Stratosphere-troposphere dynamical coupling in a changing climate

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1. Introduction

- Increasing greenhouse gas (GHG) concentrations cause an increase in tropospheric temperatures and a decrease in stratospheric temperatures (see Fig.1 left).
- Via thermal wind balance the meridionally varying temperature change modifies the zonal-mean zonal wind field (see Fig.1 right).
- The resulting changes in propagation, dissipation and breaking of atmospheric waves, which are most prominent in northern winter, cause a strengthening of the stratospheric meridional overturning circulation, and yield implications for:
  - ➢ the downward propagation of stratospheric anomalies (see Section 2).
  - ➢ the occurrence frequency of extreme stratospheric events, such as major sudden stratospheric warming (SSW) events (see Section 3).
  - ➢ the impact of stratospheric disturbances on surface climate (see Section 4).

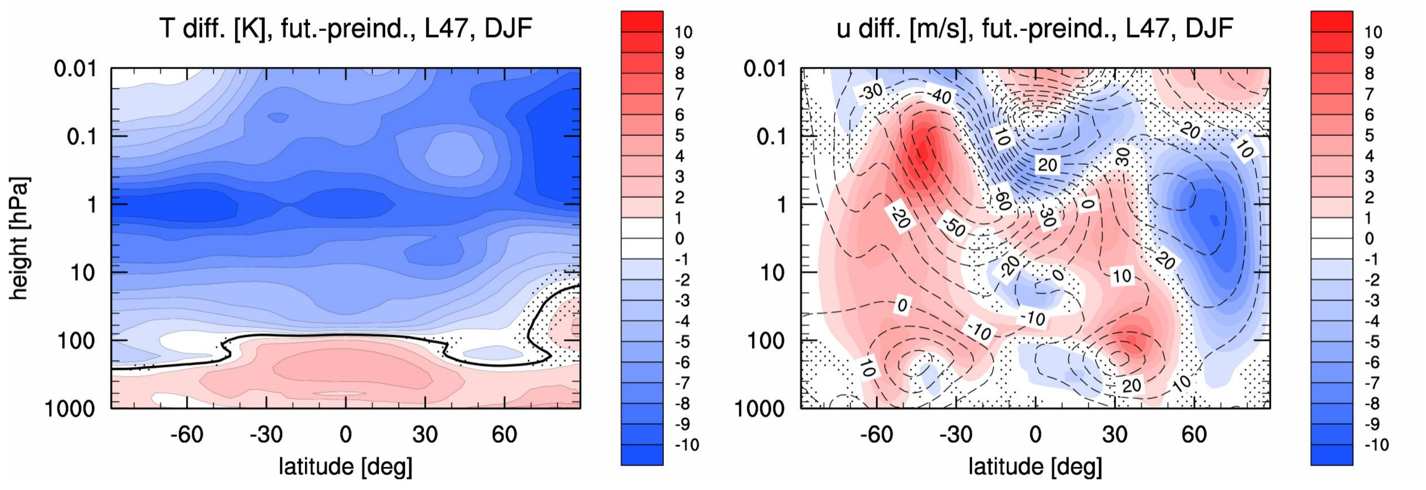

Figure 1: Zonal-mean temperature (left) and zonal wind (right) difference between future and preindustrial climate states, derived from ECHAM6 sensitivity simulations. Dotted areas indicate differences below the 2-sigma level. Dashed contours (right) show the zonal-wind field of the preindustrial control run.

Aim of this study

- We analyse multi-decadal sensitivity simulations performed with the atmospheric General Circulation Model (GCM) ECHAM6 in order to investigate the impact of increasing GHG concentrations on the communication of a stratospheric disturbance to the troposphere.
- The CMIP5 simulations performed with the coupled atmosphere-ocean-land GCM MPI-ESM are analysed with regard to the occurrence frequency of major SSWs, and the impact of these extreme stratospheric events on surface climate.

Model simulations

- ECHAM6 atmospheric GCM:
  - ➢ 50-year sensitivity simulations for preindustrial (1860), present-day (1990) and future (2050, after RCP4.5) climate states in the T63L47 configuration.
- MPI-ESM coupled atmosphere-ocean-land GCM:
  - ➢ 1000-year preindustrial (1850) control run, and transient simulations of the historical period (1850-2005) as well as future scenarios RCP4.5/8.5 (2006-2300) in the LR configuration (47 atmospheric layers).

