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Zonally asymmetric ozone and their effects on the stratospheric temperature, polar vortex and planetary wave propagation

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- outline

+ there are stratospheric zonally asymmetric ozone changes in trend-like and decadal scales

+ former sensitivity studies showed that zonally asymmetric ozone changes (O3*) in the UT/LS region have a significant influence on tropospheric circulation due to the induced radiative forcing

+ the extension of this investigation to the middle atmosphere where direct solar radiation is more important via ozone was done

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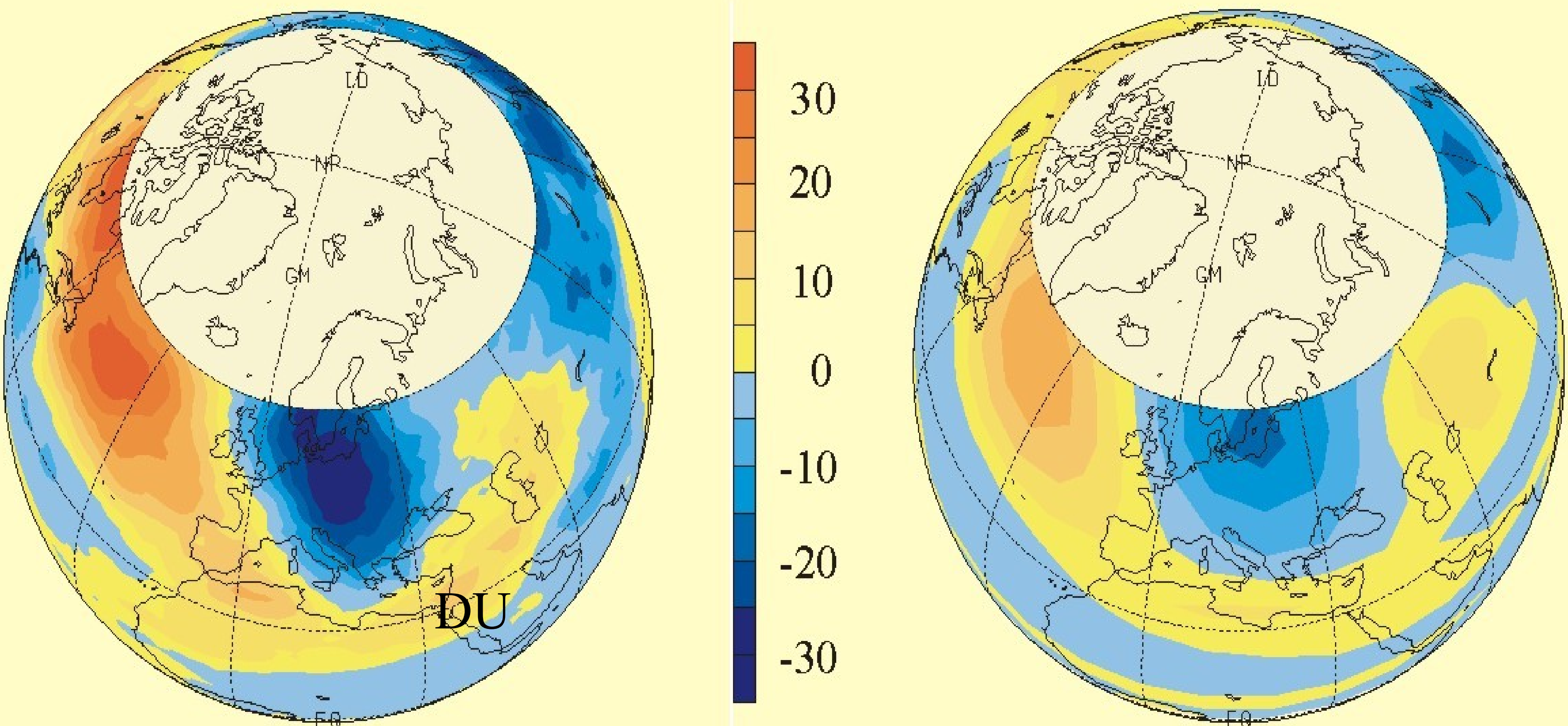
Motivation (a) decadal

