M12 #845

Stratospheric ozone feedbacks under global warming in ICON

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Motivation

Comprehensive Earth system models now include more processes than ever. However, atmospheric chemistry is still computationally expensive and hence, is often neglected in Earth system models. E.g. Nowack et al. (2014) and Marsh et al. (2016) simulated large changes in in ozone in the tropical tropopause layer as a response to increasing CO2. However, their results regarding the equilibrium climate sensitivity (ECS) are inconclusive.

To analyze the impact of stratospheric ozone feedbacks on ECS, we use a linearized ozone scheme. This enables us to evaluate ozone feedbacks in long simulations with high resolution but minimizes the computational costs. As a first step, we compare the linearized ozone scheme to CMIP5 climatology and satellite data.

Conclusion

We found that the ozone profiles from the linearized Cariolle scheme agrees with the CMIP6 climatology. But overestimates the ozone values in the mesosphere compared to CMIP5, which leads to too high temperatures in the mesosphere. A too strong stratospheric circulation causes a steeper latitudinal gradient of total ozone column.

Overall, the linearized Cariolle ozone scheme calculates ozone distributions which are in the range of the CMIP climatologies. The response to global warming of the Cariolle scheme agrees with the response of full chemistry models. We plan to compare the linearized ozone scheme to a full chemistry model to evaluate the utility of the Cariolle scheme for long climate simulations.

1. Climate Sensitivity may change with Interactive Chemistry

- Chemical feedbacks induced by a change in the radiative forcing may alter the equilibrium climate sensitivity (ECS) and the atmospheric circulation.
- Nowack et al. (2014) and Marsh at al. (2016) found quantitatively similar changes in tropical ozone, when interactive chemistry was included in their models. But they differ in upper tropical tropospheric water vapor changes.
- Nowack et al. (2014) showed a 1 K decrease in ECS with interactive ozone, Marsh et al. (2016) found no change in ECS.

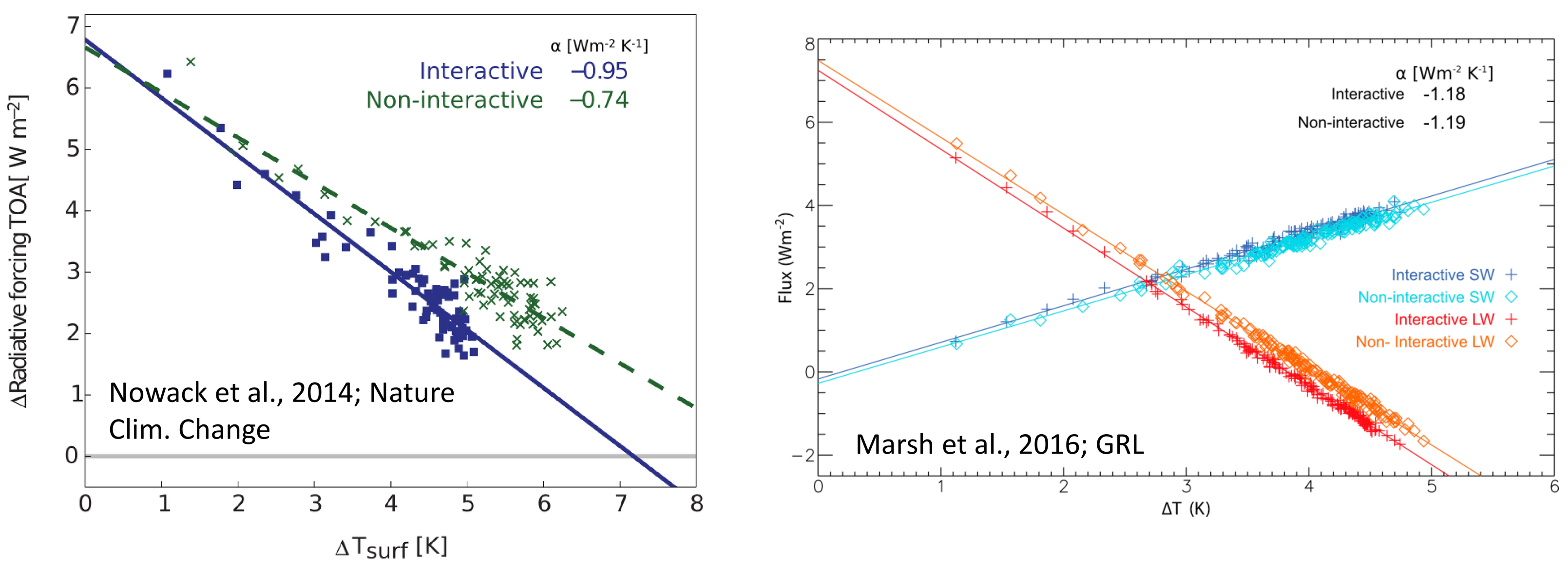

Fig 1.: Gregory regression plot for abrupt 4xCO_2 for (left) all radiative component for an experiment with interactive chemistry (blue) and an experiment with prescribed pre-industrial chemically and radiatively active gases (green) and (right) for shortwave and longwave component for an experiment with interactive chemistry (blue/cyan) and an experiment with prescribed pre-industrial chemically and radiatively active gases (red/orange).

