Planetary waves and their role in stratosphere-troposphere coupling under a changing climate – Simulations with ECHAM 6

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Introduction

Stratosphere and troposphere are coupled via radiative, dynamical and chemical processes. In this work we focus on the dynamics of stratosphere-troposphere coupling in Northern hemispheric winter, when planetary waves originating from the troposphere propagate up into the stratosphere. Their dissipation decelerates the polar night jet, which, in extreme cases, can lead to the occurrence of a major sudden stratospheric warming (SSW) event. Climate change could affect both planetary wave sources and their propagation. Several studies pointed out that changes in stratospheric conditions may have implications for the troposphere. This has been in particular shown for the Northern Annular Mode index, which at the surface is highly correlated to the North Atlantic Oscillation.

To investigate the impact of climate change on the coupling of the stratosphere-troposphere system, 50-year model simulations with the ECHAM6 general circulation model were performed for time slices reflecting preindustrial, present-day and future climate states. Boundary conditions of the three different time slices are characterized by greenhouse gas (GHG) concentrations, sea surface temperatures (SSTs), aerosol data as well as ozone levels. The differences between these three simulations with regard to stratosphere-troposphere coupling are presented.

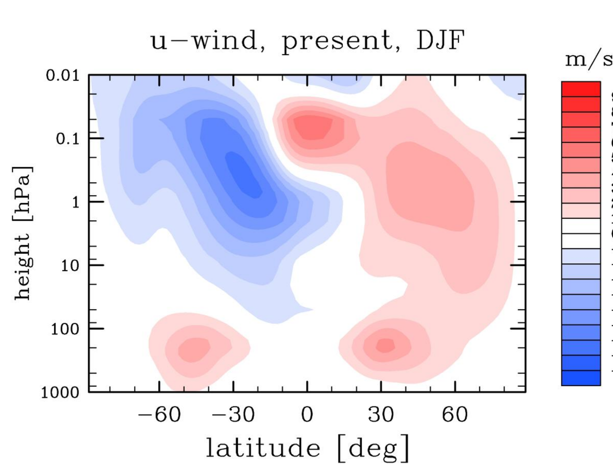
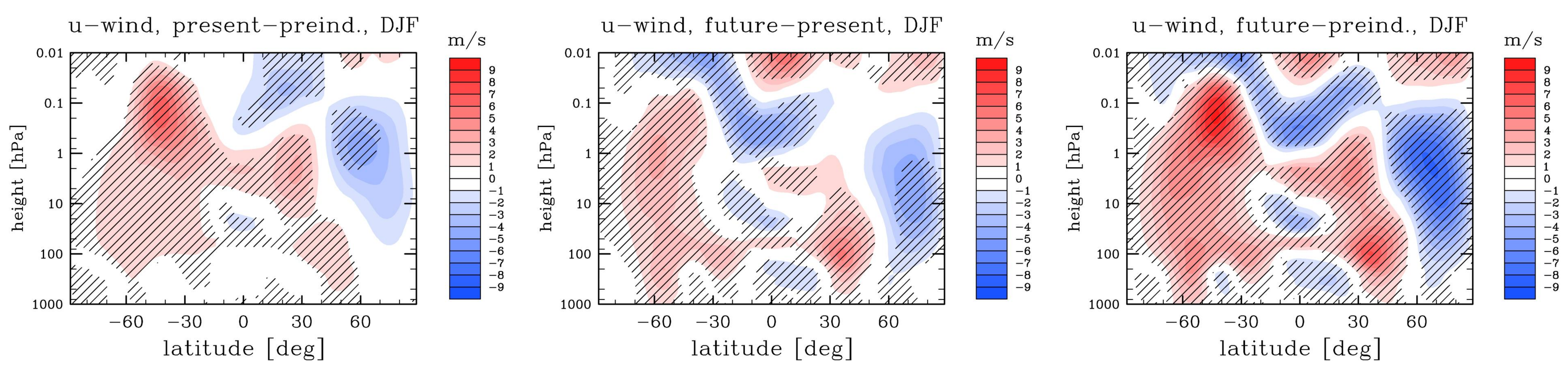


Figure 1: Zonal-mean winds obtained from the climatological year of the present-day time-slice simulation, averaged over DJF, are presented (upper left panel). Additionally, differences between the three time slices are depicted (other panels), which are of 95% significance in shaded areas.



Preliminary work & general aim of this study

As a first step of our study, the ECHAM6 model was run in the T63L47 resolution (extending up to 0.01 hPa). Age-of-air tracer data obtained from these simulations imply that the Brewer-Dobson Circulation, which is the stratospheric part of the residual mean meridional circulation, accelerates under increasing GHG concentrations (see Fig. 4). A derivation of the tropical upwelling velocity at the tropopause supports this. In this work we address the role of planetary waves in the coupling of the stratosphere-troposphere system, as it is simulated in these ECHAM6 runs.

