Sensitivity of tropospheric climate change to lower stratospheric wind biases

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Abstract

We investigate the apparent sensitivity of tropospheric climate change to the properties of orographic gravity wave drag (OGWD) discussed in *Sigmond et al.* [2008]. In that study it was found that the tropospheric circulation response to doubling CO_2 was strongly sensitive to the settings (strength) of OGWD. Here we demonstrate that, rather than being related to non-linearity in the response of the OGWD, the sensitivity of the tropospheric climate change response is almost entirely due to the action of resolved planetary waves and their sensitivity to the initial $1xCO_2$ basic state winds. Therefore, OGWD only plays a role in determining the basic state of the control climate, in particular the mid- to high-latitude lower stratospheric zonal wind.

Introduction

- In *Sigmond et al.* [2008] it was found that the tropospheric circulation response to CO_2 doubling is very sensitive to the settings of the parameterized orographic gravity wave drag (OGWD), more than to the presence or absence of a well-resolved stratosphere (Fig. 1, shading)
- This suggests that the sensitivity may be due to a non-linearity in the OGWD response to CO_2 doubling (Fig. 1, magenta contours)
- If this were true, then the tropospheric circulation response to climate change would seem to depend on the detailed properties of OGWD parameterizations. This would pose a major concern given that such parameterizations remain poorly constrained by measurements.

1: U, OGWD response

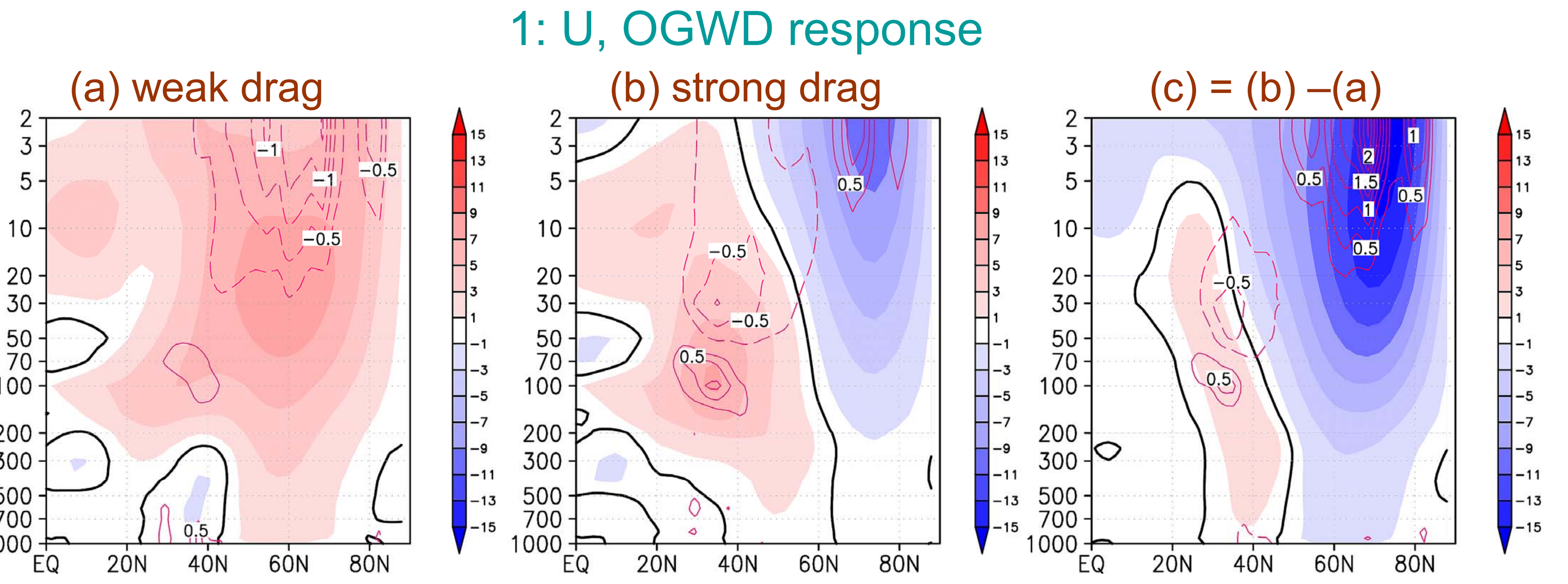

Fig. 1: The doubled CO_2 response of DJF zonal wind (shading, in m/s) and OGWD (magenta contours, in m/s/day) in runs with (a) weak drag, (b) strong drag, and (c) their difference. The black solid line is the zero zonal wind response contour.