2. Downward propagation of stratospheric anomalies: The Northern Annular Mode

- Anomalies of the stratospheric polar vortex are reflected by the Northern Annular Mode (NAM) index, which is calculated here as the leading principal component time series of geopotential height anomalies within 20N-90N latitude on a pressure surface (more details: *Zonal-mean EOFs* in Baldwin & Thompson 2009).
- Anomalies in the NAM index were found to propagate downward and, in some cases, cause a significant impact on the troposphere-surface system (e.g. Baldwin & Dunkerton 2001).
- A stratospheric weak (strong) vortex event is triggered, when the NAM index at 10 hPa exceeds -3 (+2) standard deviations.
- When a weak vortex event is triggered in ECHAM6, there is always an associated major SSW coinciding within five days of the central date of the weak vortex event.

Composites of weak/strong vortex events:

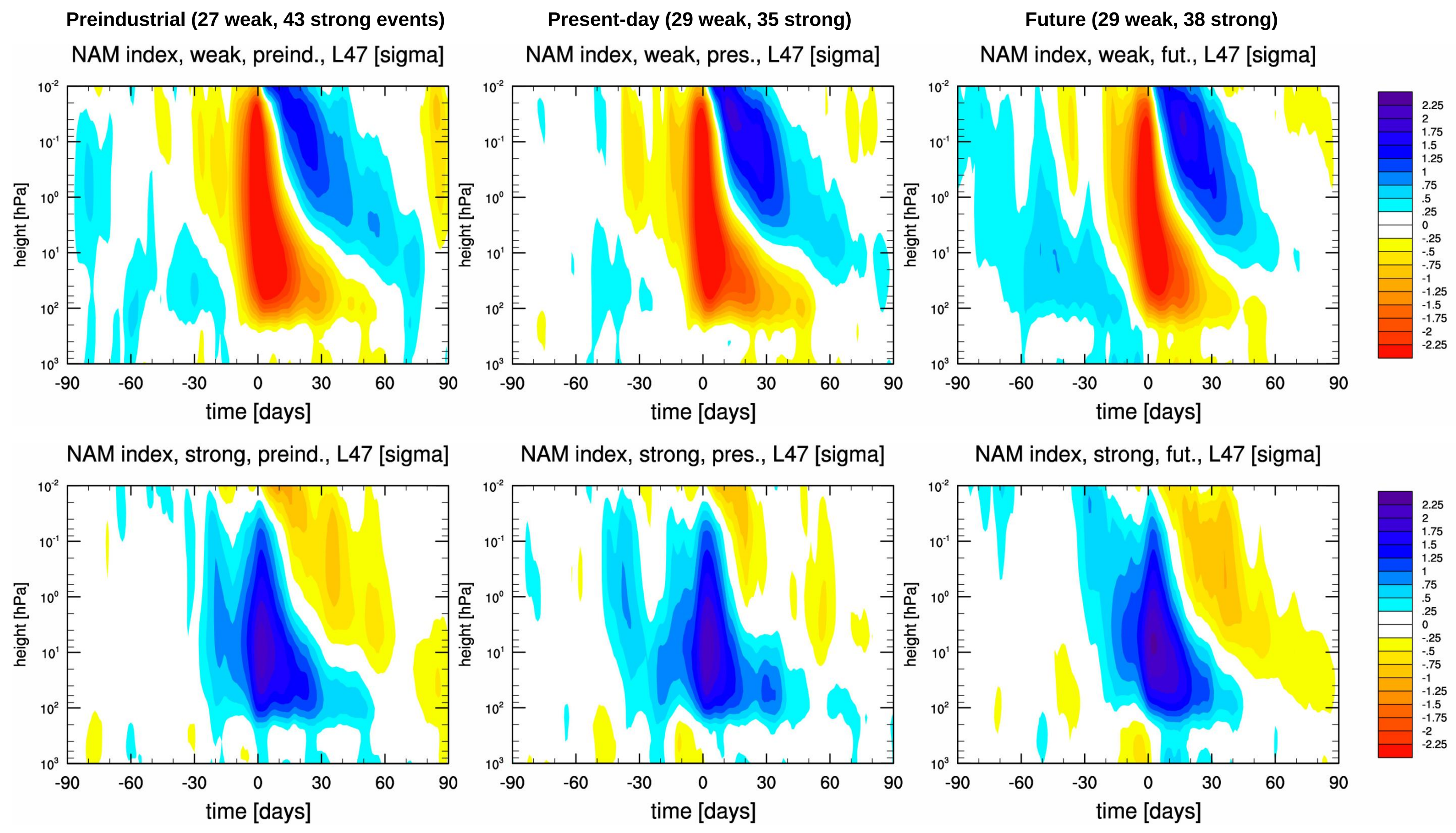

Figure 2: Downward propagating negative (top) and positive (bottom) NAM index events for preindustrial (left), present-day (middle) and future (right) ECHAM6 sensitivity simulations.