Decadal changes of total O3* for January of the 1980ies

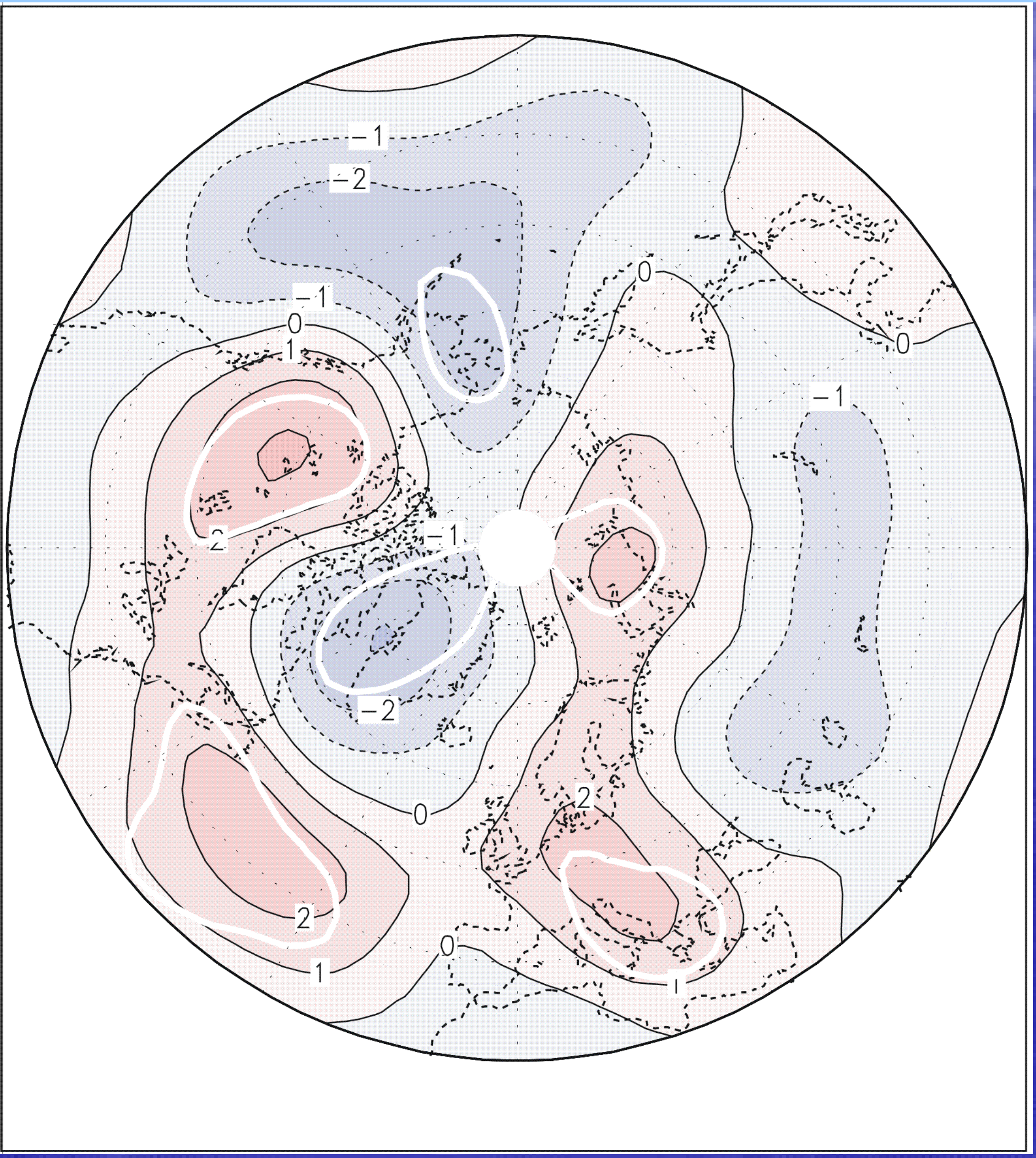


Observation TOMS

Model LIMO3

after Peters & Entzian J.Clim. 1999

Motivation (b) trend-like



Trend of geopotential height
January 1959-2001 (NCEP-reana)
(zonally asymmetric, 300 hPa, m/ a)

white lines indicate areas of significance (>95%)

Note: From a known empirical regression formula (Entzian & Peters 2003) follows also a trend-like O3* (zonally asymmetric) change of total ozone for January

from Peters et al., 2007

Motivation (c)

- **Open questions**

+ What is the structure of the decadal and trend-like zonally asymmetric ozone changes in the middle atmosphere?

    ➔ *ERA-40 and satellites*

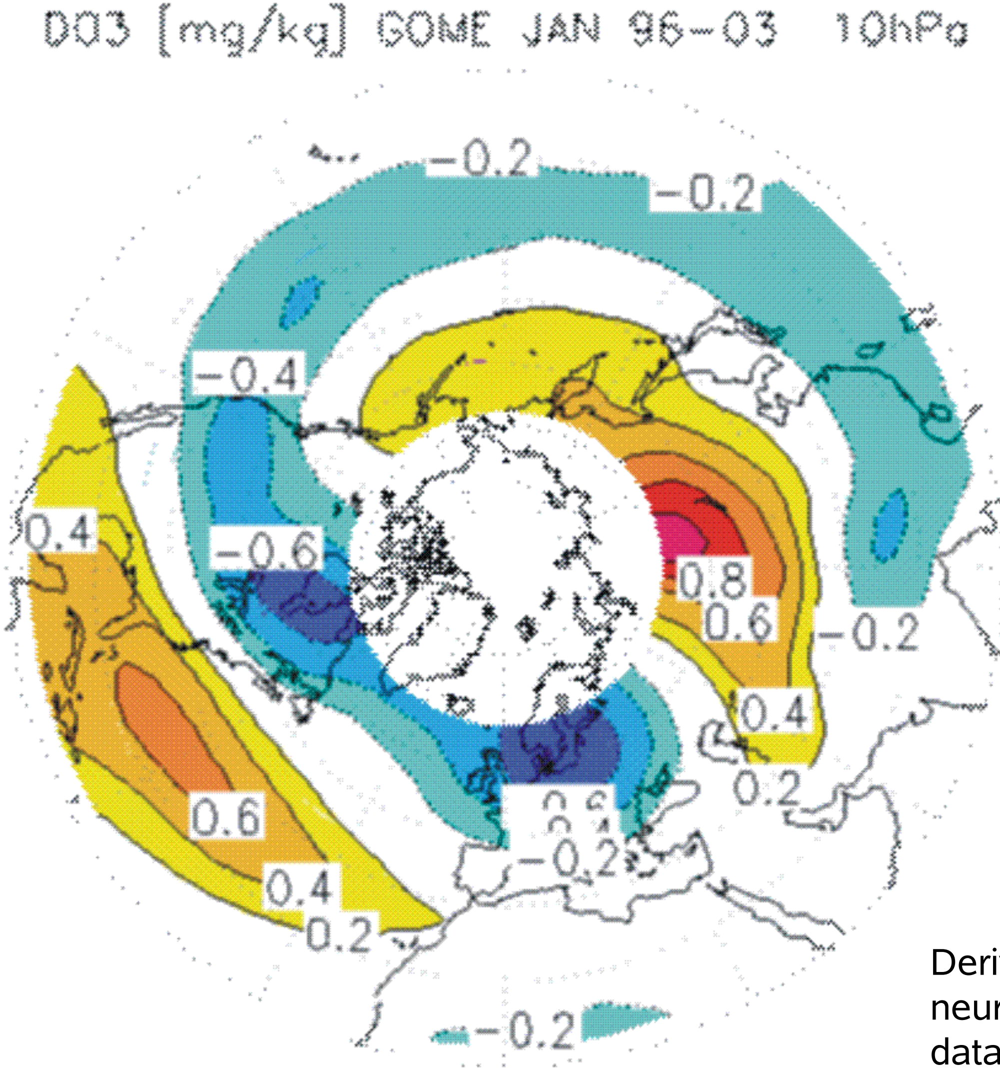
+ Which direct or indirect effect have the induced changes of solar radiative forcing?

    ➔ *heating rates*

+ How do the zonally asymmetric ozone changes influence the coupling of atmospheric layers?

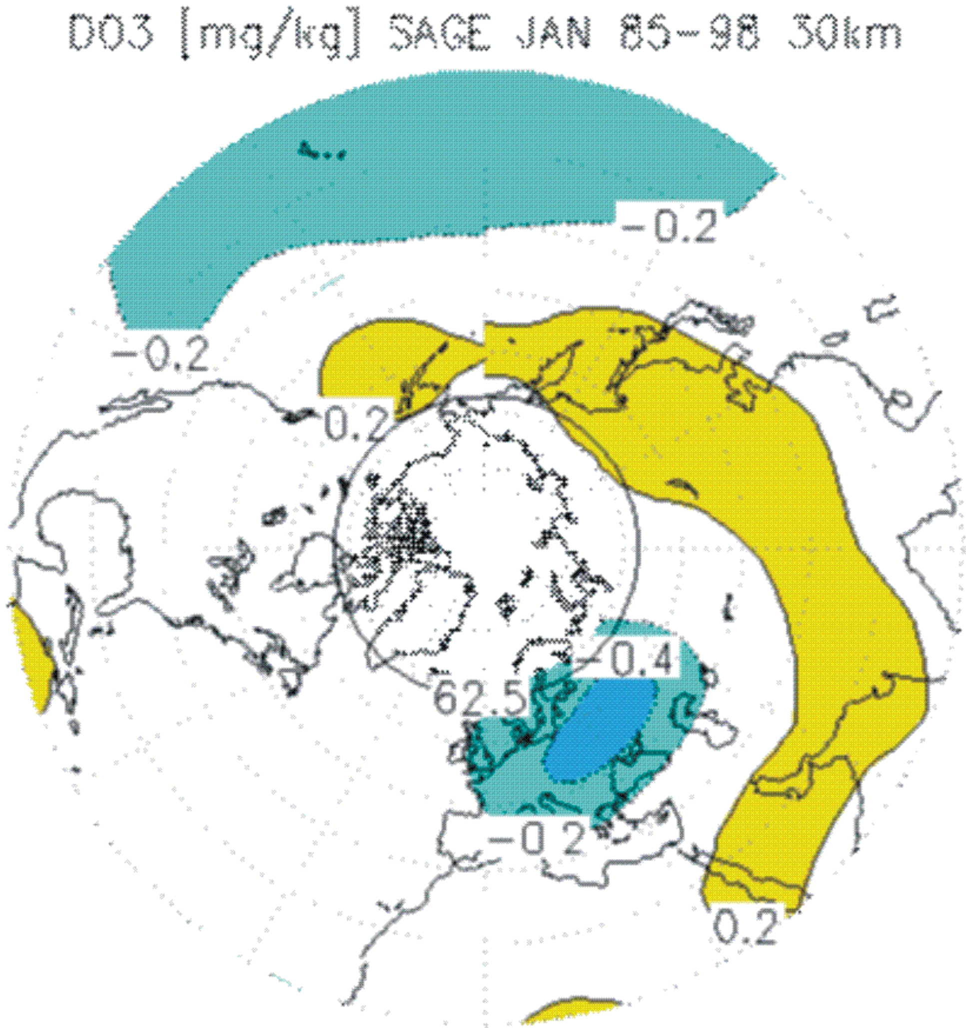
    ➔ *GCM sensitivity runs without O3* and with O3* changes*

