Supporting Information for "Towards the direct simulation of the quasi-biennial oscillation in a global storm-resolving model"

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Contents of this file

Introduction This supplementary material gives information on the impact of the chosen spatial and temporal coarse-graining on the results presented in the manuscript. Section 1 deals with how the chosen horizontal remapping method and the resolution of the horizontal Gaussian target grid affect the transformed Eulerian mean (TEM) diagnostics. Section 2 deals with how the temporal output interval of the model affects the spectra of

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the vertical Eliassen-Palm (EP) flux, which is a measure of the vertical wave activity flux in the TEM framework.

1. Impact of horizontal remapping method on TEM diagnostics

As shown in Figures S1 and S2, the characteristics of all TEM diagnostics, including the divergence of the vertical EP flux, are more or less independent of the chosen horizontal coarse-graining.

2. Temporal aliasing

As demonstrated by Kirchner (2005), aliasing can cause pronounced white-noise tailing in power spectra, which can be distorted even far below the Nyquist frequency. Therefore, we hypothesized that temporal aliasing may also be responsible for the noisy zonal wavenumber-frequency spectrum of the vertical Eliassen-Palm flux (EP flux) in the ICON simulation (see Fig. 12a). Fast and short gravity waves (GWs) can have periods as short as 10 minutes, which is well below the output interval of 3 h, making our instantaneous output strategy prone to temporal aliasing.

To verify this hypothesis, we performed a simulation with the ICON model using the R2B8 horizontal grid ($\Delta x \approx 10\,\mathrm{km}$) and a model configuration comparable to that of the main simulation analyzed in the manuscript (see Sec. 2.1) with an output interval of 10 minutes[1] over a simulation period of 29 days. For this simulation, we calculated two different $5^\circ\,\mathrm{S} - 5^\circ\,\mathrm{N}$ mean zonal wavenumber-frequency spectra of the vertical EP flux at an altitude of 17 km: (1) based on all available instantaneous 10-minutely output, and (2) based on a set of 3-hourly subsampled instantaneous output. The spectra are shown in Figures S3 – S5.

This work confirms that the noisy zonal wavenumber-frequency spectrum of the ICON simulation is the imprint of temporal aliasing. As a consequence, the absolute east- and westward vertical EP flux for GWs with $|k| > 18$ is underestimated if calculated based on 3-hourly output compared to if calculated based on 10-minutely output.

References

Kirchner, J. W. (2005). Aliasing in $1/f^{\alpha}$ noise spectra: Origins, consequences, and remedies. *Physical Review E*, *71*(6). doi: 10.1103/physreve.71.066110

Notes

1. An output interval of 10 minutes has been found to be sufficient to capture all resolved GWs in an ICON simulation with the R2B8 grid

