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Supplement of:

Effects of missing gravity waves on stratospheric dynamics; part 1: climatology

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S1 Introduction

This document contains supplementary figures and some related information for the article *"Effects of missing gravity waves on stratospheric dynamics; part 1: climatology"* by R. Eichinger et al..

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S2 Additional figures

S2.1 Refractive index climatologies

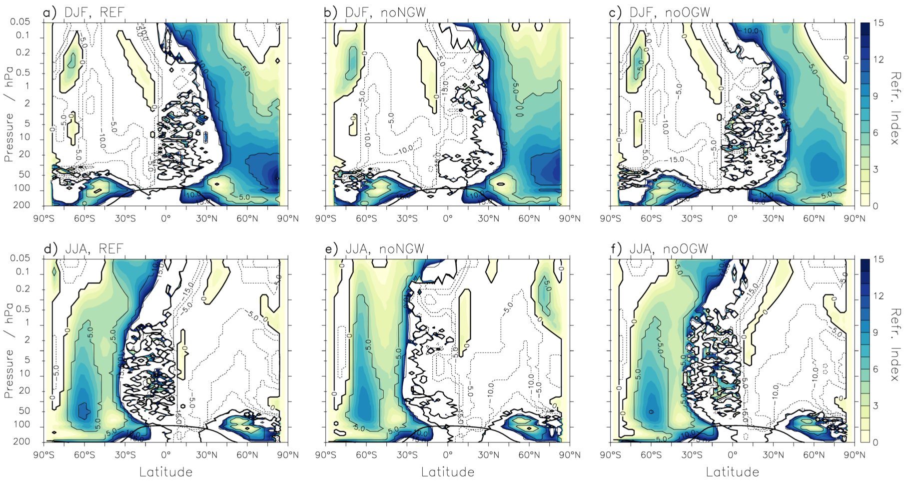

Fig. S1 Refractive index climatologies of the REF (a, d), noNGW (b, e) and noOGW (c, f) simulations for DJF (a-c) and JJA (d-f). Negative values are not shown because a negative RI means that no wave propagation can take place. Note that the colour bar is cut above a RI of 15, because in the tropics the index is blurred due to the calculation method. The thick black line denotes the corresponding tropopause.

S2.2 EP-flux and EPfd climatologies

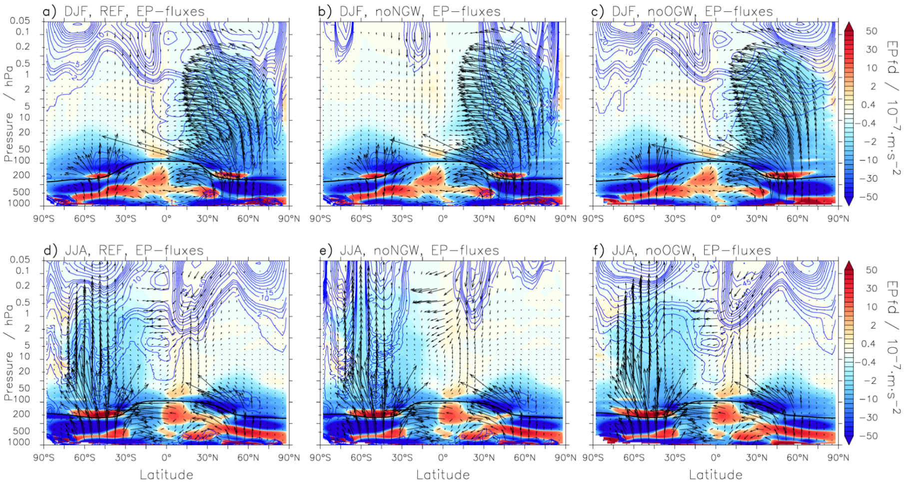

Fig. S2 EP-flux and EPfd climatologies of the REF (a, d), noNGW (b, e) and noOGW (c, f) simulations for DJF (a-c) and JJA (d-e). The contour lines denote the total climatological GW drag of the respective simulation. In the troposphere, all values have been scaled by 0.1 for visual purposes.

S2.3 Tropical upwelling

Tropical upwelling can be derived from momentum balance through the mass-flux streamfunction difference between the turnaround latitudes. These are calculated as the maximum/minimum of the streamfunction at the given pressure level. As air enters the stratosphere primarily in the tropics, tropical upwelling is a key feature of stratosphere-troposphere coupling (Randel et al., 2008) and it can be used as measure of the strength of the residual circulation (Holton et al., 1995). In a multi-model analysis, Dietmüller et al. (2018) have recently shown that this indeed holds for large regions of the stratosphere, especially for tropical upwelling at 70 hPa.