Zonally asymmetric ozone variations O_3^* at 30 km – GOME



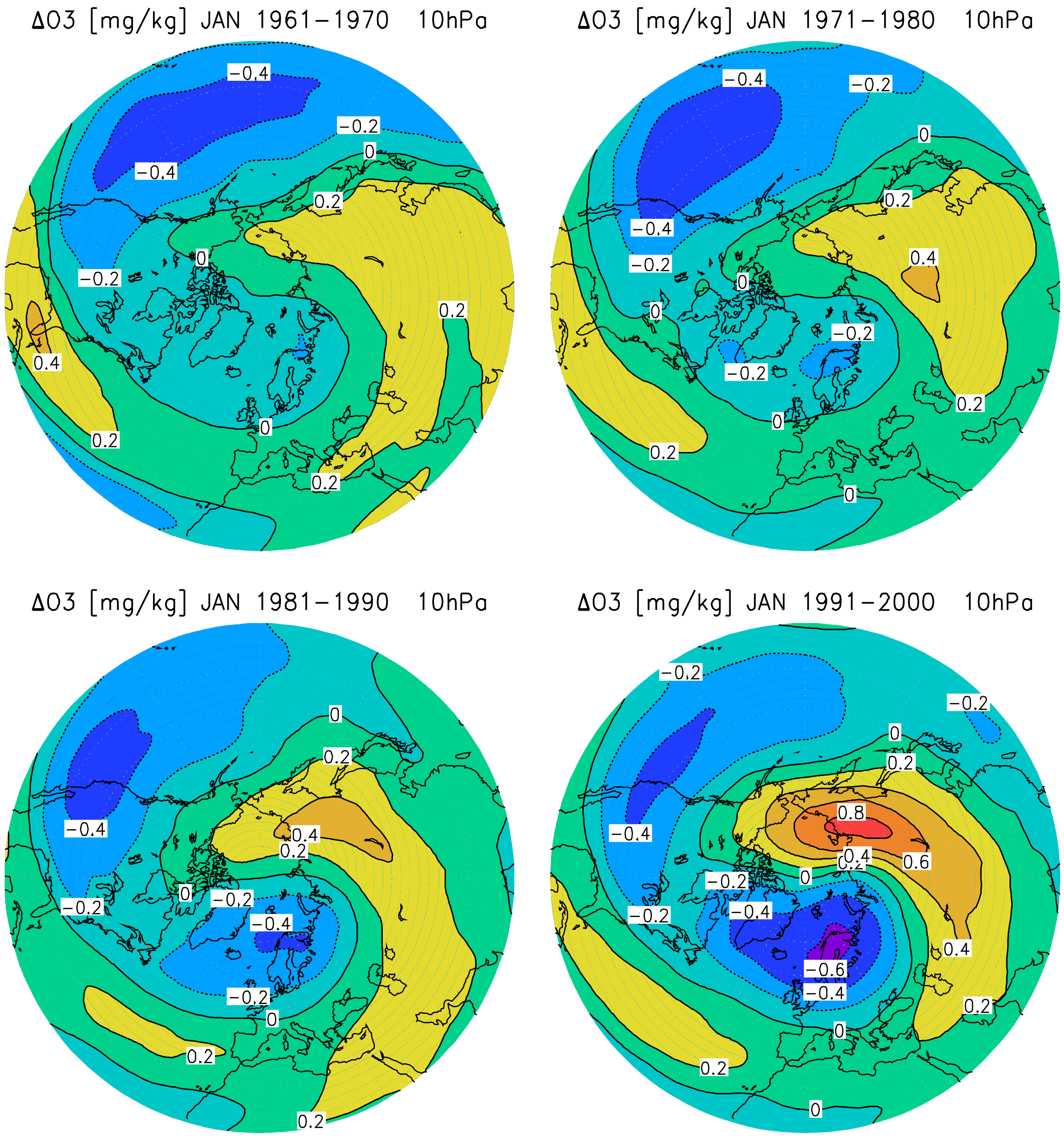
Derived from GOME by neuronal network technique, data output on 5x5° grid boxes (provided by A. Kaifel, ZWS)

Zonally asymmetric ozone variations O_3^* at 30 km – SAGE



max. ≈ 900 profiles per month,
sampled on 10°x10° grid boxes

Decadal changes of zonally asymmetric ozone variations O_3^* at 10 hPa – ERA – 40 – data set