Model and experiments

- Canadian AGCM (CCCma AGCM3) at T63 horizontal resolution.
- 40-year control and $2xCO_2$ time slice runs (doubled atmospheric CO_2 concentration and ΔSST field that represents the effects of global warming)
- 'low-top' version: with 32 levels, top at 1 hPa (IPCC AR4 version)
- *Scinocca and McFarlane* [2000] OGWD scheme. We change the factor *gphil* that scales the total amount of freely propagating mountain waves, from 1.0 (high *gphil* or strong drag run), which is the value in the operational model, to 0.25 (low *gphil* or weak drag run).

Role of orographic gravity wave drag

To determine the importance of non-linearity in the OGWD response to CO_2 doubling, we repeat the warming experiments with OGWD held fixed. This is accomplished as follows:
- A climatology of monthly mean OGWD from the $1xCO_2$ simulations for weak and strong drag simulations is diagnosed
- Then, we repeat the $2xCO_2$ simulations but apply the $1xCO_2$ climatology of OGWD as a prescribed forcing in place of the OGWD calculated by the model. In this way, we determine the response to CO_2 doubling independent of the influence of OGWD. The response in this set of experiments is presented in Fig. 2 below and can be compared directly to Fig. 1.

2: U response (fixed OGWD)

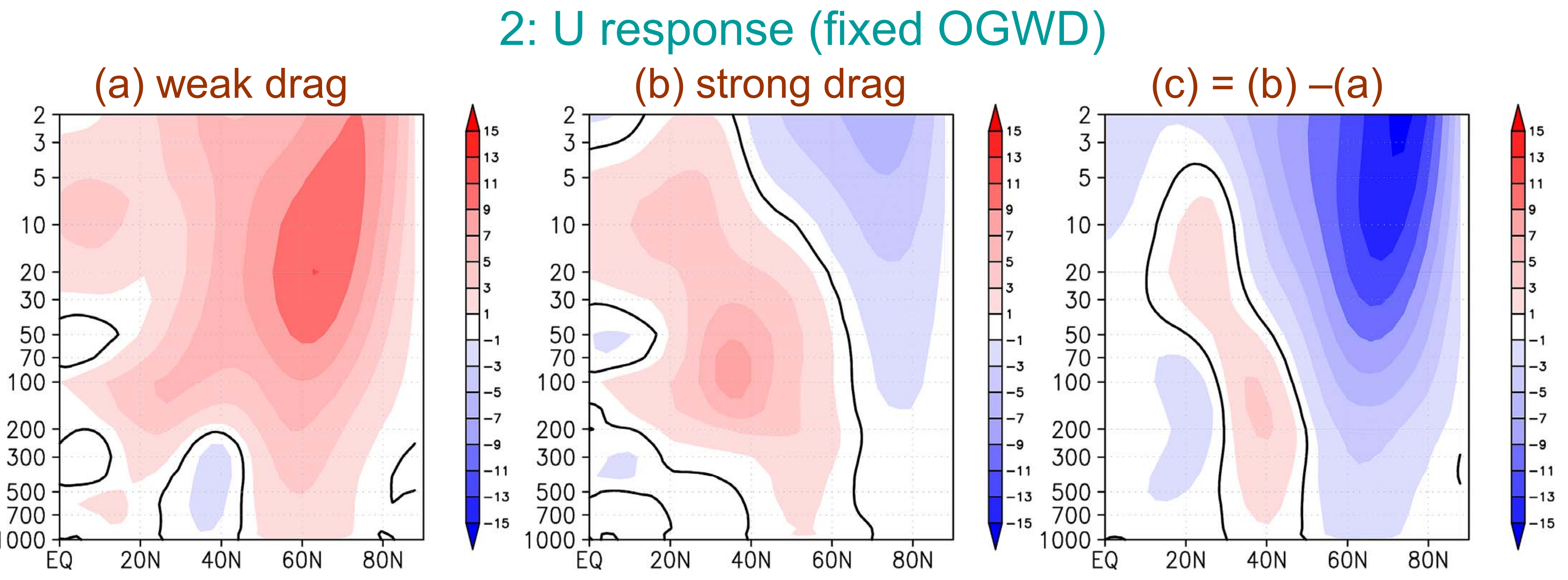

Fig. 2: As Fig. 1, except for the CO_2 doubling response in experiments with prescribed OGWD from $1xCO_2$ runs. Note that no contours of OGWD response are drawn since the OGWD response is zero by construction.