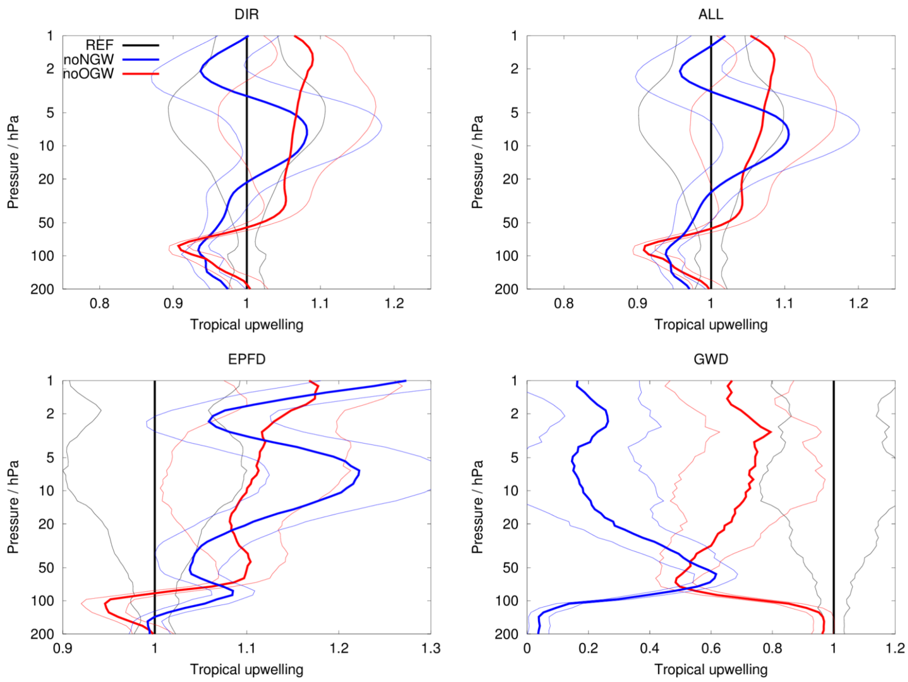

Fig. S3 Tropical upwelling of the noNGW and the noOGW simulations as function of altitude relative to the normalised REF simulation calculated "directly" (DIR) and with the DWC principle for total wave driving (ALL), resolved wave driving (EPFD) and for gravity wave driving (GWD).

S2.4 Wave forcing of streamfunction

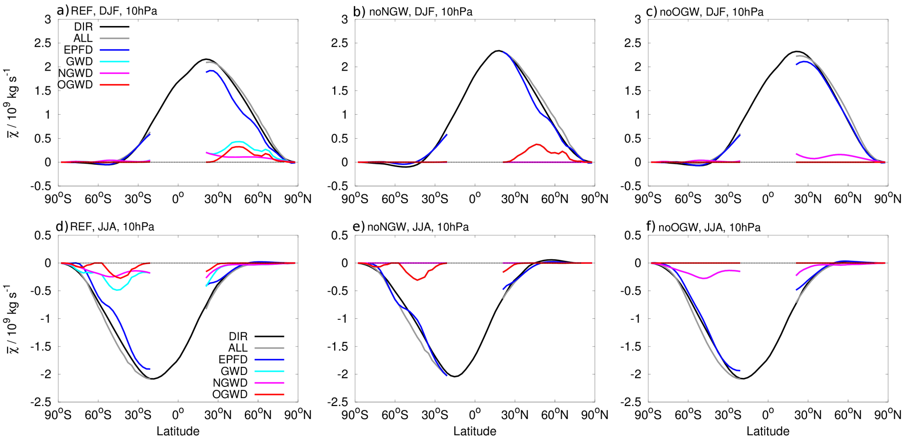

Fig. S4 Climatologies of the meridional streamfunction for the REF (a, d), noNGW (b, e) and noOGW (c, f) simulations at 10 hPa for DJF (a-c) and JJA (d-f). The streamfunction is calculated "directly" via the TEM equations (DIR, black) and with the downward control method for the sum (ALL, grey) of the Eliassen-Palm flux divergence (EPFD, blue) and total GW drag (GWD, light blue), which is the sum of orographic (OGW, red) and non-orographic (NGW, pink) GW drag.