60ies

70ies

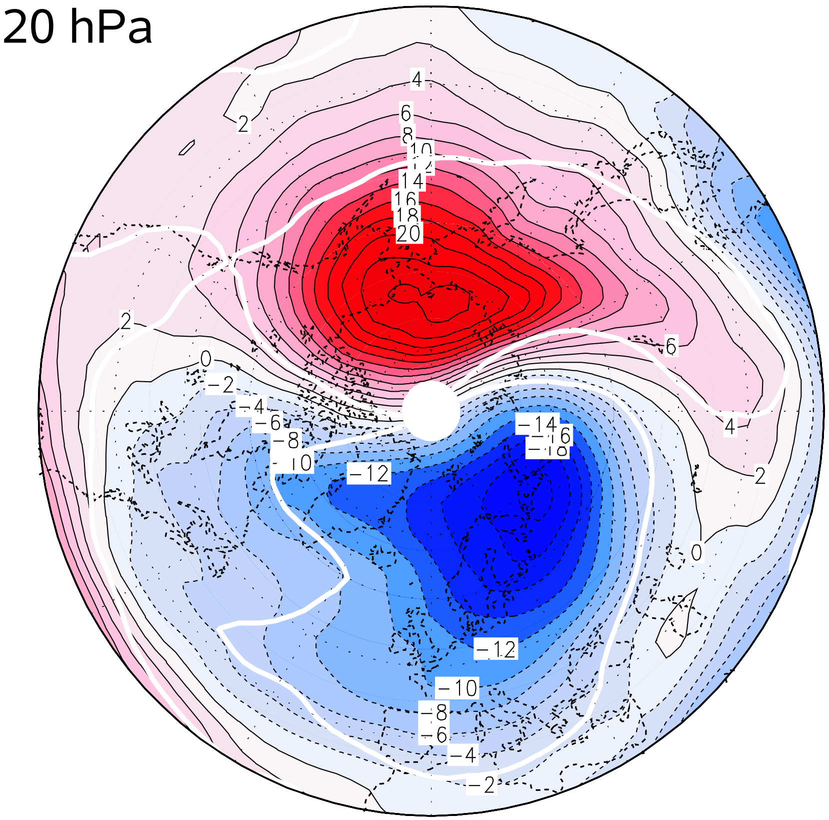
80ies

90ies

max. amplitude:
0.8 mg/kg (10%)

Trend in zonally asymmetric ozone of ERA-40 at 20 hPa for January

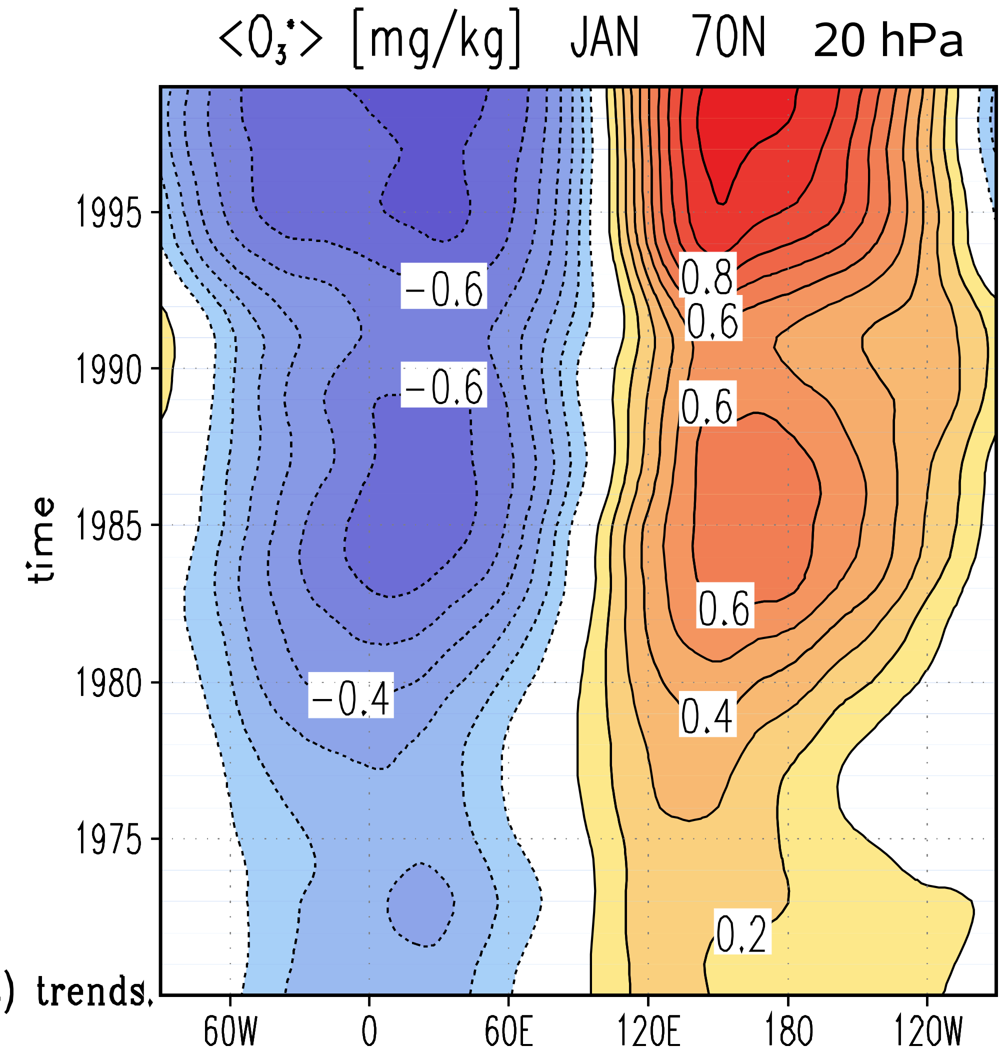
trend of O3* [μg/kg/a]



January 1960–2002

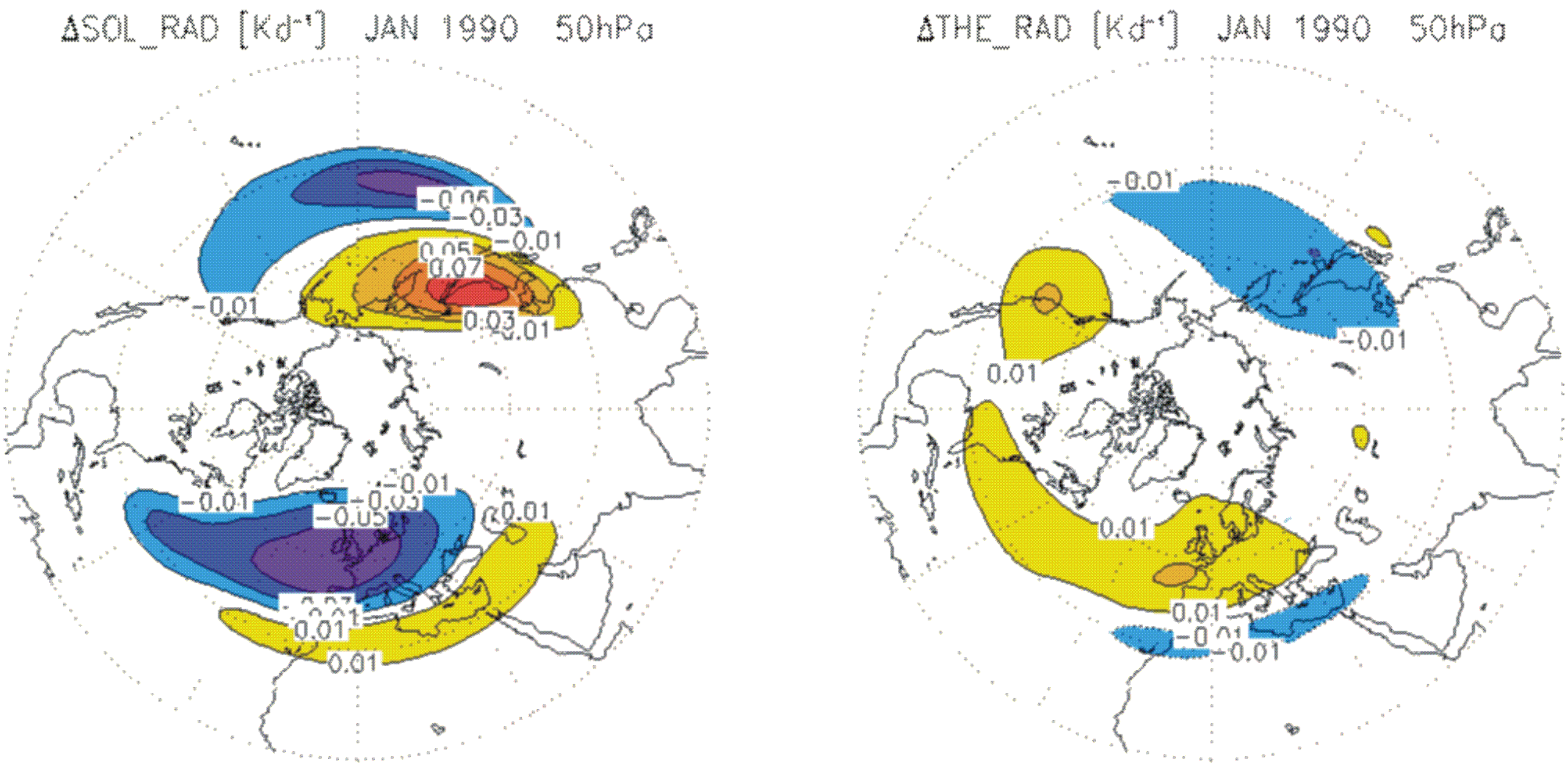
White lines indicate areas of significant (>95%) trends.