- ➢ The downward propagation of NAM anomalies seems to slightly accelerate under a changing climate, as the interaction time between stratosphere and troposphere becomes shorter.
- ➢ However, composite plots do not show any remarkable impact of a changing climate on the downward propagation of a stratospheric disturbance.

3. Extreme stratospheric events: Major sudden stratospheric warmings

- The dissipation and breaking of large-scale planetary waves propagating upward from the troposphere to the stratosphere decelerates the polar night jet and, in extreme cases, causes the occurrence of a major SSW event.
- After e.g. Charlton & Polvani (2007), a major SSW event is triggered, when the zonal-mean zonal wind at 60N latitude at 10 hPa turns easterly during November-March (final warmings are excluded).

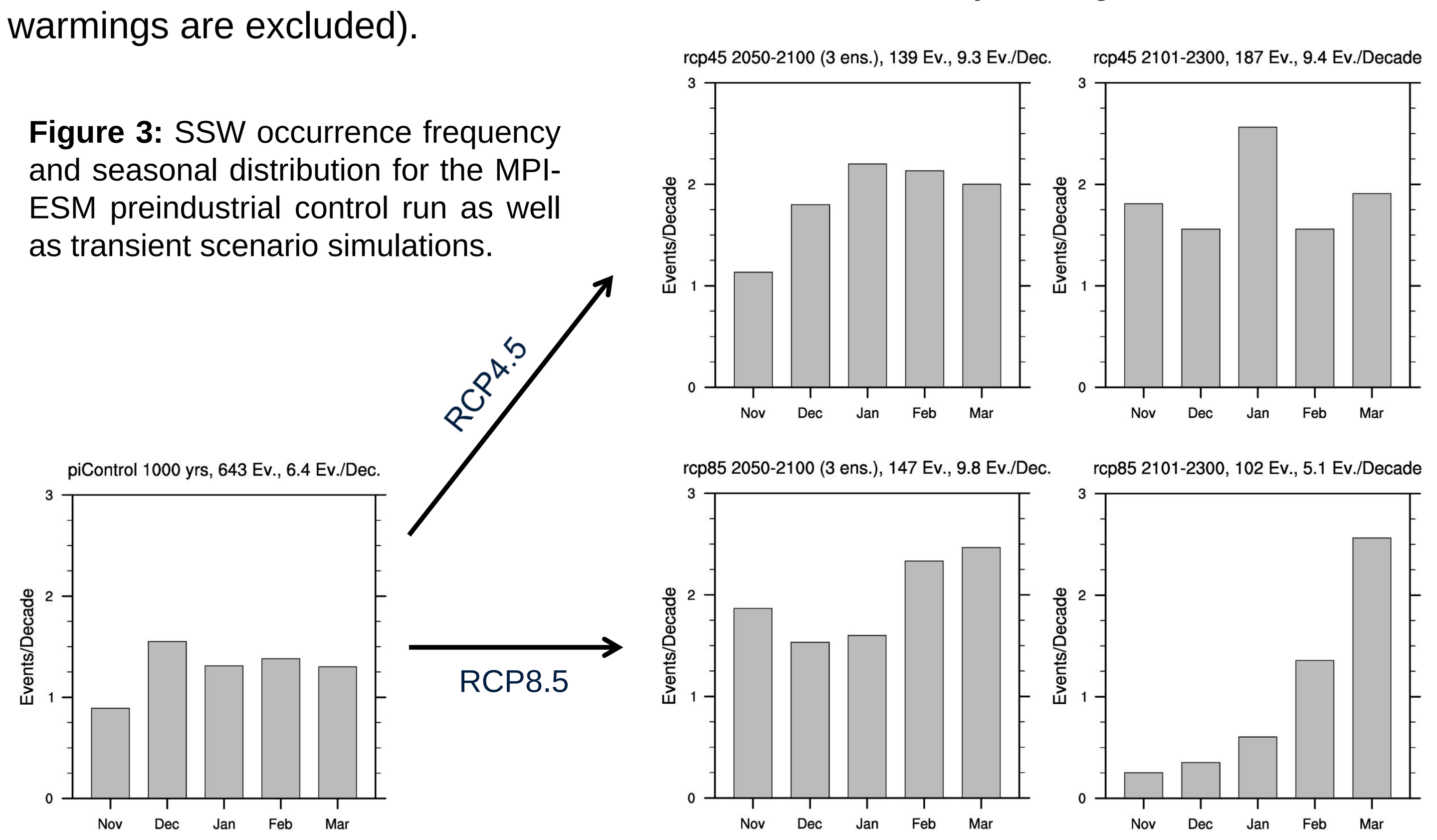

Figure 3: SSW occurrence frequency and seasonal distribution for the MPI-ESM preindustrial control run as well as transient scenario simulations.

