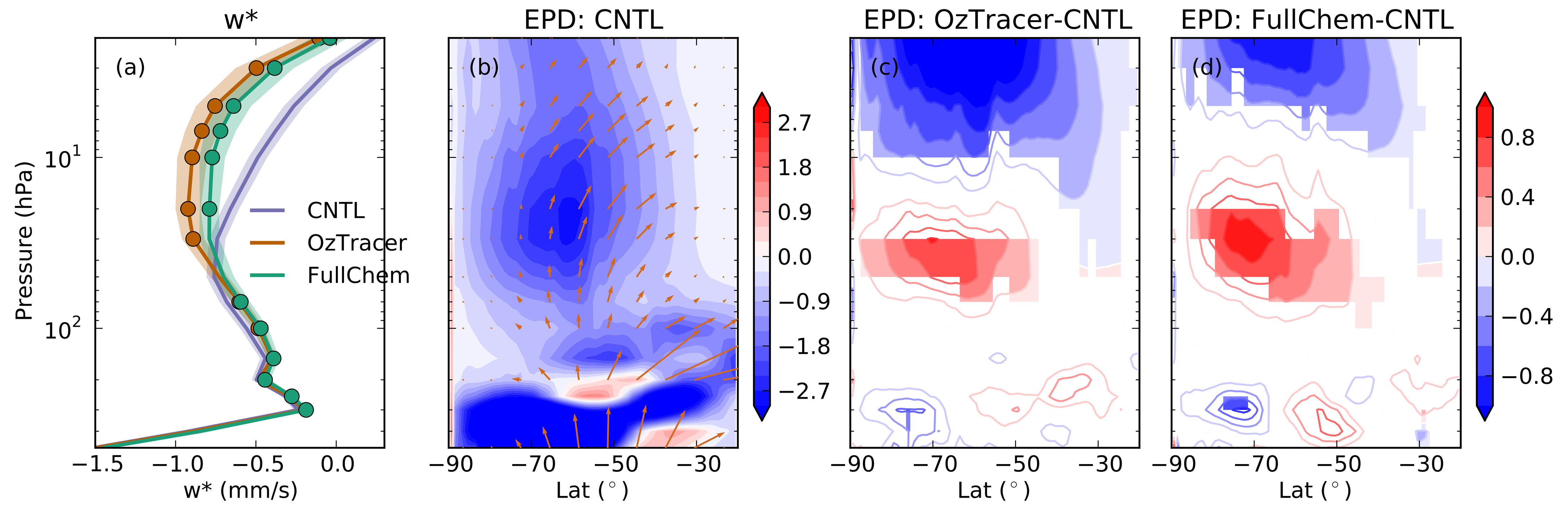
$$\left.\frac{\partial[O3]}{\partial t}\right|_{chem} = P - \frac{[O3]}{\tau}$$

where production rate P and life time τ are prescribed as monthly zonal mean from FullChem.