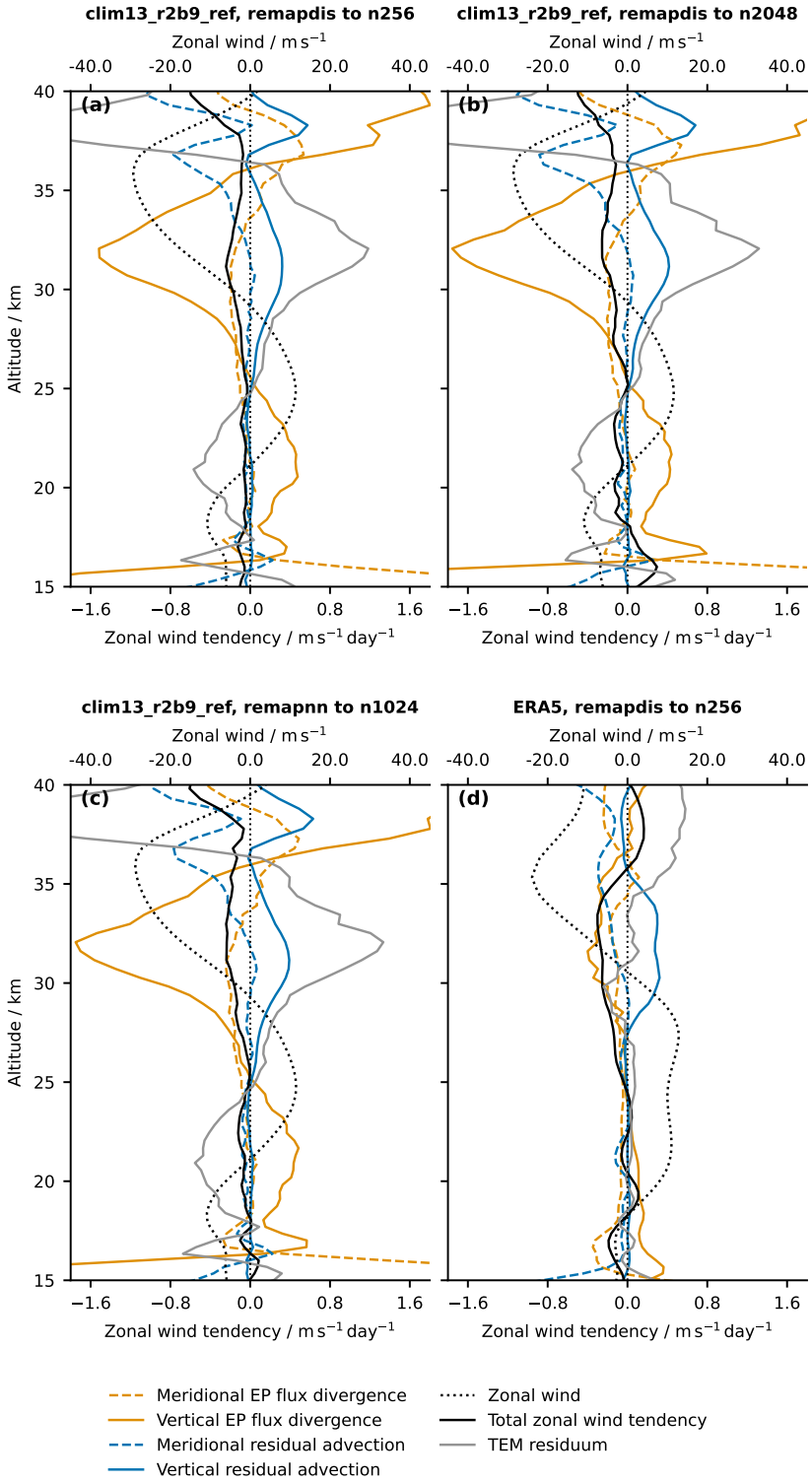

Figure S1. 5° S – 5° N mean profiles of the TEM zonal wind tendencies due to different processes (see legend) averaged over the period June 01, 2004–June 24, 2004 for **(a-c)** the ICON simulation using different horizontal remapping methods and **(d)** the ERA5.1 reanalysis. The x-axis for the zonal wind is given at the upper spine.

