Sensitivity of Simulated Mesospheric Transport of Nitrogen Oxides to Parameterized Gravity Waves

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Motivation

After a sudden stratospheric warming event the transport of nitrogen oxides (NOx) produced by energetic particles is strongly enhanced. However, this downward transport is in general underestimated in models covering this altitude range. McLandress et al. (2013; JGR) stated that after a SSW the non-orographic gravity waves drive the circulation and thereby the descent of tracers (e.g., CO, NOx) from the thermosphere. Siskind et al. (2015; GRL) suggested that a weak mesospheric descent is caused by an underestimation of the non-orographic gravity wave drag.

Here, we analyze the sensitivity of simulated mesospheric transport of NOx to changes in the parameterized gravity wave sources.

Conclusion

We found that with a stronger gravity wave source, less NOx is transported after the SSW to the mesosphere and the elevated stratopause descends more rapidly to its climatological altitude. We observe the opposite by **weakening the gravity wave sources** yielding a better agreement with the observations.

The amount of the transported NOx is controlled by the **altitude at which momentum is deposited** in the atmosphere. The higher the altitude where the momentum is deposited in the upper mesosphere, the stronger is the descent of NOx. A **small wave amplitude** favors the transition to turbulence at a higher altitude due to the exponential increase of the amplitude with height.

1. Experimental Design

- General circulation and chemistry model HAMMONIA (Hamburg Model of Neutral and Ionized Atmosphere) – T63 L119
- Nudged up to 1 hPa to ERA-Interim data
- Four experiments with changed gravity wave sources:
    - Control experiment
    - Strengthening of frontal source ("front on")
    - Strengthening of background source ("strong")
    - Weakening of background source ("weak")

2. Sensitivity of NOx Transport

- Strengthening of gravity wave sources reduces NOx transport, while a weakening of the gravity wave sources strengthens the NOx transport.
- Elevated stratopause descends too quickly with stronger gravity wave sources but remains longer at a higher altitude with a weaker gravity wave source.