Dynamics Leads to Stronger Cooling in Models with Interactive Ozone

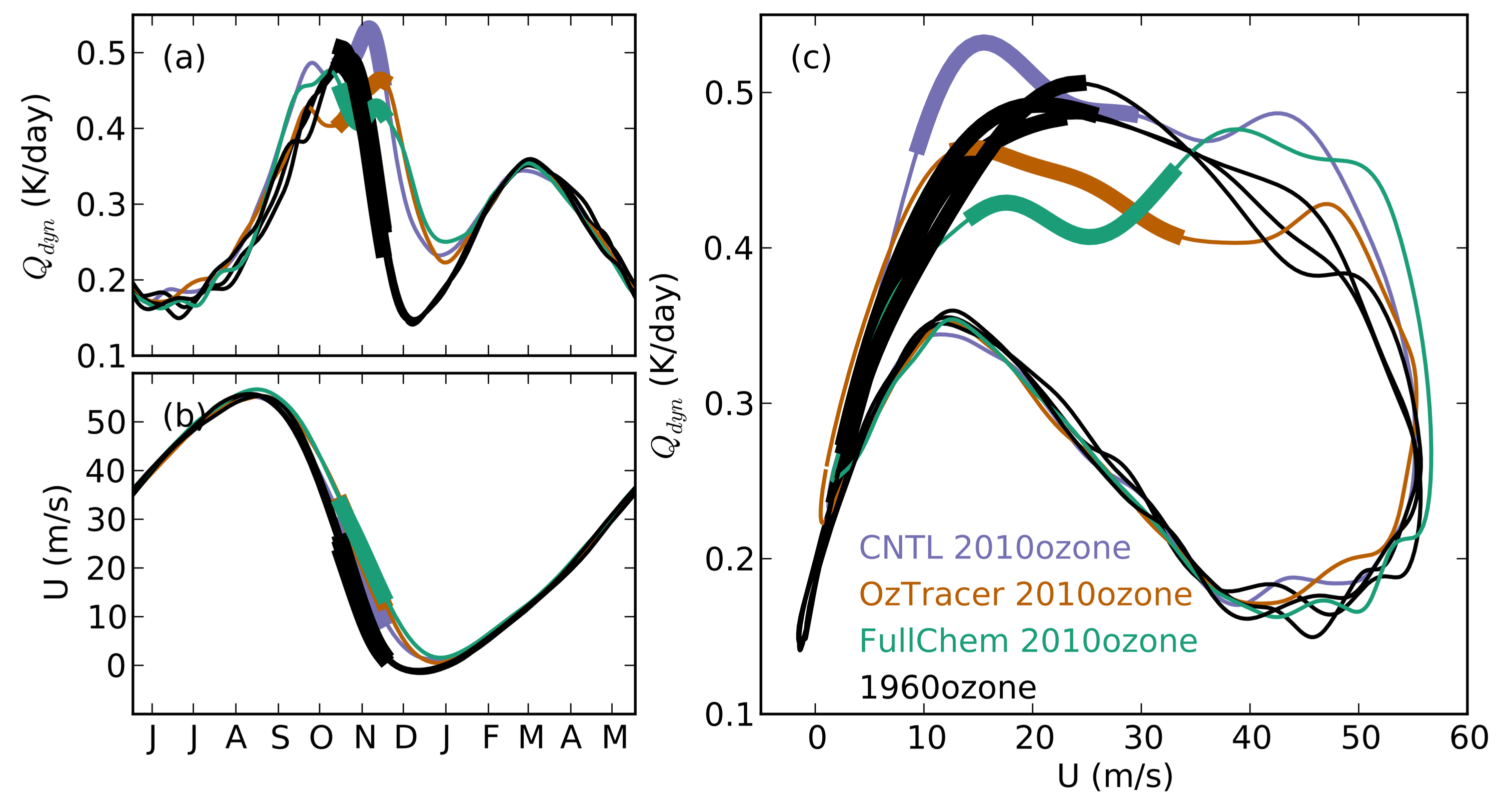


←Climatology difference between the 2010ozone and 1960 simulations for (a) temperature, (b) ozone concentration, (c) shortwave heating rates, and (d) dynamical heating rates. All variables are averaged over 60°S-90°S at 100 hPa. Shading indicates the 95% confidence interval. Circles marks the value that is significantly different from the CNTL simulation at the 95% confidence level. Both OzTracer and FullChem simulate significant stronger cooling than CNTL in Nov and Dec, which is driven by the difference in the dynamical heating rates instead of the radiative heating rates.



↑ Comparison of dynamics in Nov among the three 2010ozone simulations. (a) w* over 60°S-90°S; (b) EP flux and its divergence from CNTL; (c) EP flux divergence OzTracer-CNTL; (d) EP flux divergence FullChem-CNTL.

