The impact of the stratosphere on tropospheric climate change

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Abstract

We compare the doubled CO_2 responses in various versions of an AGCM without a well-resolved stratosphere ("low-top" model) to that in a model with a well-resolved stratosphere ("high-top" model). We find significant differences between the tropospheric circulation responses to climate change in operational versions of the low-top and high-top model. Surprisingly, further analysis shows that the different responses are due to differing settings of parameterized orographic gravity wave drag, and not due to the absence or presence of a well-resolved stratosphere.

Introduction

- Previous studies suggest that the stratosphere has an impact on tropospheric climate change (e.g., *Scaife et al.* [2005]).
- There is not yet a consensus on how high a model domain needs to extend to capture this downward influence (e.g., *Shindell et al.* [1999]; *Gillett et al.* [2002])
- This is a relevant question given that most GCMs used for climate change projections do not include a well-resolved stratosphere.

Model setup

- We use different high-top and low-top versions of the Canadian **AGCM** (CCCma AGCM3) at T63 horizontal resolution.
- We perform 40-year **control and 2xCO_2 timeslice** runs (doubled atmospheric CO_2 concentration and ΔSST field that represents the effects of global warming)
- We employ the following model versions:

HIGH: operational high-top model (CMAM), 71 levels, top at 0.0006 hPa (CCMVal version, dynamics only)
LOW: operational low-top model (AGCM3), 32 levels, top at 1 hPa (IPCC AR4 version)
LOWERED: lowered version of HIGH, 41 levels, top at 10 hPa
LOW-G: as LOW, but with orographic gravity wave settings of HIGH

Role of well-resolved stratosphere

1: SLP response (DJF)

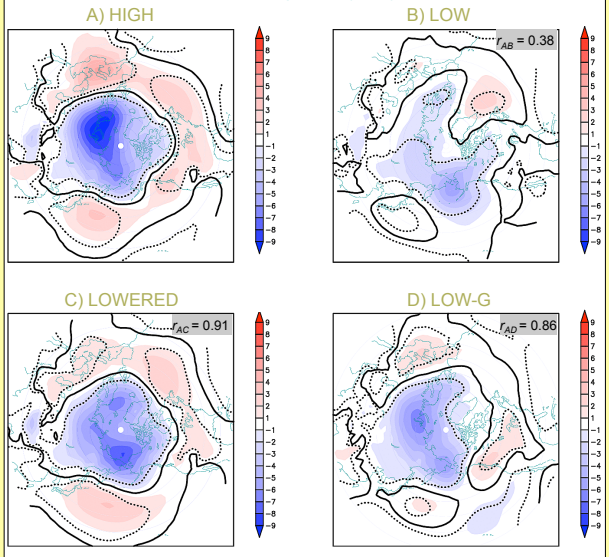

Fig. 1: Sea level pressure (SLP) response to CO_2 doubling (in hPa). Solid line is zero response line; dotted line indicates statistical significance at 95% (t-test)

- Tropospheric circulation response in **HIGH** (Fig. 1a, 2a) is **very different** from that in **LOW** (Fig. 1b, 2b); the spatial correlation coefficient of SLP responses north or 45°N (r) in Fig. 1a and Fig. 1b is small (r_{AB} =0.38)
- At first sight, this suggests that well-resolved stratosphere is important for tropospheric response to climate change
- **However**, HIGH and LOW operational models have **different model settings**, which can also contribute to response differences
- For **cleaner comparison**, we compare response of HIGH to LOWERED (with identical model settings, but 10 hPa model top; Fig 1c, 2c)
- **LOWERED response very similar** to **HIGH response** (SLP: r_{AC} = 0.91)
- Well-resolved stratosphere **not important** for tropospheric climate change (at least, in NH boreal winter in this AGCM)

2: [U] response (DJF)

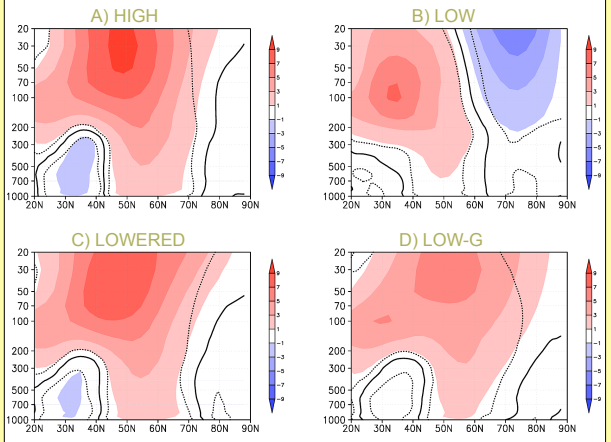

Fig. 2: As Fig. 1 but for zonal mean zonal wind (in m/s) response to CO_2 doubling.

What causes anomalous response in LOW?

3: [U] Control run (DJF)

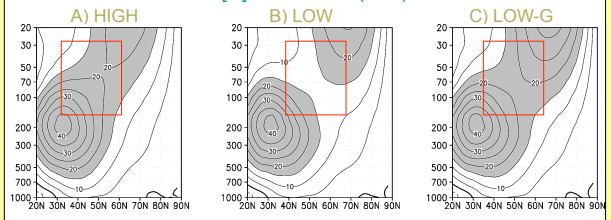

Fig. 3: The zonal mean zonal wind (in m/s) in the control run.

- **LOW climatology** (Fig. 3b) suffers from **weak wind bias** (~ too narrow wave guide) in lower stratosphere (red box), compared to HIGH (Fig. 3a) and observations.
- This bias in control climate is **alleviated when OGWD settings are made consistent with HIGH** (LOW-G, Fig. 3c).
- The ***response*** to CO_2 doubling in low-top model is much more similar to that in HIGH when OGWD settings are made consistent with HIGH (**LOW-G,** Fig. 1d, 2d; r_{AD} = 0.86) → anomalous settings of OGWD is cause of anomalous response in LOW.
- Response to climate change is **more dependent on settings of OGWD than on model lid height**.

Conclusions

- Response to climate change in operational low-top model is very different from that in operational high-top model.
- This difference is not related to differences in model lid height, but instead, caused by differences in settings of orographic gravity wave parameterization, which controls the zonal wind in the lower stratosphere.
- Thus, we do find influence of (lower) stratospheric zonal wind on tropospheric response to climate change, but we do not need a fully resolved stratosphere to capture this downward influence.
- Response to climate change is highly dependent on OGWD strength, see *Sigmond and Scinocca* poster for follow-up study.
- More details on the present study: see *Sigmond et al.* [2008]

References

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