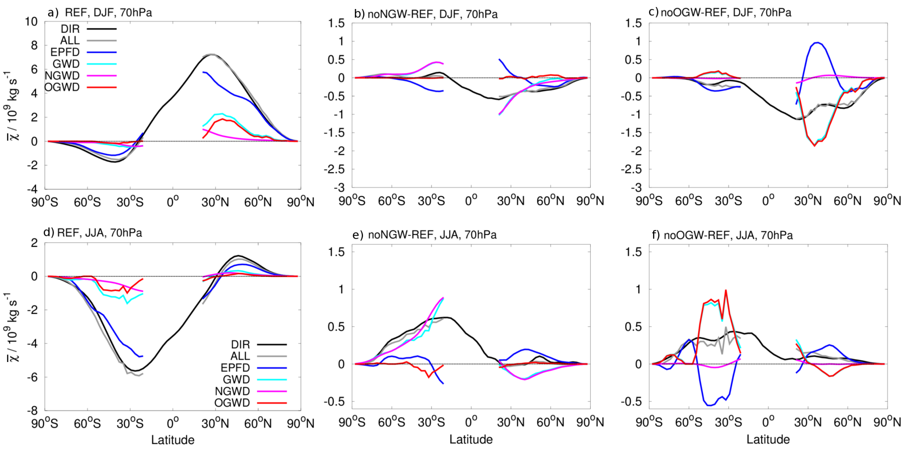

Fig. S5 Climatologies of the meridional streamfunction for the REF simulation at 70 hPa for DJF (a) and JJA (d) and streamfunction differences between the noNGW and the REF simulation (b, e) and between the noOGW and the REF simulation (c, f) at 70 hPa. The colours are set as in Fig. S4.

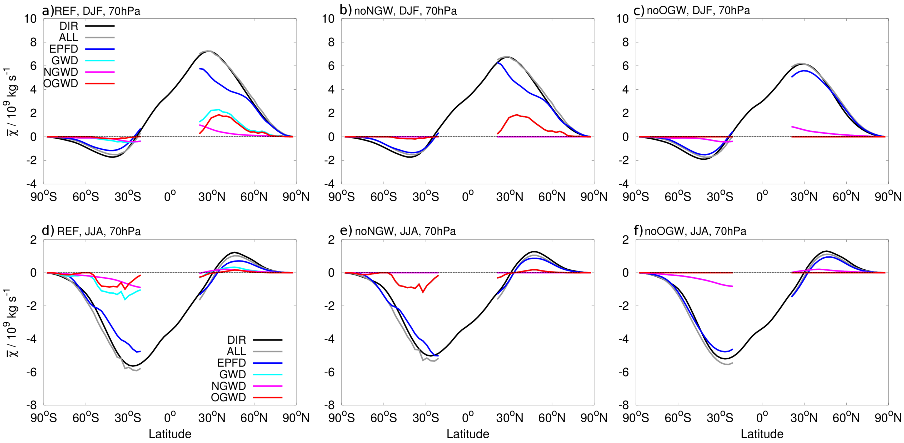

Fig. S6 As Fig. S4 but at 70 hPa.