- The doubled CO_2 circulation responses in the absence of OGWD changes (Fig. 2) are very similar to the full responses (Fig. 1).
- Thus, non-linearity in the OGWD response plays little or no role in the circulation response sensitivity
- Instead, the primary warming sensitivity seems to be due to differences in the basic state winds in the weak and strong drag control climates

Why is the warming response sensitive to the control basic state?

3: U, Refractive index, control

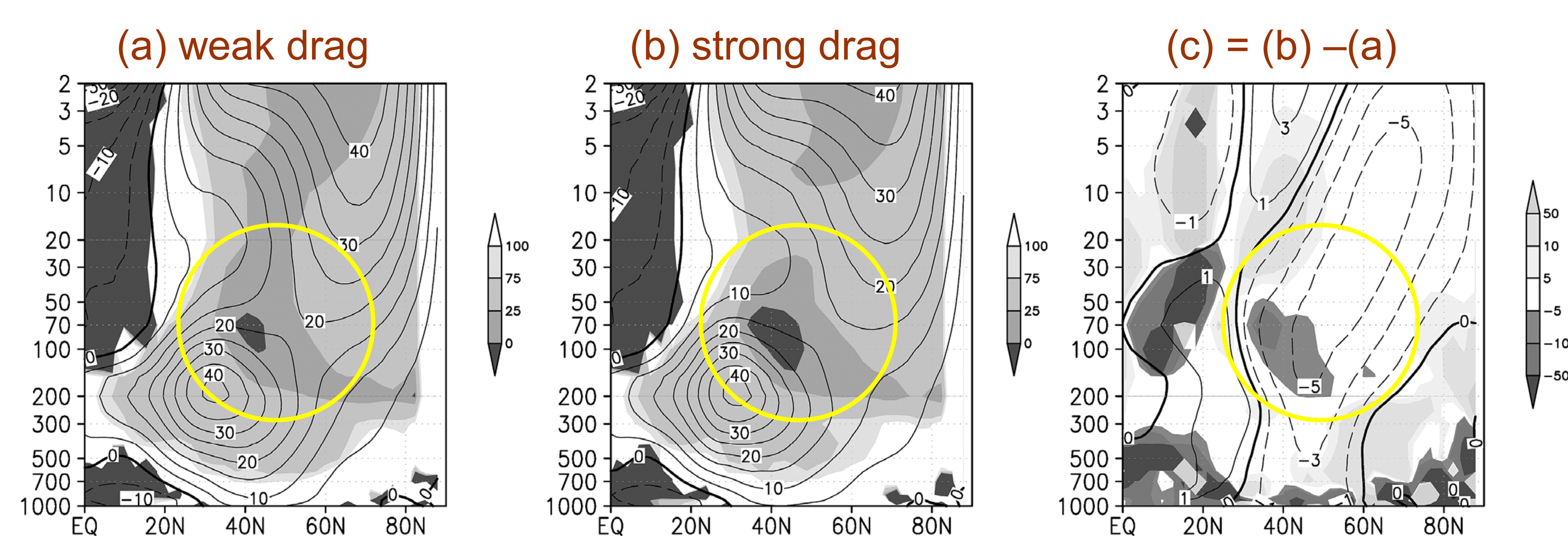

Fig. 3: The $1xCO_2$ DJF zonal wind (contours, in m/s) and refractive index (shading) in runs with (a) weak drag, (b) strong drag, and (c) their difference.

- The strong drag control simulation (Fig. 3b) has weak lower stratospheric winds relative to the weak drag simulation (Fig. 3a), and relative to observations.
- The weaker winds in the strong drag run are associated with a larger region of negative refractive index (Fig. 3b, dark shading), and a narrower wave guide, whereas the weak drag run has stronger winds and a wider wave guide (Fig. 3a).