evolution of O3* [mg/kg]



(note: 20 μg/kg year^{-1} = 0.2 mg/kg decade^{-1})

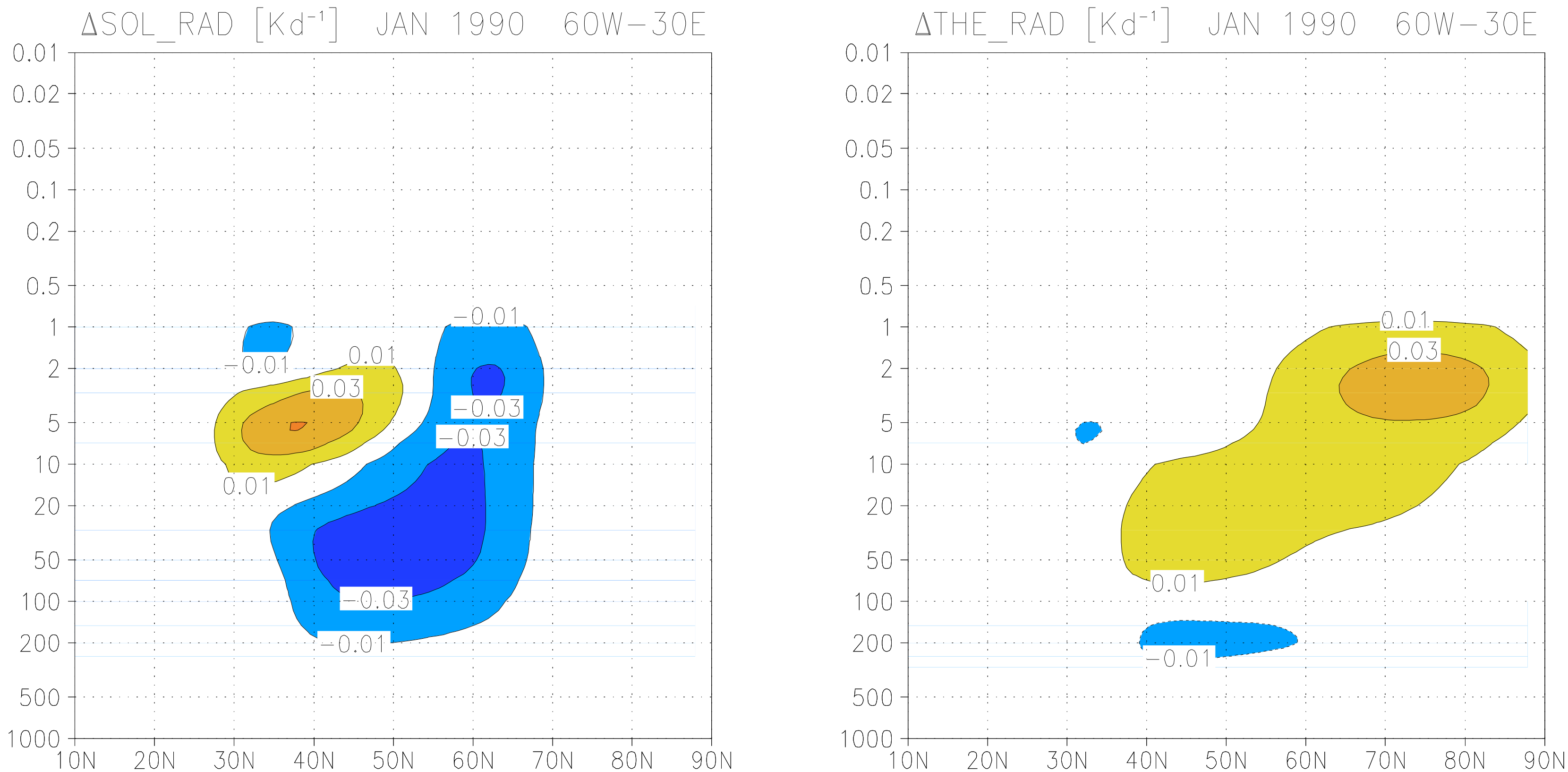
Radiative perturbations due to the zonally asymmetric ozone variations O_3^* at 50hPa



Solar (left) and thermal (right) radiative heating rates [K day^{-1}] induced by O_3^* at 50hPa, averaged over January (calculated with MAECHAM5 including AMIP-SST)

After Gabriel et al. GRL2007

Radiative perturbations due to O_3* – North-Atlantic / Europe



Solar (left) and thermal (right) radiative heating rates [K day^{-1}] induced by O_3*, averaged over January and over a zonal sector of 60°W-30°E

After Gabriel et al. GRL2007

Model and Setup

- GCM MAECHAM5 (resolution: T42, 39 levels up to 0.01 hPa)

  ☞ Roeckner et al., MPI Report 349, 2003

Control run:

10 years with AMIP-SST 1989-1999,
including zonal mean ozone climatology (Fortuin & Kelder, 1998)

Model experiment:

January mean zonal asymmetric ozone variations O_3*
of 1990ies (ERA-40)
are added, starting with October (500hPa ≥ p ≥ 1ha, φ ≥ 30° N)