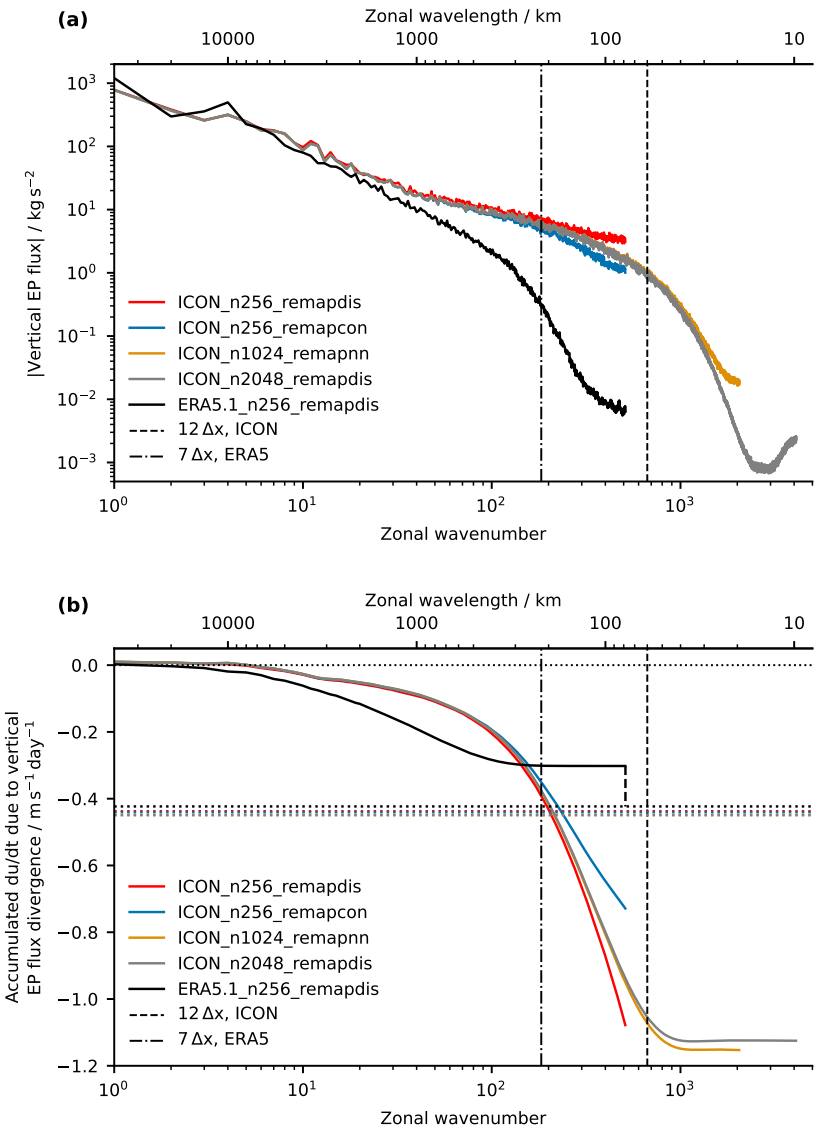

Figure S2. 10° S – 10° N mean zonal wavenumber spectra of **(a)** the vertical EP flux at 18 km and **(b)** the cumulative sum of the zonal acceleration due to the divergence of the vertical EP flux averaged between 29 km and 34 km for the different remapping methods applied. The spectra are averaged over the period June 01, 2004–June 14, 2004. For ERA5, the dashed vertical line at the end of the spectrum marks the TEM residuum, which is dominated by the contribution of parameterized gravity wave forcing. The horizontal dotted lines in panel **(b)** mark the effective vertical wave forcing, i.e. the vertical wave forcing which would be sufficient to close the TEM momentum budget. Vertical black lines mark the effective resolutions of ICON (dashed) and ERA5 (dashed-dotted).