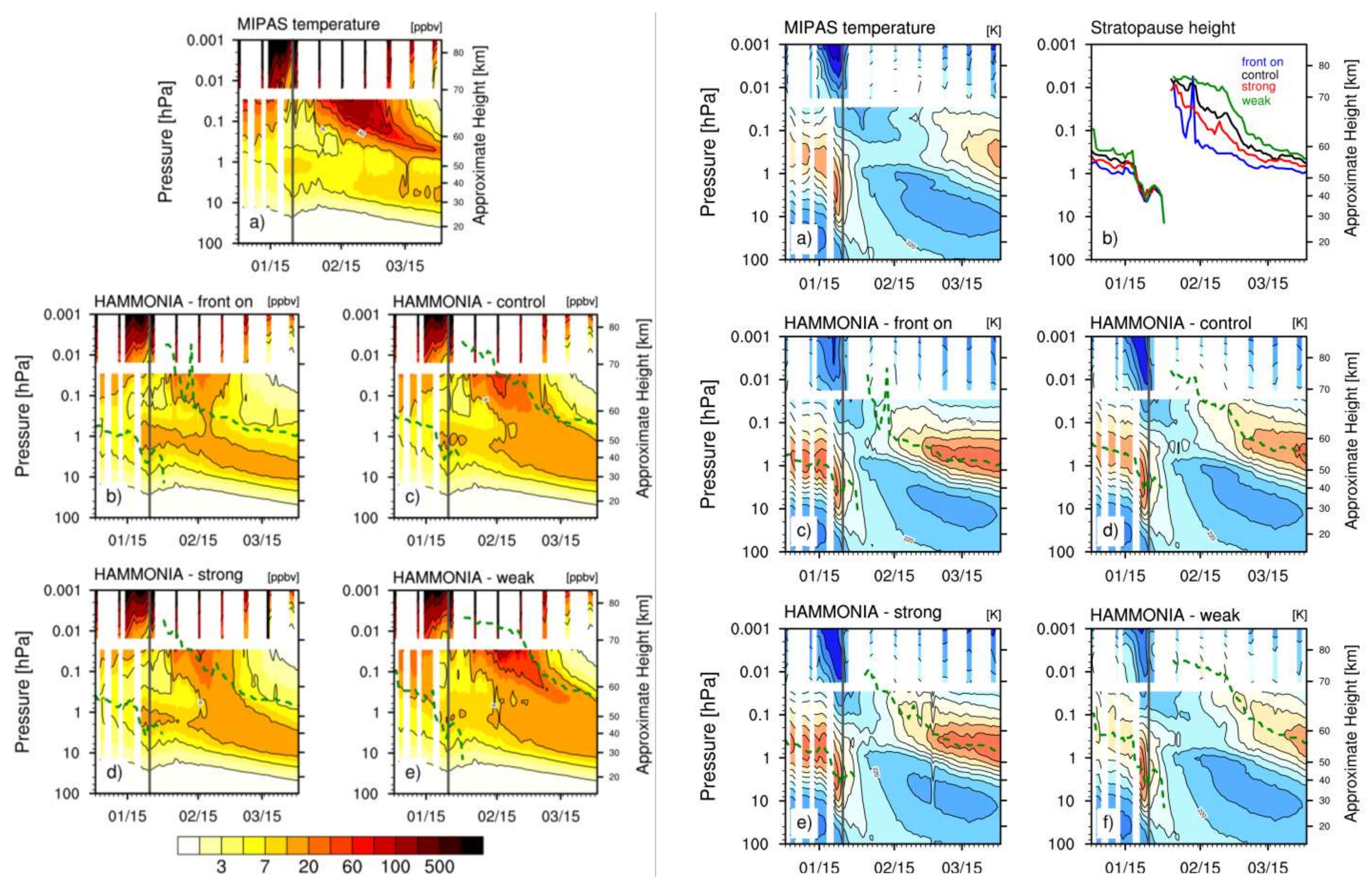


Fig 1.: (left) NOx volume mixing ratio and (right) temperature over 60°N - 90°N for January to April 2009 in (a) MIPAS and four HAMMONIA simulations: (b) "front on", (c) "control", (d) "strong" and (e) "weak".

3. Changes in the Vertical Wind

- Weakened downwelling with stronger gravity wave sources, while a strengthened downwelling with a weaker background source.

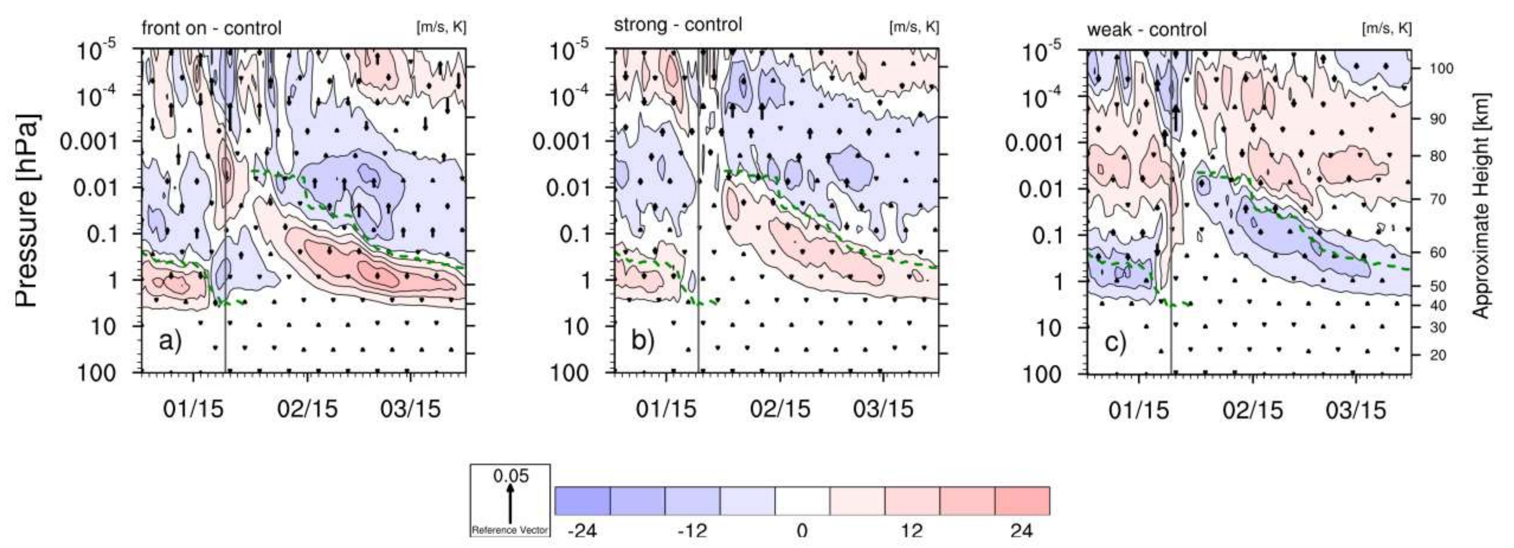


Fig 2.: Temperature and residual vertical wind differences [K, m/s] for January to April 2009. Anomalies to the control experiment are given for (a) "front on", (b) "strong" and (c) "weak".