→ 10 winter periods (DJF) with and without O_3*

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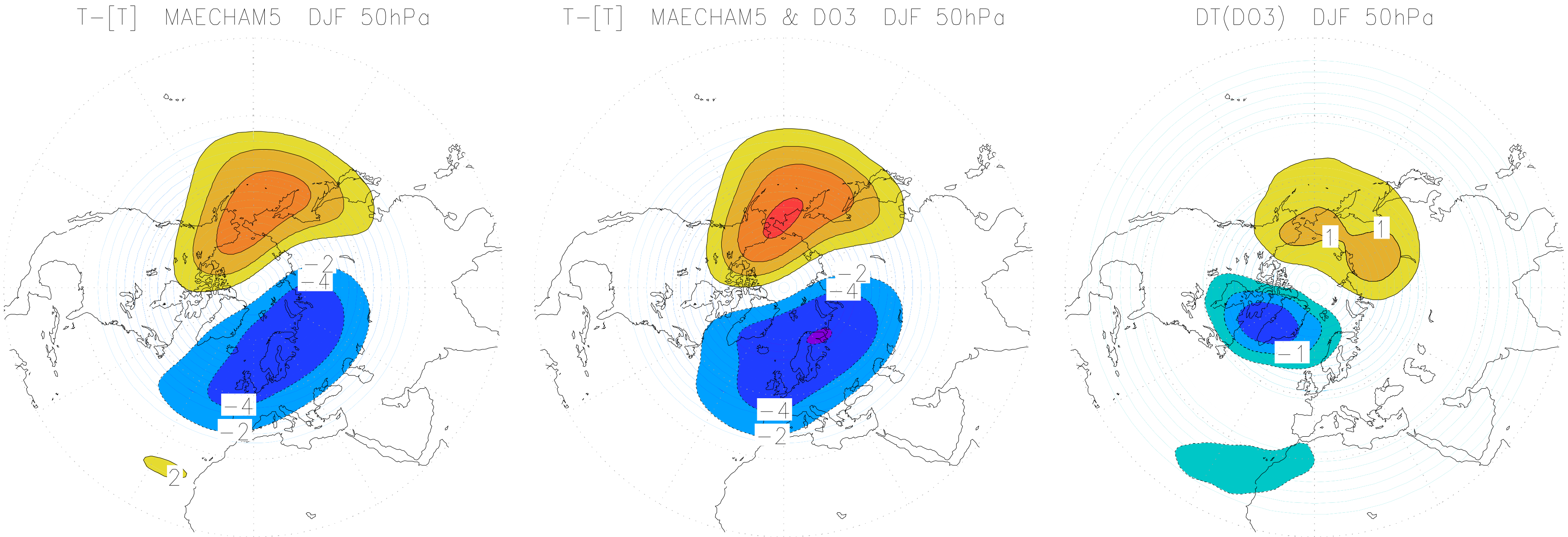
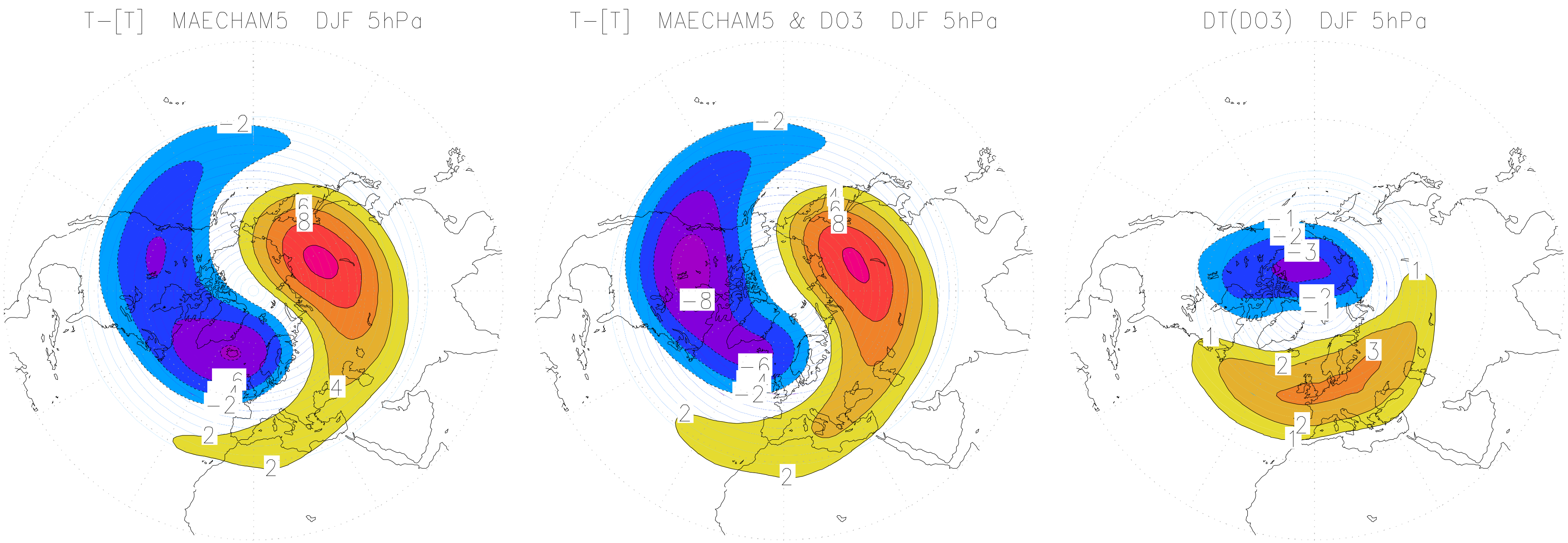
Model result: Temperature perturbations T* induced by O_3* at 50 hPa (ca. 20 km)



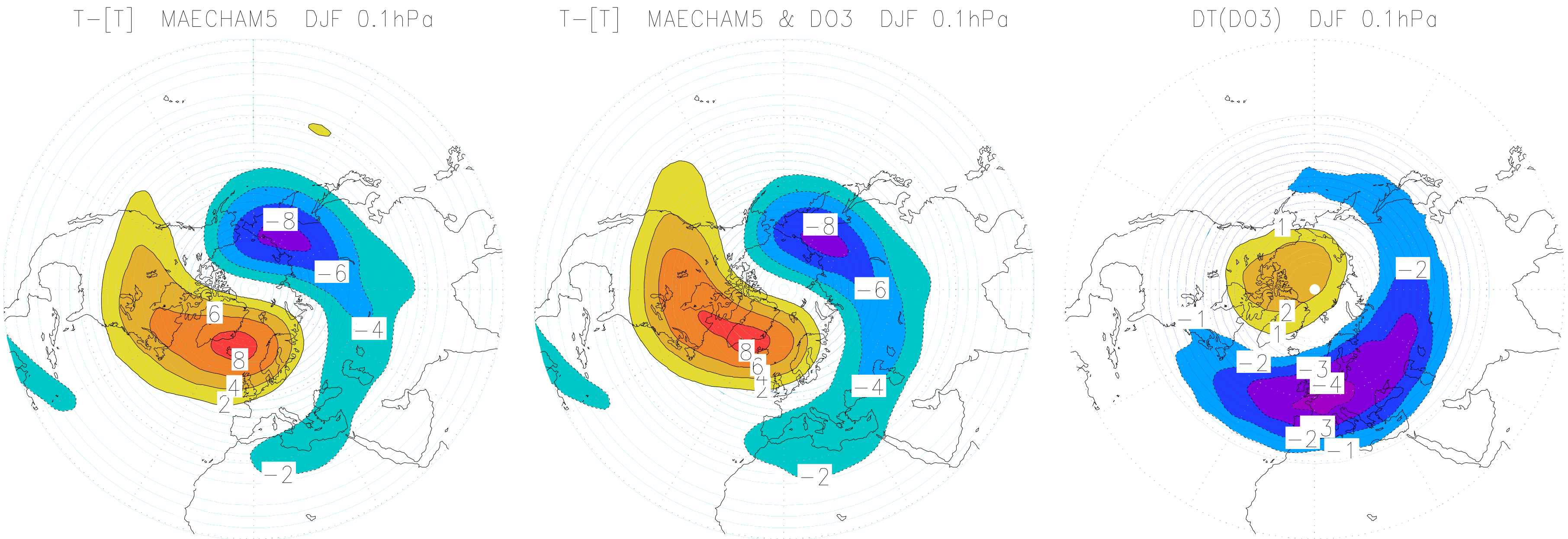
Deviations from zonal mean temperature without (left) and with (middle) O_3*, and difference DT* (right), averaged over the 10 winter periods of 1990ies, at 50hPa