The general aim of our study lies, however, on the impact of the model configuration. Different vertical resolutions and extents will be used, and the influence of the coupling of ECHAM6 to the MPI-OM ocean model will be tested.

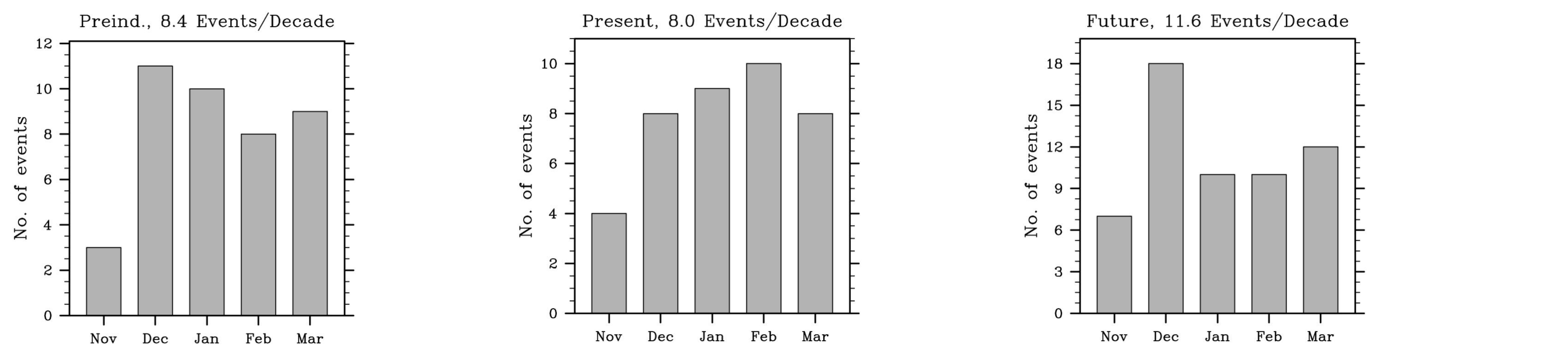


Figure 2: The distribution of major SSW events as well as their frequency in the three different time-slice simulations are presented. For the definition of an SSW we follow Charlton & Polvani 2007. An event is triggered by a zonal-mean zonal wind reversal at 10 hPa and 60 deg N from November to March. Final warmings are excluded.

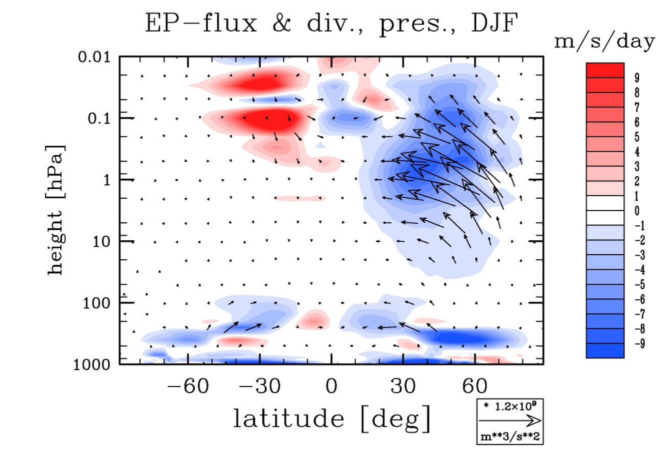
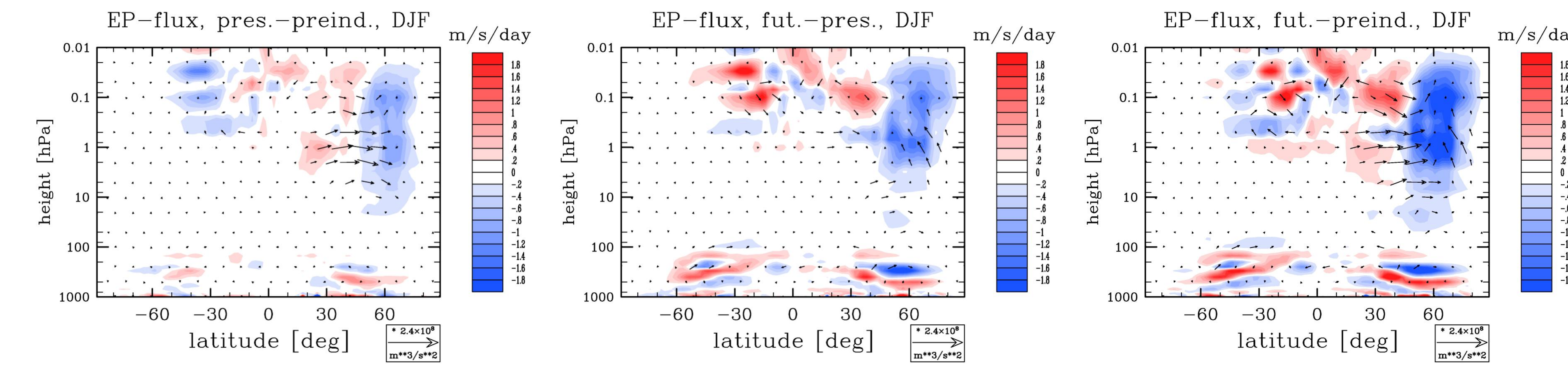


