A different perspective on how parameterized orographic gravity waves influence atmospheric transport and dynamics in current generation global climate models

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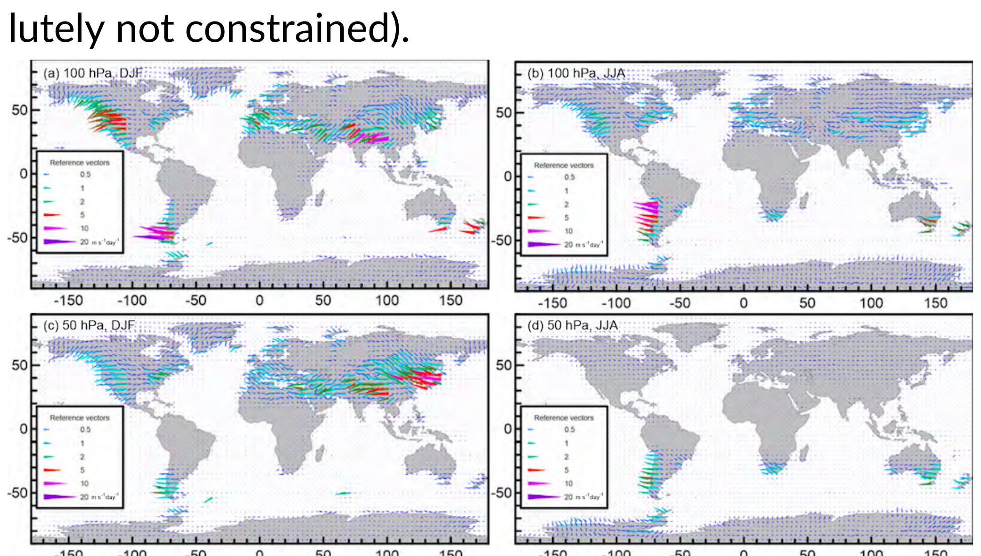
Gravity waves

In the terrestrial atmosphere, internal gravity waves (GWs) are a naturally occurring and **ubiquitous, though intermittent** phenomenon. Also, GWs are asymmetrically distributed around the globe, concentrating in so-called **hotspots**. According to their sources, we divide GWs into non-orographic and orographic GWs (OGWs). Consideration of GW-related processes is necessary for a proper description and modelling of the middle and upper atmosphere (e.g., Fritts and Alexander, 2003).

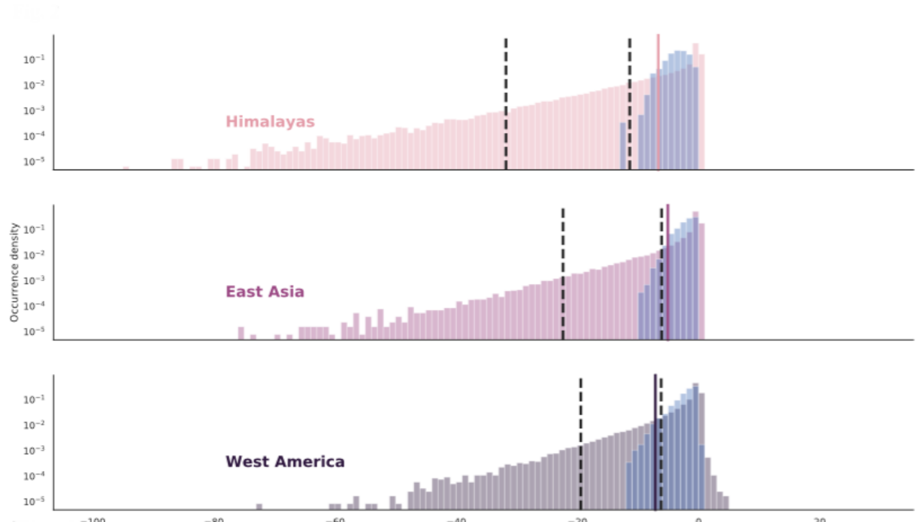
GW representation in models

In current generation global circulation models (GCMs), GWs are usually smaller than the model grid resolution and the majority of their spectrum **must be parameterized**. All GW parameterizations employ various degrees of simplifications (GW sourcing, propagation and dissipation processes) and rely on certain **tuneable** parameters, which are poorly constrained by observations. These parameters determine the strength and distribution of the resulting GW drag (GWD) that enters the dynamical core of the models. **Turbulent mixing** induced by GWs is not considered, only some parameterization schemes provide also the GW induced heating (absolutely not constrained).



Hotspots and intermittency of parameterized OGWD

To some extent, the intermittency (**Fig. 2**) and asymmetric spatial distribution (**Fig. 1**) of the resulting GWD is present also in the parameterization outputs (in particular for orographic GWD (oGWD)).