2. Experimental Design

- Climate model ICON (Zängl et al. 2015) – R2B04 (~T63) L47.
- Two historical AMIP run with 30 model years (1979-2009).
  - Control experiment with CMIP5 ozone climatology.
  - One Experiment with linearized Cariolle ozone scheme:

$$\frac{dX_{O_3}}{dt} = A_1 + A_2(X_{O_3} - A_3) + A_4(T - A_5) + A_6\left(\int_0^p X_{O_3}(p)dp - A_7\right) + A_8 X_{O_3}$$

A_1: Net production rate; A_2: dA_1/dX_{O_3}; A_3: Climatological ozone volume mixing ratio

A_4: dA_1/dT; A_5: Temperature; A_6: $dA_1/d(\int_0^p A_3(p)dp)$

A_7: $\int_0^p A_3(p)dp$; A_8: Heterogeneous chemistry term

3. Cariolle Ozone agrees with CMIP6

- Good agreement between Cariolle ozone profile and CMIP6 climatology (Hegglin et al. 2017, in preparation), but the maximum is too small in the Cariolle scheme.

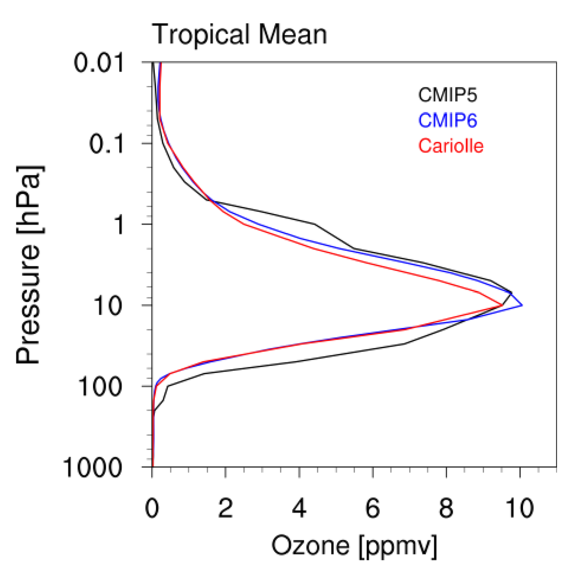

Fig 2.: Tropical (10°S – 10°N) mean ozone volume mixing ratio [ppmv] for CMIP5 (black) and CMIP6 (blue) climatologies and a model simulation with linearized Cariolle ozone scheme (red).

4. Differences in the Zonal Wind and Temperature

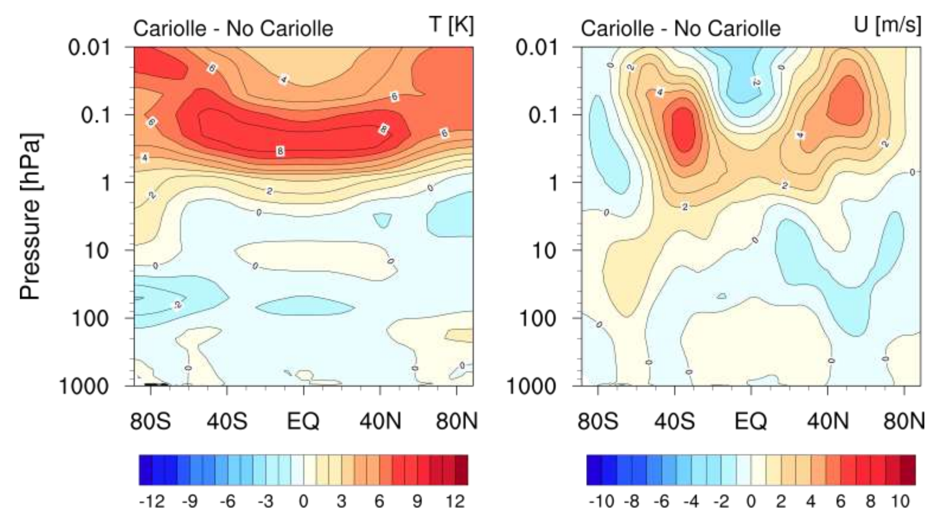

Fig 3.: Zonal mean (left) temperature [K] and (right) zonal wind [m/s] difference between the experiment with linearized ozone scheme (Cariolle) and the control experiment (no Cariolle) .