4: EP-flux, EPFD, response

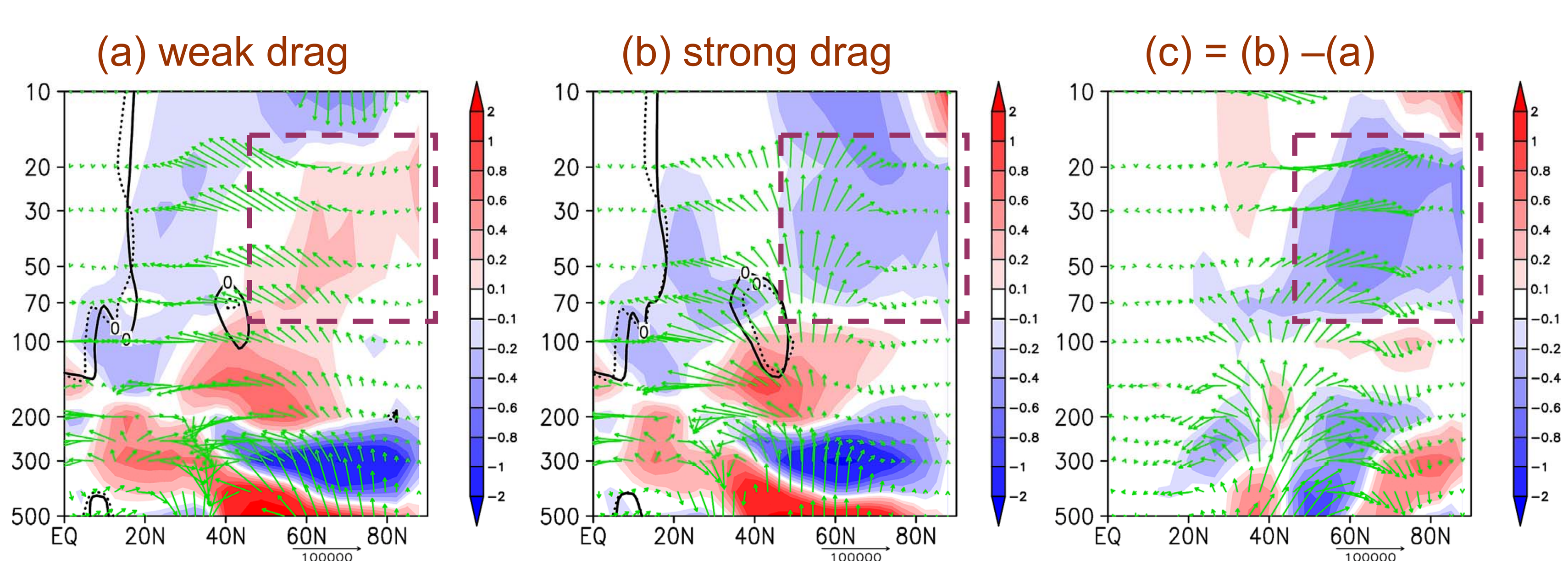

Fig. 4: The CO_2 doubling response of DJF EP-flux (vectors), and EP-flux divergence (shading, in m/s/day) in runs with (a) weak drag, (b) strong drag, and (c) their difference. The black solid (dotted) contour line in (a) and (b) defines a refractive index value of zero in the control ($2xCO_2$) runs.

- Sensitivity of the zonal wind response is consistent with that of EP-flux divergence (EPFD): the strong minus weak drag response differences of both the zonal wind (Fig. 1c, shading) and the resolved wave driving (Fig. 4c, shading) are negative in the polar lower stratosphere (dashed box in Fig. 4)
- In both weak and strong drag runs, the primary resolved wave response to CO_2 doubling is increase of wave activity from troposphere (green vectors, Fig. 4)
- In the weak drag run, the wide wave guide (~small negative refractive index region; Fig. 4a, contours), allows the extra wave activity (in response to CO_2 doubling) to propagate towards the equator, causing positive EPFD (Fig. 4a, shading) response in the polar region
- In the strong drag run, the narrow wave guide causes the extra wave activity to reflect towards the pole, causing negative EPFD (Fig. 4b, shading) response in polar region

Conclusions

- Tropospheric circulation response to CO_2 doubling is sensitive to the strength of orographic gravity wave drag (OGWD)
- This is not caused by a non-linearity in the response of OGWD to CO_2 doubling.
- Instead, the response sensitivity is related to the control basic state and the action of resolved waves, and can be understood from refractive index arguments
- The only role of OGWD in the sensitivity identified in *Sigmond et al.* [2008] is in determining the control basic state.
- Therefore, any other parameter setting or physical process that changes zonal wind in mid- to high-latitude lower stratosphere would also influence the tropospheric circulation response to increasing greenhouse gases in a similar manner
- The current study does not support the idea that the tropospheric circulation response to climate change depends on the specific details of OGWD parameterizations.

References

- Scinocca, J. F., and N. A. McFarlane (2000), The parameterization of drag induced by stratified flow over anisotropic orography, Q. J. R. Meteorol. Soc., 126, 2353–2393.
- Sigmond, M., J. F. Scinocca, and P. J. Kushner (2008), Impact of the stratosphere on tropospheric climate change, Geophys. Res. Lett., 35, L12706, doi:10.1029/2008GL033573.