S2.5 AoA, RCTT and A_mix climatologies

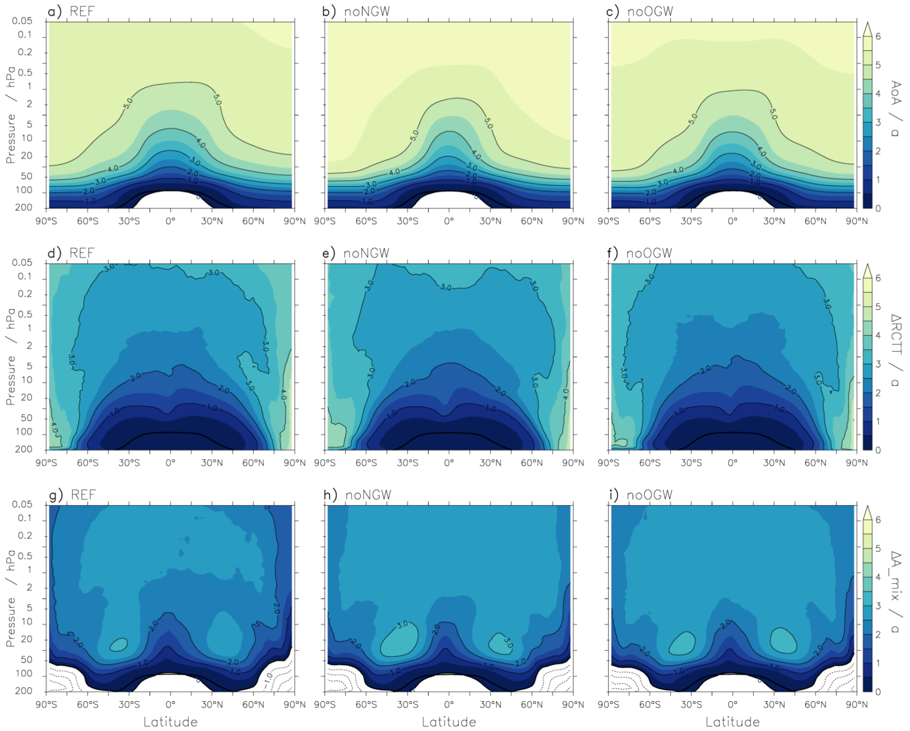

Fig. S7 AoA (a-c), RCTT (d-f) and A_mix (g-i) climatologies of the REF (a, d, g), noNGW (b, e, h) and noOGW (c, f, i) simulations, respectively. The thick black line denotes the corresponding annual mean tropopause. The unit a stands for years (lat. anni).

S2.6 Mixing efficiency

As a diagnostic of the relative strength of mixing, we calculate the mixing efficiency ϵ, which is defined as the ratio of the mixing mass flux to the net mass flux between the tropics and the extratropics. ϵ can be derived by means of the tropical leaky pipe (TLP) model (Neu and Plumb, 1999), a one-dimensional transport model of the stratosphere, and it can be used to quantify the strength of mixing across the subtropical barrier. ϵ is approximately proportional to the relative increase in AoA due to mixing. The mixing efficiency is obtained by the TLP models' best fit to the AoA profile for the altitude range from the tropopause to 32 km (details for the calculation of the mixing efficiency are given in Garny et al., 2014). The mixing efficiency has been shown to be a useful diagnostic tool in a number of studies (e.g. Garny et al., 2014; Dietmüller et al., 2017; Eichinger et al., 2019). Tab. S1 provides an overview of the climatological ϵ of the three simulations and of its variability.

Simulation	REF	noOGW	noNGW
ϵ	0.30	0.37	0.36
$\sigma(\epsilon)$	0.004	0.009	0.005

Table S1 The climatological mixing efficiency ϵ of the three simulations and the corresponding standard deviation σ.

References

Dietmüller S, Garny H, Plöger F, Jöckel P, Duy C (2017) Effects of mixing on resolved and unresolved scales on stratospheric age of air. Atmospheric Chemistry and Physics 17:7703–7719, doi:10.5194/acp-17-7703-2017

Dietmüller S, Eichinger R, Garny H, Birner T, Boenisch H, Pitari G, Mancini E, Visioni D, Stenke A, Revell L, Rozanov E, Plummer DA, Scinocca J, Jöckel P, Oman L, Deushi M, Kiyotaka S, Kinnison DE, Garcia R, Morgenstern O, Zeng G, Stone KA, Schofield R (2018) Quantifying the effect of mixing on the mean age of air in ccmval-2 and ccmi-1 models. Atmospheric Chemistry and Physics 18:6699–6720, doi:10.5194/acp-18-6699-2018

Eichinger R, Dietmüller S, Garny H, Šácha P, Birner T, Böhnisch H, Pitari G, Visioni D, Stenke A, Rozanov E, Revell L, Plummer DA, Jöckel P, Oman L, Deushi M, Kinnison DE, Garcia R, Morgenstern O, Zeng G, Stone KA, Schofield R (2019) The influence of mixing on the stratospheric age of air changes in the 21st century. Atmospheric Chemistry and Physics 19:921–940, doi:10.5194/acp-19-921-2019

Garny H, Birner T, Bönisch H, Bunzel F (2014) The effects of mixing on age of air. Journal of Geophysical Research: Atmospheres 119(12):7015–7034, doi:10.1002/2013JD021417

Holton JR, Haynes PH, McIntyre ME, Douglass AR, Rood RB, Pfister L (1995) Stratosphere-troposphere exchange. Reviews of Geophysics 33:403–439, doi:10.1029/95RG02097

Neu JL, Plumb RA (1999) Age of air in a leaky pipe model of stratospheric transport. Journal of Geophysical Research: Atmospheres 104(D16):19243–19255, doi:10.1029/1999JD900251

Randel WJ, Garcia R, Wu F (2008) Dynamical balances and tropical stratospheric upwelling. Journal of the Atmospheric Sciences 65(11):3584–3595, doi:10.1175/2008JAS2756.1