Brewer-Dobson circulation (BDC)

The analytical model of the BDC (i.e. a meridional overturning circulation influencing stratospheric composition), is usually defined as consisting of a **diffusive part**, and the **advective residual mean circulation** (or alternatively, *diabatic circulation*). Assuming **steady, conservative waves**, the residual mean circulation is equivalent to a Lagrangian-mean circulation to the **second order of wave amplitude** (Bühler, 2014).

To date understanding of the GW impact

Under the so-called wave-driving paradigm (Holton et al., 1995) it is assumed that the residual mean circulation is driven by a so-called **extratropical wave "pump"** in the stratosphere and mesosphere. Both branches (shallow and deep) are considered to be primarily driven by the extratropical **resolved wave forcing with regional contributions by GWD**.

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Orographic gravity wave drag is.....

- ..**intermittent and zonally asymmetrically** distributed.
- ..maximal in the **extratropical LS** constituting the **dominant forcing** component there (in NH).
- ..connected with the **residual circulation** via the **compensation mechanism**. (*Net drag is the driver, or the other way around?*).
- ..affecting **transport properties in the stratosphere by altering upward propagation** of Rossby waves (extratropical LS).
- ..directly influencing **mixing by in-situ creation** of Rossby waves.
- ..possibly playing a role in Rossby wave **finite amplitude and breaking** events.

Open question:

"To what extent is the OGWD representation the cause for the mismatch between modeled and observed tracer distribution and variability in the LS?"

+ Keep in mind that the turbulent mixing by breaking GWs is not taken into account in parameterizations.

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Novelty of the study

- Detailed analysis of **OGWD impact on the model dynamics** taking into account intermittency and zonally asymmetric distribution.
- Focus on the complex OGWD **influence on transport** (including mixing) in the models, which **cannot be compensated** like for the residual circulation driving.

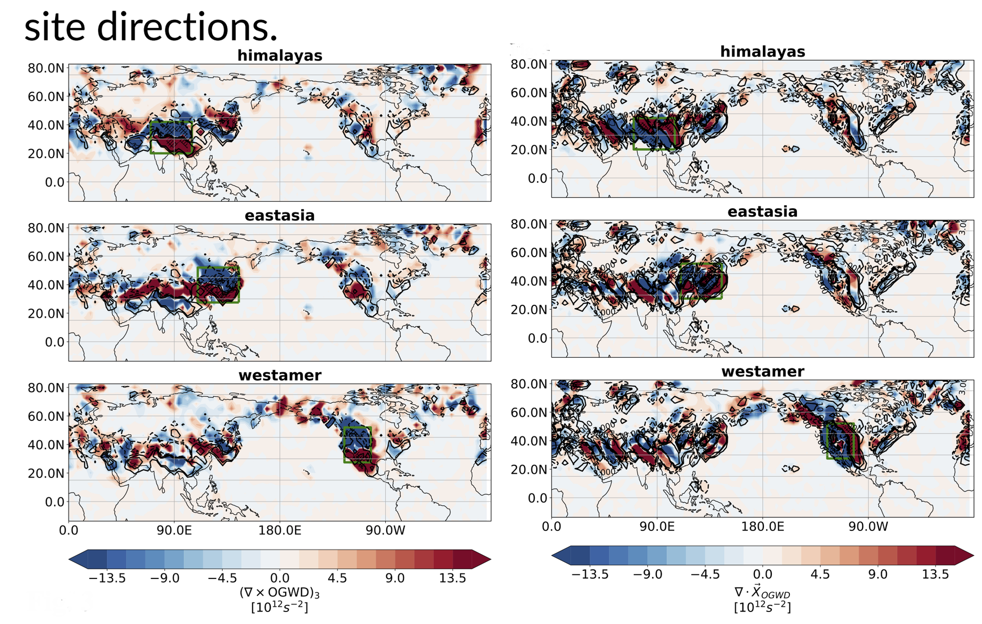
Methodology

- CMAM-sd (McLandress et al., 2013): 3D OGWD and momentum flux data available on 6 hourly basis.
- Composite analysis with regard to extreme OGWD events in particular hotspots (see **Fig. 2**).