Model result: Temperature perturbations T* induced by O_3* at 5 hPa (ca. 35 km)



Deviations from zonal mean temperature without (left) and with (middle) O_3*, and difference DT* (right), averaged over the 10 winter periods of 1990ies, at 5hPa

Model result: Temperature perturbations T* induced by O_3* at 0.1 hPa (ca. 65 km)

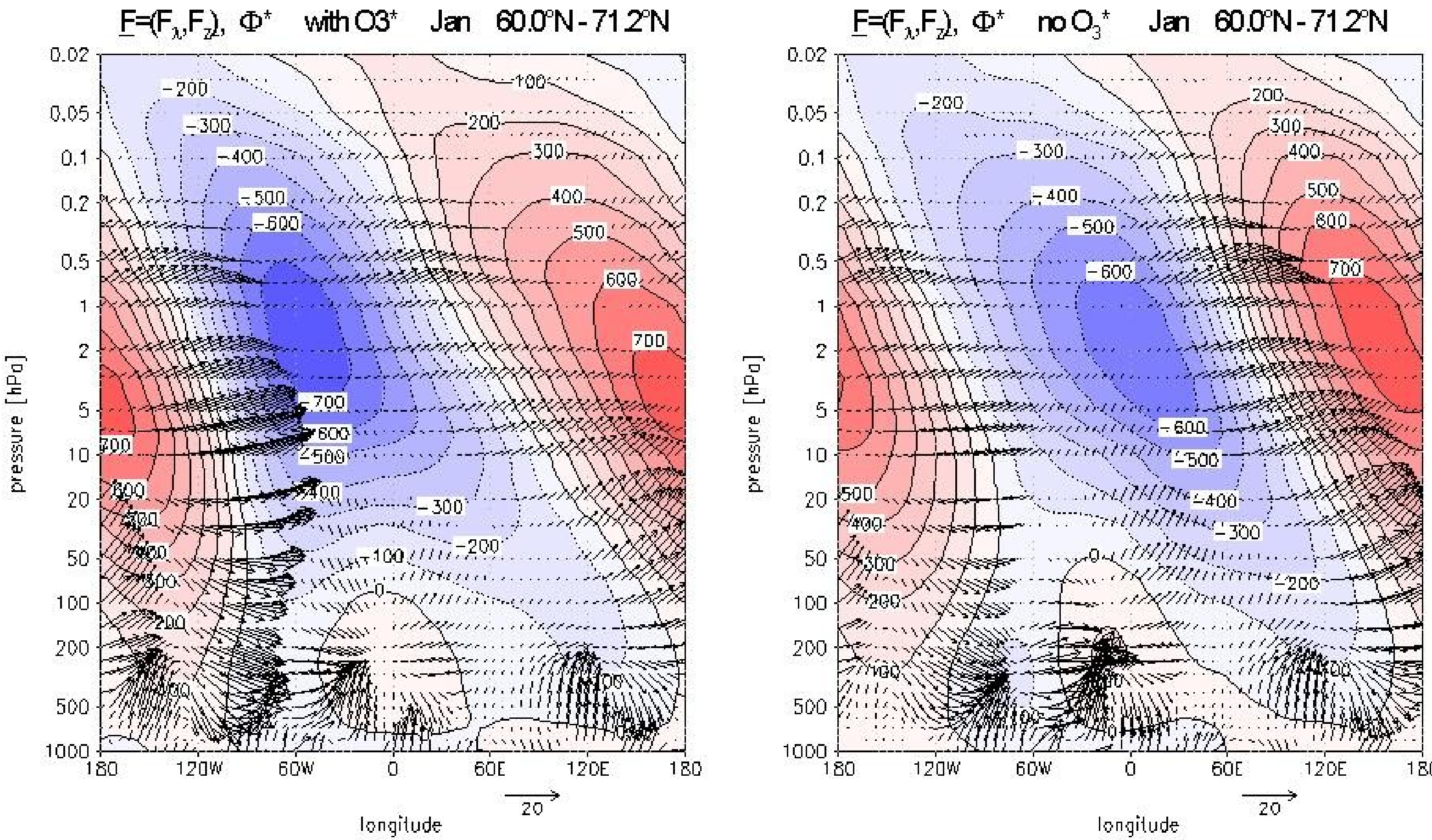


Deviations from zonal mean temperature without (left) and with (middle) O_3*, and difference DT* (right), averaged over the 10 winter periods of 1990ies, at 0.1hPa