- Good agreement of tropospheric and stratospheric temperatures and winds.
- Largest differences are in the mesosphere due to higher ozone values in Cariolle scheme than in the CMIP5 climatology.

5. Comparison of Total Column Ozone

- Overestimated ozone values in the polar region and underestimated ozone values in the Tropics may result from a too strong circulation in the model.
- Overall global ozone structure is well captured.

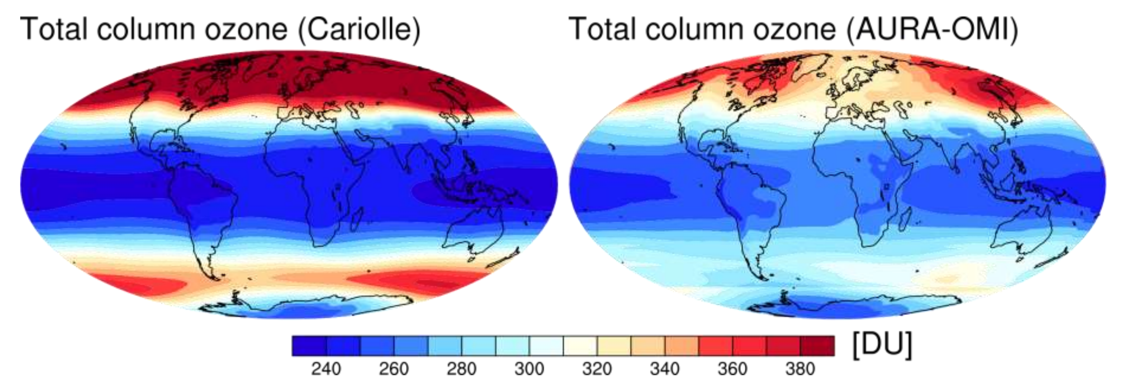

Fig 4.: Total column ozone [DU] for (left) model simulation with linearized Cariolle ozone scheme and (right) AURA-OMI satellite data. The total column ozone of AURA-OMI is provided by Greg Bodeker of Bodeker Scientific, funded by the New Zealand Deep South National Science Challenge.

6. Ozone under global warming

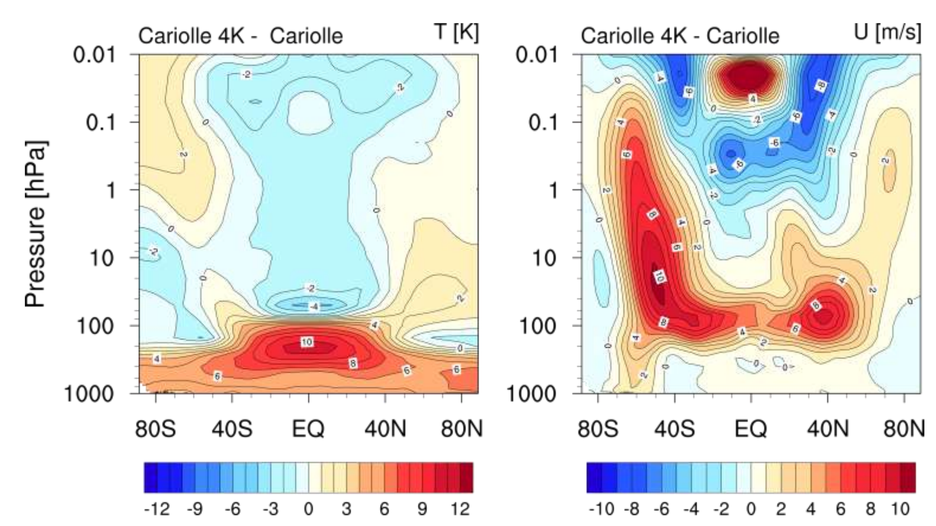

Fig 5.: Zonal mean (left) temperature [K] and (right) zonal wind [m/s] difference a AMIP+4K experiment with linearized ozone scheme (Cariolle 4K) and a AMIP experiment with linearized ozone scheme (Cariolle).

- Response to global warming with linearized ozone scheme is in the range of response of full chemistry models.

7. Next Steps

- Comparison of the linearized Cariolle ozone scheme to a simulation with full interactive gas-phase chemistry by using ICON-ART (Rieger et al. 2015).
- Analysis of the sensitivity of atmospheric circulation to increased vertical resolution near the tropopause.

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