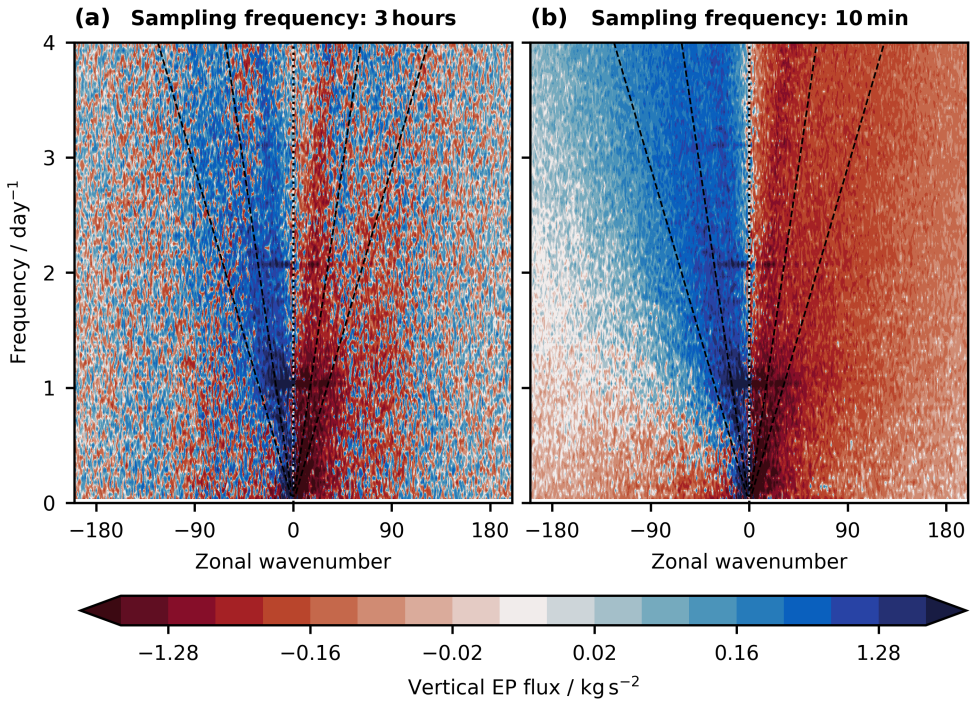

Figure S3. Zonal wavenumber-frequency spectrum of the $5° \text{ S} - 5° \text{ N}$ mean vertical EP flux at an altitude of 17 km calculated based on **(a)** 3-hourly and **(b)** 10-minutely instantaneous output fields from the same ICON simulation. The spectra are calculated based on 29 days.

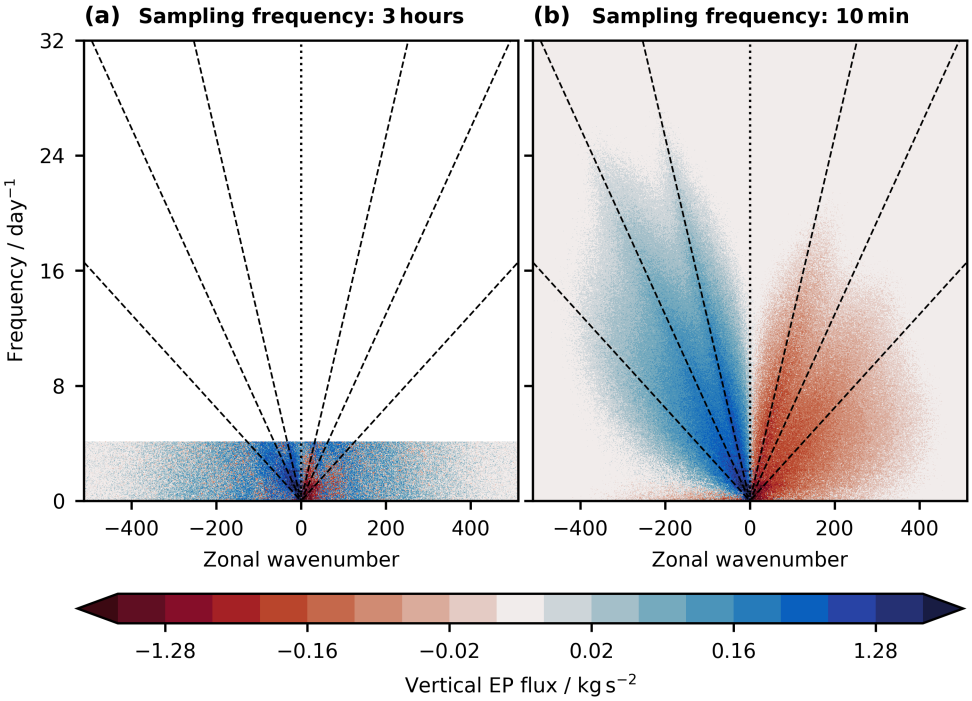

Figure S4. Zonal wavenumber-frequency spectrum of the $5° \text{ S} - 5° \text{ N}$ mean vertical EP flux at an altitude of 17 km calculated based on **(a)** 3-hourly and **(b)** 10-minutely instantaneous output fields from the same ICON simulation. The spectra are calculated based on 29 days.