4. Changes in the Gravity Wave Drag

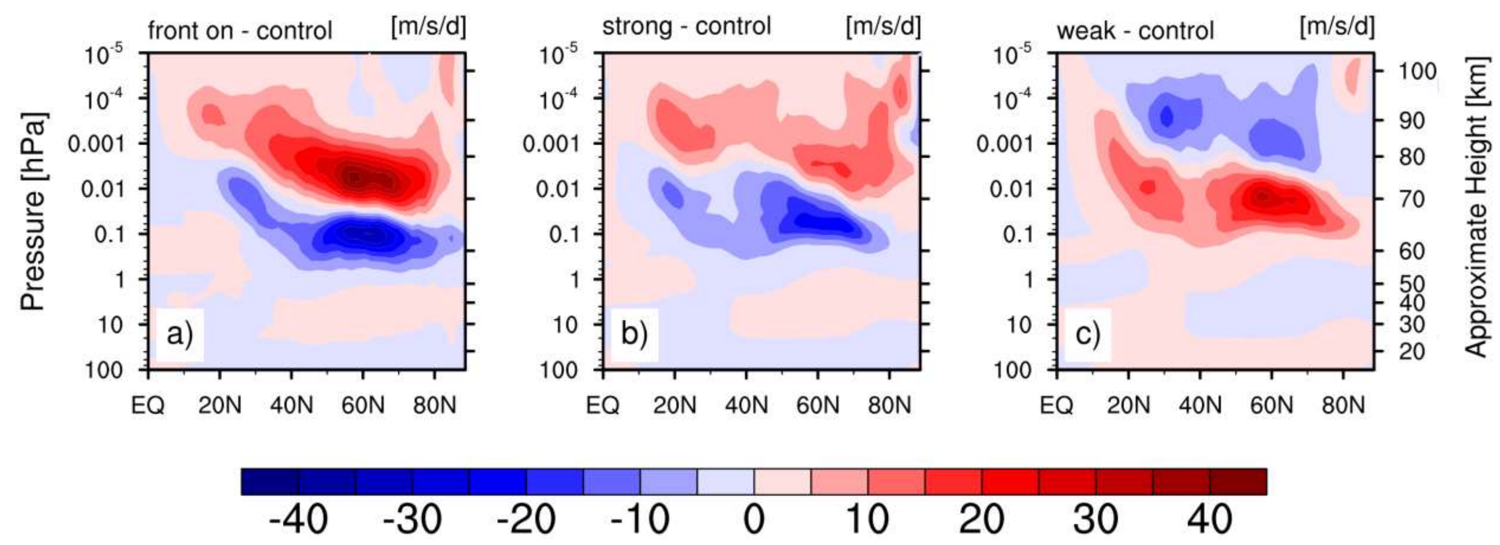
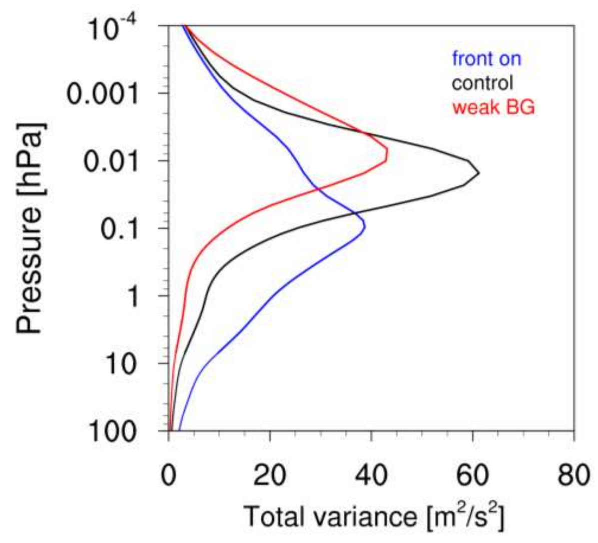


Fig 3.: Difference in the non-orographic gravity wave drag [m/s/d] for February 10th to March 12th, 2009. Anomalies to the control experiment are given for (a) "front on", (b) "strong "and (c) "weak".