Shows the coupling between stratosphere and mesosphere

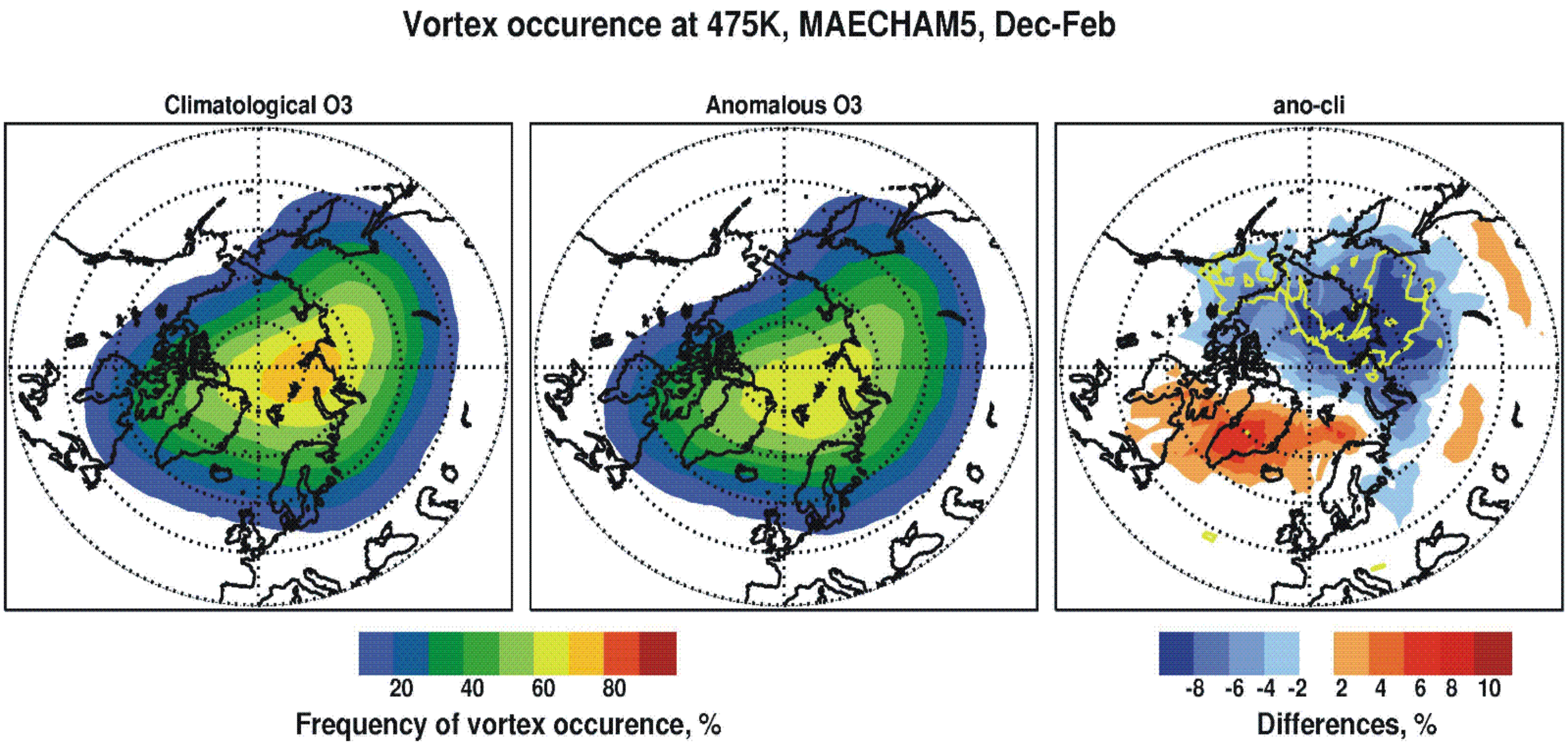
After Gabriel et al. GRL2007

Changes in planetary wave propagation induced by O_3^* – 60.0-71.2°N



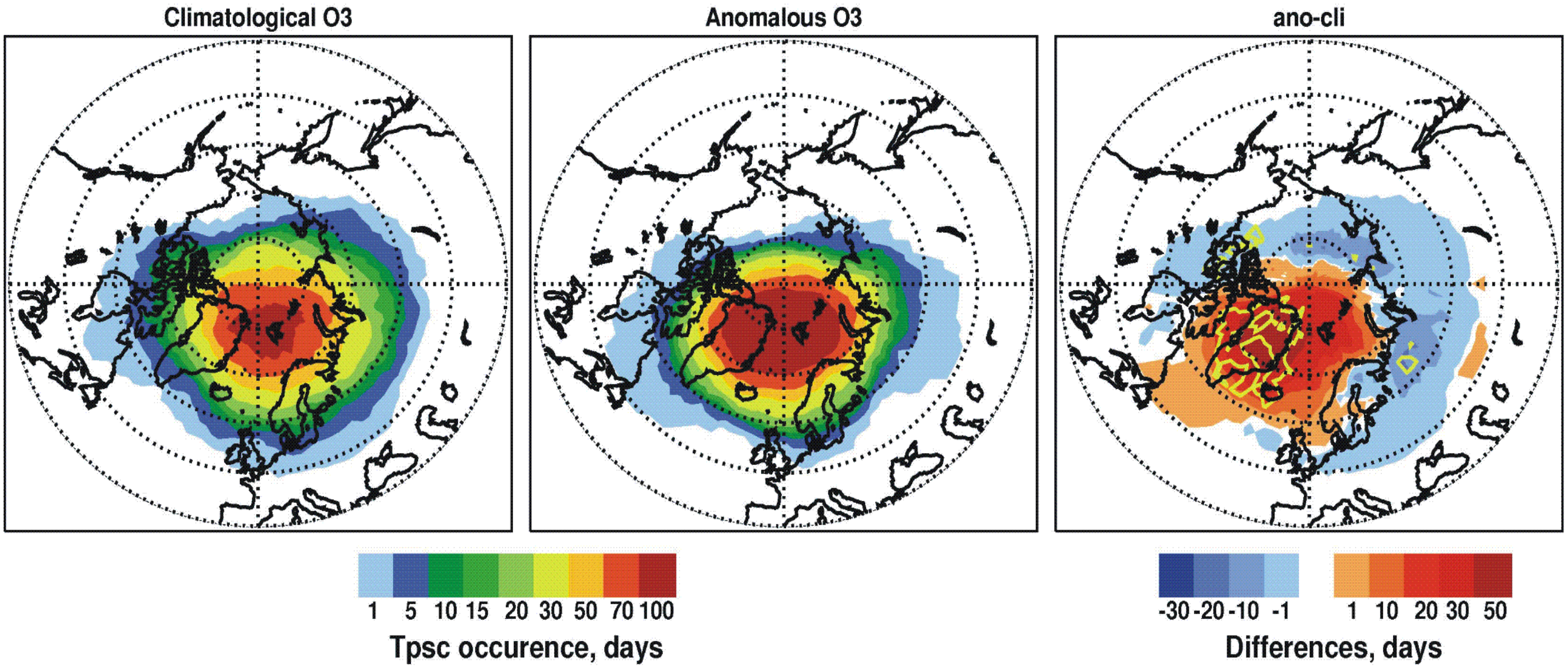
10-year means of the deviation of geopotential from zonal mean and of the wave activity flux vectors for the model run with O3* (left) and without O3* (right), averaged over 60-71.2°N; isolines of Φ^* in gpm, the wave flux vectors are scaled by $(p/p0)^{-1/2}$ (F_λ, 100^*F_z).

After Gabriel et al. GRL2007



Sparc-07-dpe-16

Tpsc occurence at 475K, MAECHAM5, Dec-Feb



Results - Summary

- Decadal increase in wave 1 structure of zonal ozone variations O_3* in middle / upper stratosphere (derived from ERA-40)

- The imposed radiative changes induce an increase and shift of planetary wave 1 in temperature (which can be attributed to a change in wave propagation characteristics):
  - 1-2 K in lower stratosphere
  - 2-3 K in middle / upper stratosphere
  - 3-4 K in lower mesosphere

- The induced changes in wave 1, i.e. in position & strength of polar vortex impose a increase of cold temperatures related to PSCs, a westward shift of pronounced diffluent/confluent flow fields with increased poleward RWB events in the UT/LS region over the North-Atlantic / European region

- The induced changes in wave 1 in temperature (i.e. in position & strength of polar vortex) and the related shift of poleward RWB events in the North-Atlantic / European region indicate a different coupling of atmospheric layers in different regions.

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