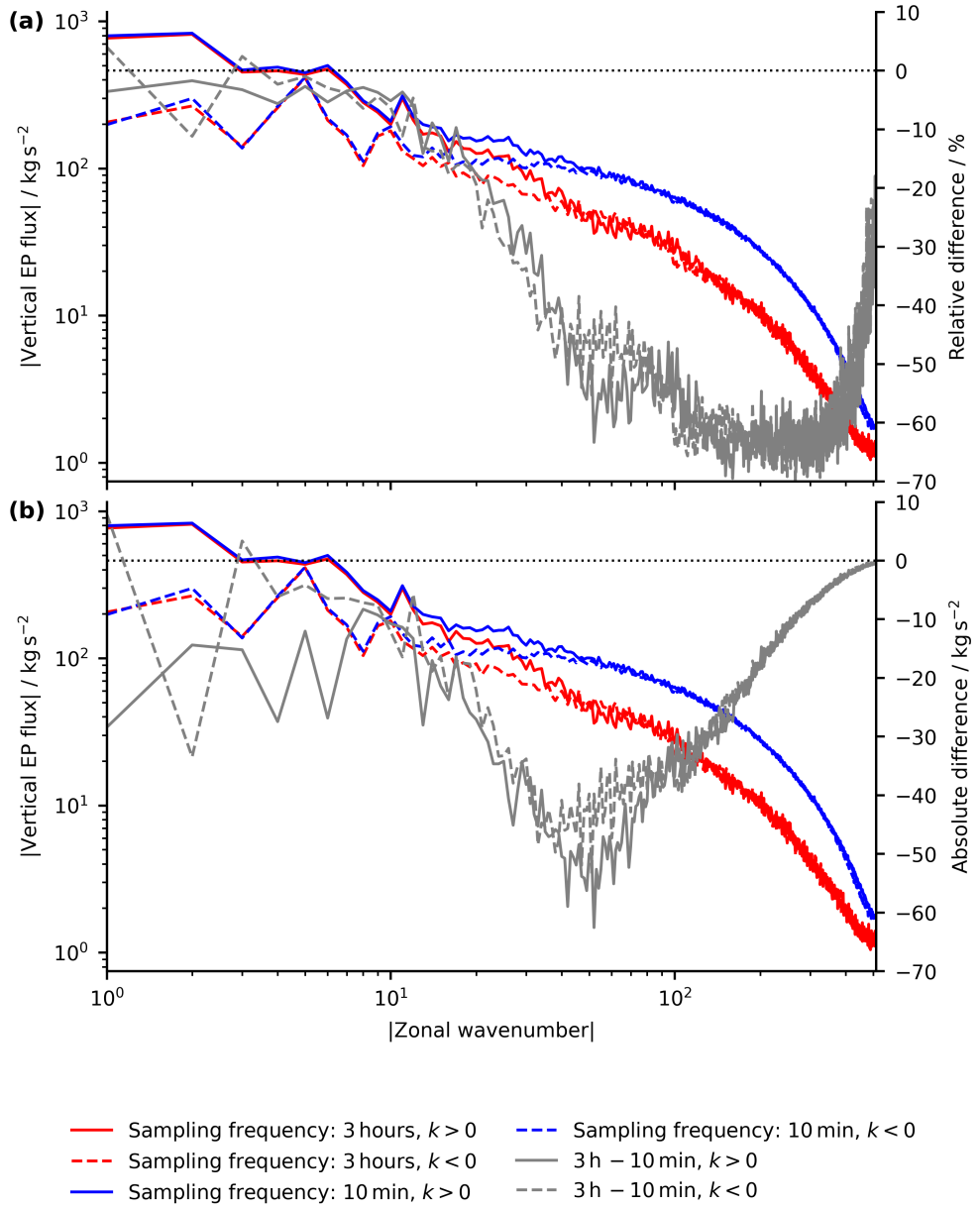

Figure S5. Zonal wavenumber spectra of the 5° S − 5° N mean vertical EP flux at an altitude of 17 km calculated based on 3-hourly and 10-minutely instantaneous output fields from the same ICON simulation. The spectra are calculated based on 29 days. The difference between the spectra based on 3-hourly and 10-minutely instantaneous output fields is plotted in gray lines with the y-axis given on the right-hand side of each panel: panel **(a)** showing the relative difference and panel **(b)** showing the absolute difference.