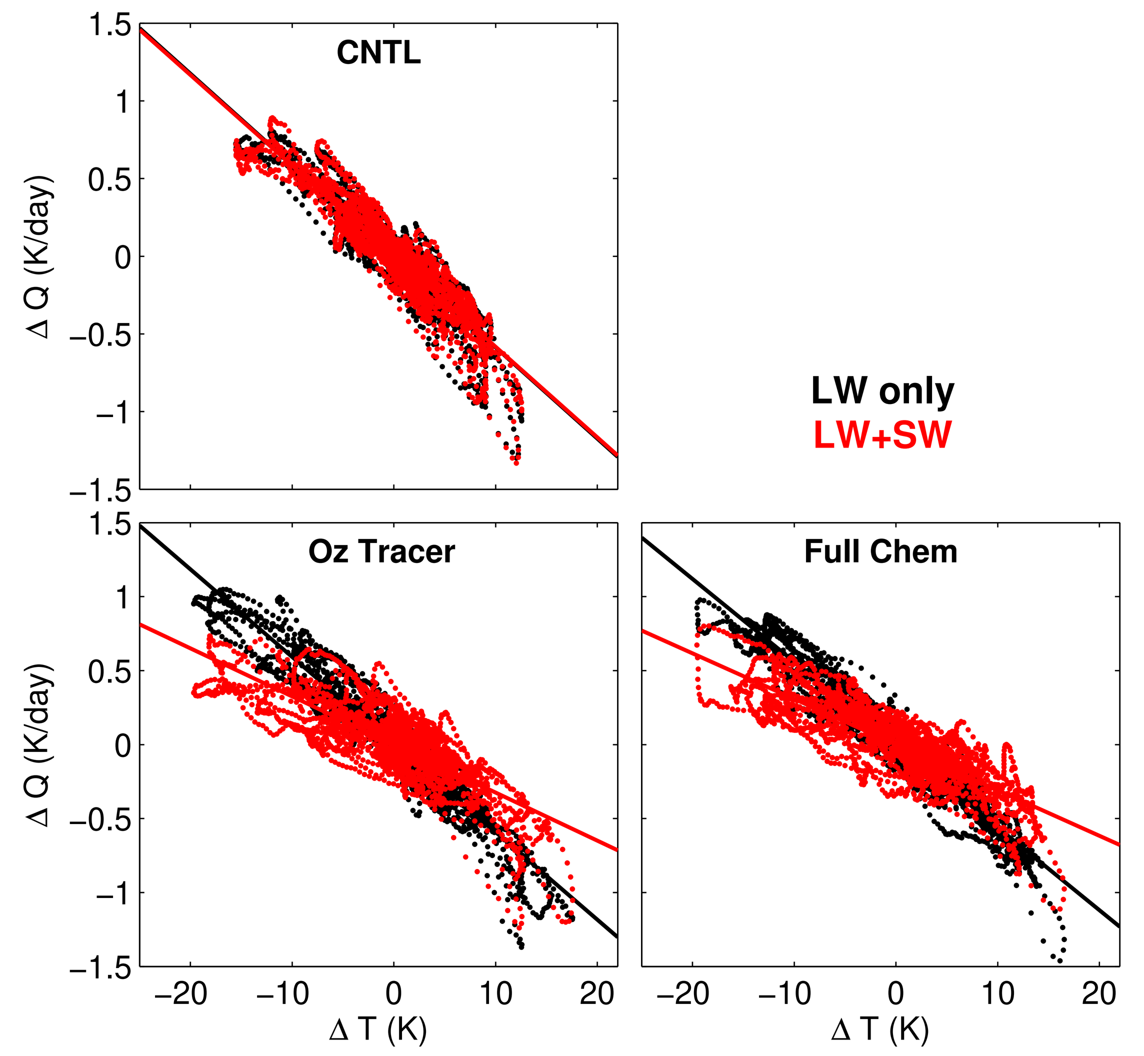
Zonal Wind Does Not Explain the Difference in Dynamical Heating Rates



← Seasonal cycle of the dynamical heating rates over 60°S-90°S at 100 hPa and the strength of the polar night jet (zonal wind at 60°S 50 hPa). The month Nov is highlighted by the thicker lines. Both too-strong and too-weak jets prohibit wave propagation, and therefore leads to weaker wave-driven circulation and weaker dynamical heating. However, FullChem and OzTracer show weaker dynamical heating than CNTL under the similar wind condition.

Radiative Damping of the Waves

Radiative damping is the main mechanism how wave dissipation occurs in the lower stratosphere. The strength of the radiative damping hence affect the strength of the wave-driven circulation and the dynamical heating at the polar lower stratosphere. The absorption of shortwave radiation of ozone leads to a weaker radiative damping. Prescribing ozone ignores the covariance between ozone and temperature, and therefore overestimate the radiative damping strength and the dynamical heating.



↑ Scatter plot of the radiative heating rate anomalies against temperature anomalies at 60°S and 50 hPa. The anomalies are calculated using the daily mean with climatological mean seasonal cycle and zonal mean removed. The strength of the radiative damping can be inferred from the slope.

References

[1] Solomon, S., et al., 1999, *Rev. Geophys.*, 37, 275-316.
[2] Gillett, N. P., et al., 2009, *GRL*, 36, L10809.
[3] Neely, R. R., III, et al., 2014, *GRL*, 41, 8602-8610.
[4] Li, F., et al., 2016, *J. Clim.*, 29, 3199-3218.

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