Figure 3: Eliassen-Palm (EP) fluxes and divergences obtained from the climatological year of the present-day time-slice simulation, averaged over DJF, are presented (upper left panel). Additionally, differences between the three time slices are depicted (other panels). Both fluxes and divergences are scaled by the inverse of density. By dividing the EP-flux divergences depicted in these plots by the cosine of latitude, the EP-flux forcing on the zonal-mean flow can be obtained (Andrews et al. 1987).



Discussion of results

The Northern hemispheric winter stratosphere is dominated by a large westerly wind regime. From Fig. 1 we learn that this wind is decelerated in a changing climate. This deceleration turns out to be significant only at levels above 1 hPa from the preindustrial to the present-day state, and below 1 hPa from the present-day to the future time slice. As SSW events are defined by a wind reversal at 10 hPa and 60 deg N, a correlation between this weakening of westerly winds and the increase in frequency of SSWs in the future (see Fig. 2) seems to be obvious.

As planetary waves originating from the troposphere propagate up into the stratosphere, they transport energy upwards. From Fig. 3 we obtain that, in Northern hemispheric winter, wave activity emerging from lower stratospheric midlatitudes is transported upward and enters the lower latitudes just above the stratopause. Here the planetary waves dissipate and, thus, cause a deceleration of the westerly winds. A comparison of the three time-slice simulations implies an intensification of planetary wave dissipation over time causing an increasing deceleration of the westerly winds. An acceleration of the Brewer-Dobson Circulation, which can be derived from mean age of air data (see Fig. 4), is consistent with this.

Changes in planetary wave no. 1 amplitudes between the three time slices, as depicted in Fig. 5, are relatively small. We observe a slight increase peaking at the stratopause from the preindustrial to the present-day state, as well as a decrease at slightly lower altitudes in the future. Planetary wave no. 2 amplitudes, however, show a decrease over time of up to 20% at 10 hPa, while a relatively low increase shows up in the mesosphere.

The decrease of planetary wave amplitudes in the stratosphere does not necessarily contradict the increase in SSW frequency over time. Although the dissipation of planetary waves is assumed to cause the occurrence of an SSW event, wave amplitudes were found to be very low for some days after the event.

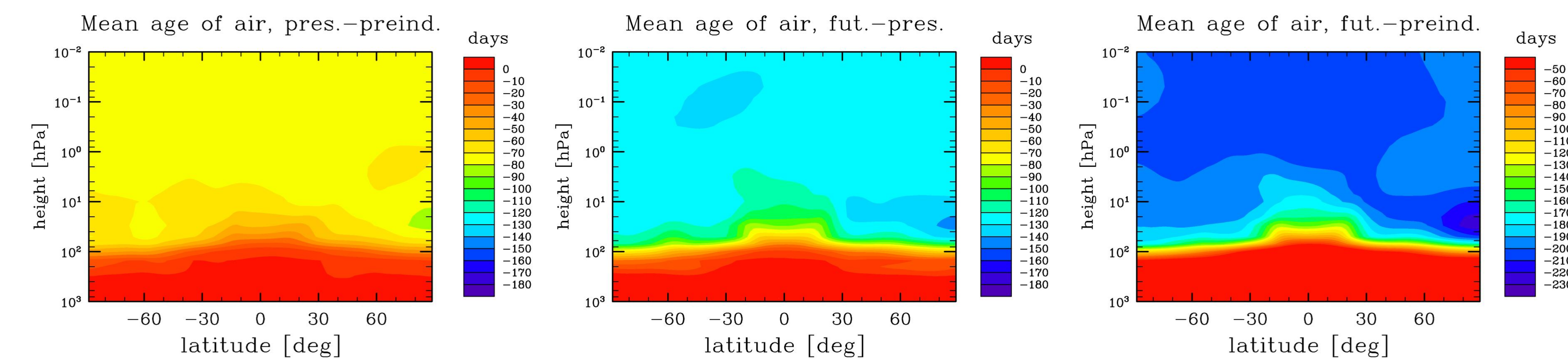


Figure 4: Differences of mean age of air between the three time–slice simulations are presented. Data was obtained by injecting a passive tracer between -5 and +5 deg N with linearly increasing concentration (Hall & Plumb 1994). Climatological years built from the last 30 years of each simulation were subtracted from each other.