**Planned are sensitivity simulations with comprehensive models with modified orography and analysis of high-resolution simulations resolving majority of the GW spectrum.*
***CMIP6** for the first time provides 3D GW related output, but monthly mean only.*

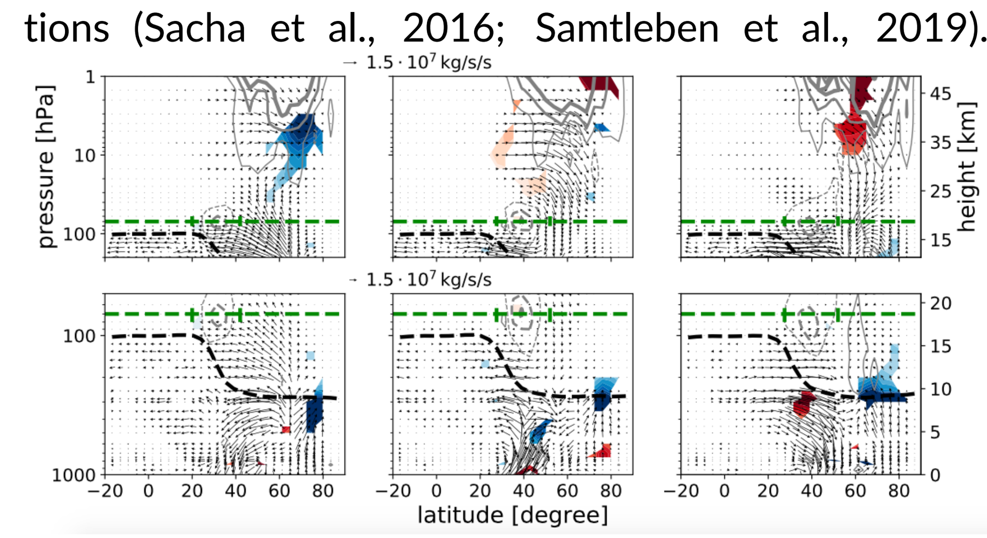
Dynamical features of OGWD

Curl (**Fig. 3, left**) and divergence (**Fig. 3, right**) of OGWD enter the divergence and vorticity equation (shown for barotropic, horizontal flow scaling), those OGWD derivatives are **absolutely unconstrained**. They probably differ largely between different parameterization schemes in terms of shape and magnitude. **Figures 3, 4 and 5** show the strong OGWD composites for particular hotspots from CMAM-sd, which uses the Scinocca and McFarlane (2000) scheme - launching two vertically propagating zero-phase-speed waves in opposite directions.

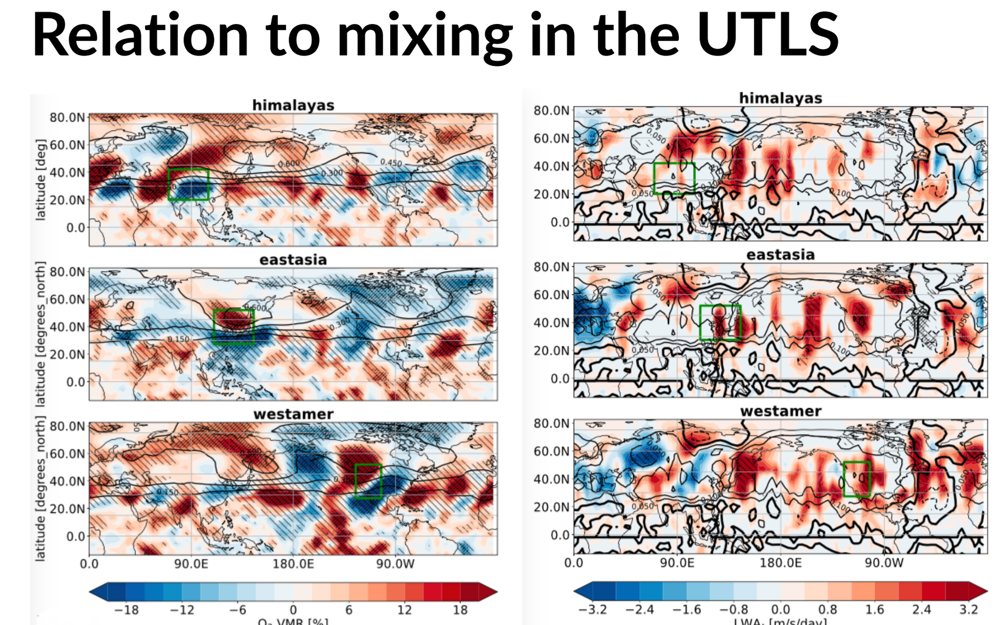


Dominant dynamical impact of OGWD

From the zonal mean perspective, the dominant dynamical effect is the **alteration of propagation of resolved waves** from the extratropical troposphere. Different hotspots act differently (**Fig. 4**), but a robust feature is the **suppression of the equatorward tilt** of the upward propagating waves. A similar response has been seen in idealized simulations (Sacha et al., 2016; Samtleben et al., 2019).



Relation to mixing in the UTLS



Significant anomalies of ozone concentrations at 100 hPa (**Fig. 5, left**) reaching also to the equatorial region (already in the troposphere) support the hypothesis that OGWD is connected with **quasi-horizontal mixing across the extratropical tropopause**. The physical mechanism is probably the **interaction with Rossby waves** (sourcing, transience). Composites are connected almost exclusively with positive finite-amplitude local wave activity tendency anomalies (**Fig. 5, right**).