- Maximum in gravity wave drag is shifted upward for a weak source.
- Altitude at which a considerable amount of momentum is deposited controls the strength of the transport.
- A deposition of momentum at a higher altitude extends the downwelling branch of the meridional circulation to a higher level.

5. Changes in the Wave Amplitude



- The initial wave amplitude is largest for "front on" and smallest for "weak".
- Increase in the wave amplitude due to decrease in density
- Critical altitude at which the wave amplitude becomes unstable is lower for "front on" and higher for "weak".

Fig 4.: Total gravity wave wind variance [$m^2 s^{-2}$] on February 18th, 2009 averaged between 60°N and 90°N for three experiments: "control" (black), "front on" (blue) and "weak" (red).

6. Free-running Simulations

- The stratospheric zonal wind extends for a weak background source further to the pole, which agrees with ERA-Interim reanalysis data.
- Mean circulation and NOx transport suggest a similar setting of the gravity wave sources (i.e., weak background and no frontal source) in nudged and free-running simulations.

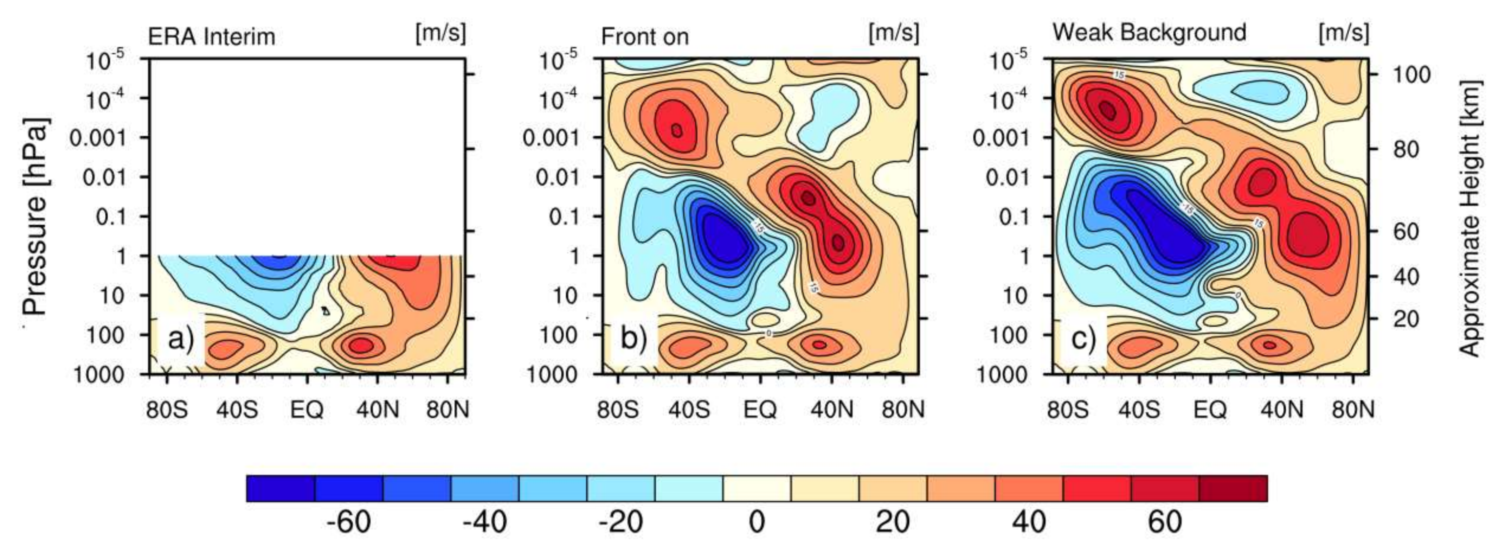


Fig 5.: Zonal mean zonal wind averaged over December - February (DJF) for (a) ERA Interim and two free-running simulations (b) with gravity waves from fronts and a strong background (σ=0.8 m/s) and (c) with a weak background (σ=0.6 m/s) and no frontal source.

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