References

Andrews, D. G., Holton, J. R. & Leovy, C. B., Middle Atmosphere Dynamics, *Academic Press, 1987*

Charlton, A. J. & Polvani, L. M., A New Look at Stratospheric Sudden Warmings, *J. Climate, 20, 449, 2007*

Hall, T. M. & Plumb, R.A., Age as a diagnostic of stratospheric transport, *J. Geophys. Res., 99, 1059, 1994*

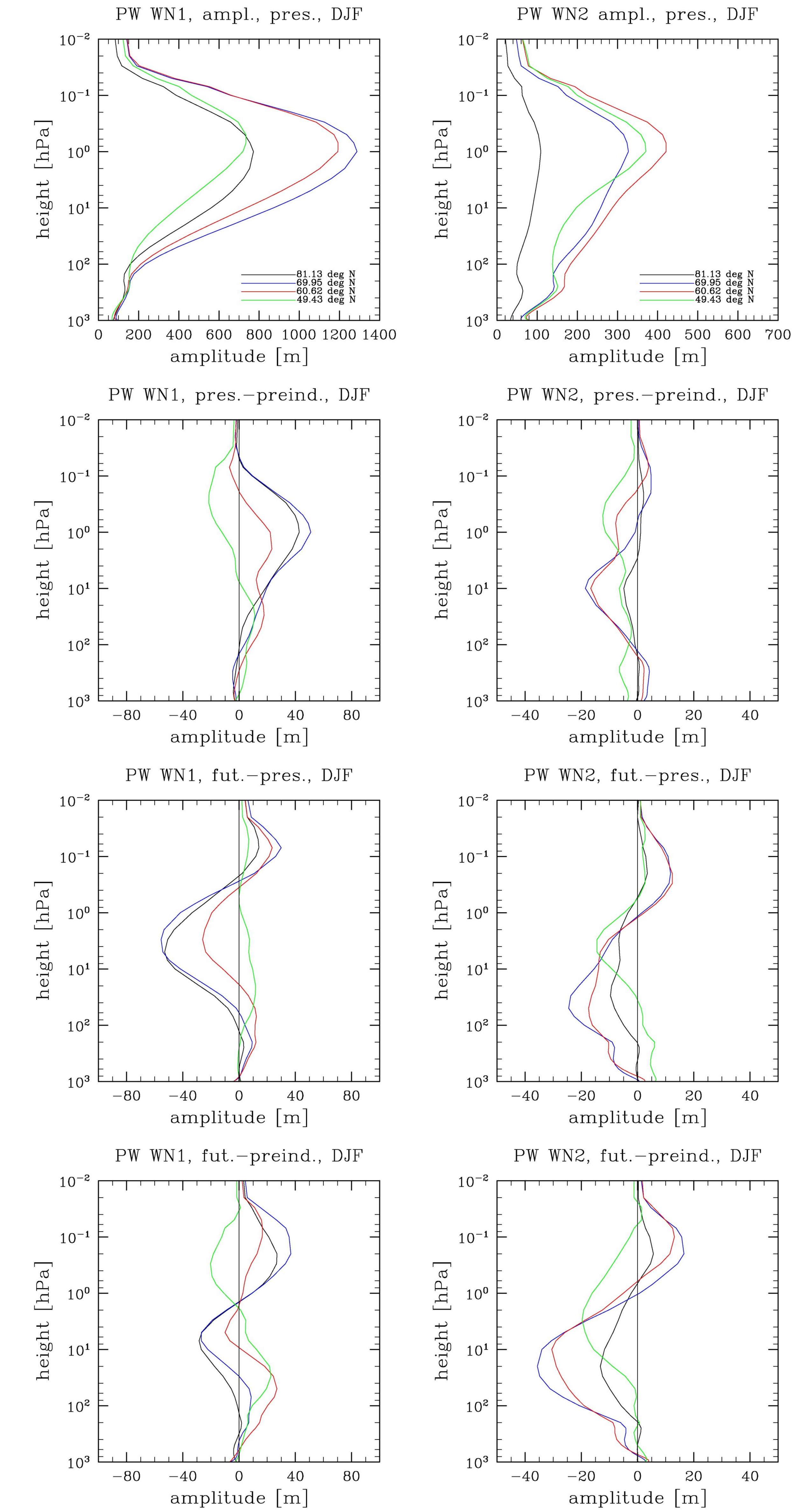


Figure 5: Planetary wave no. 1 (left) and 2 (right) amplitudes obtained from the climatological year of the present-day time-slice simulation, averaged over DJF, are presented for four different latitudes (upper panels). Additionally, differences between the three time slices are depicted (other panels).

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