- ➢ SSW frequency increases by 50% in 2050-2100 in the RCP4.5/8.5 scenarios.
- ➢ Remarkable decrease in SSW frequency is found after 2100 in the RCP8.5 scenario, coinciding with a conspicuous SSW distribution shift to late winter.

4. The North Atlantic Oscillation: How stratospheric changes may impact the surface

High correlation between the stratospheric polar vortex and the North Atlantic Oscillation (NAO) during northern winter (e.g. Schnadt & Dameris 2003):

- ➢ The positive phase of the NAO is associated with a strong polar vortex in the stratosphere, coinciding with enhanced westerlies over the North Atlantic and positive temperature anomalies over central and northern Eurasia.

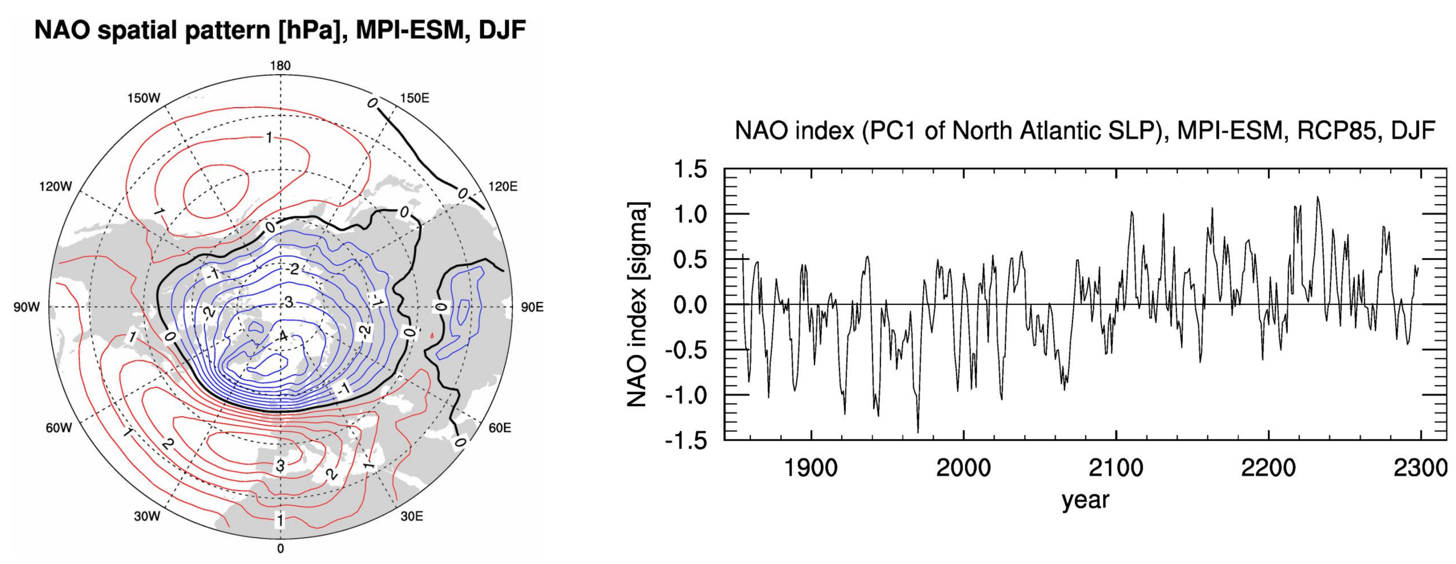

Figure 4: The NAO spatial pattern (left, leading EOF of the DJF-mean sea level pressure anomalies), derived by regressing the hemispheric sea level pressure anomalies upon the leading principal component time series (right, NAM index). For the NAM index, 5-year running-mean values are shown. Input data is an MPI-ESM historical simulation extended with an RCP8.5 simulation. The input time series was detrended before EOF analysis was applied.

- ➢ A conspicuous shift to more positive phases of the NAO is simulated in the RCP8.5 scenario after 2100, implying more mild winters in central and northern Eurasia.

5. Conclusions

- In a changing climate induced by increasing GHG concentrations the downward propagation of stratospheric disturbances, such as extreme NAM events, seems to be accelerated.
- In the second half of the 21st century, the RCP4.5/8.5 scenario simulations performed with MPI-ESM show a significant increase in the number of major SSW events, which coincide with extreme negative NAM anomalies.
- After 2100 a remarkable decrease in SSW occurrence frequency and a conspicuous SSW distribution shift to the late winter are simulated in the RCP8.5 scenario run.
- The decrease in SSW frequency in the RCP8.5 scenario after 2100 coincides with a shift to more positive NAO phases, implying more mild winters in central and northern Eurasia.

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