Interannual variability in chemistry and transport and its possible link to climate change: stratospheric ozone and water vapor

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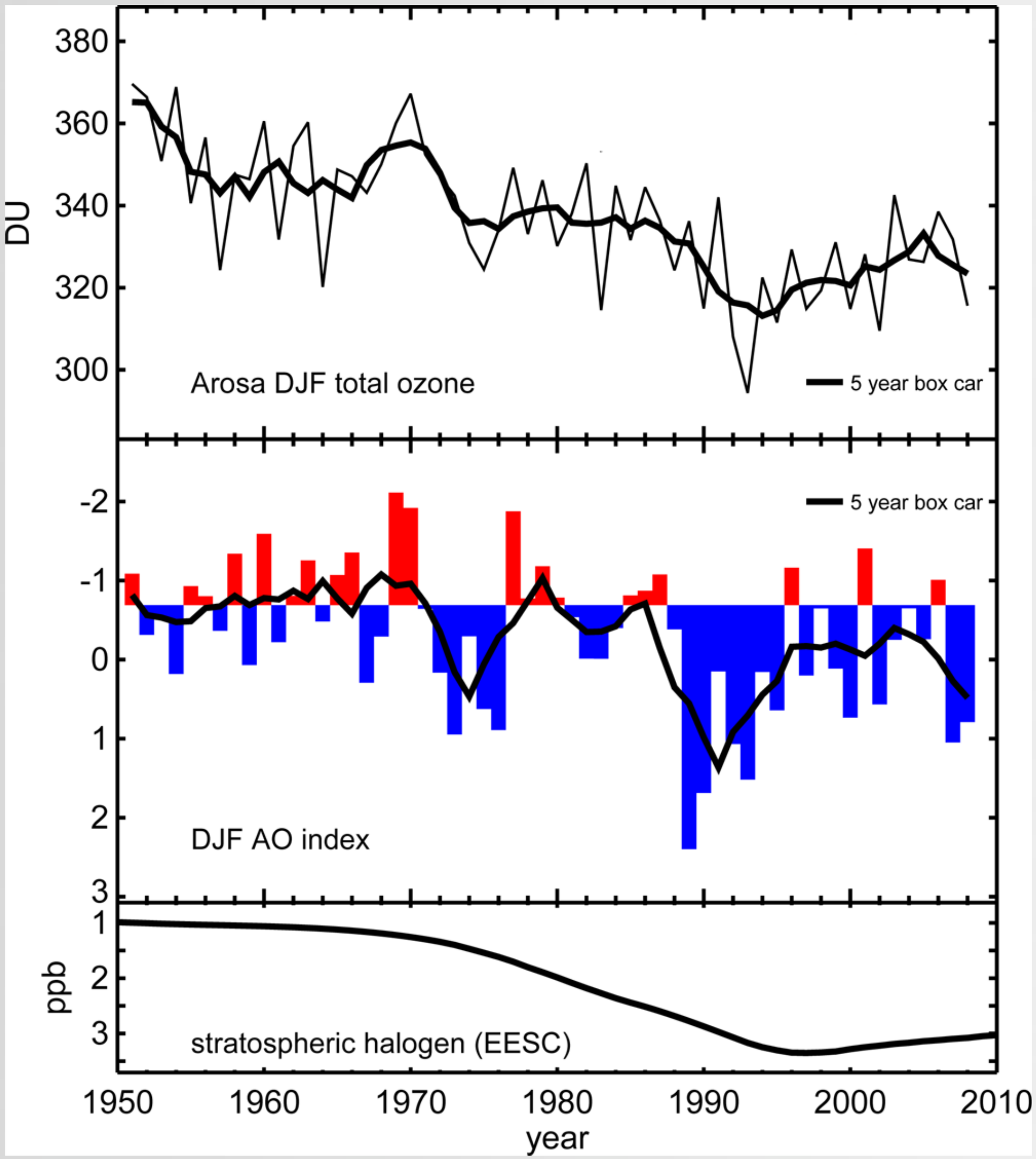
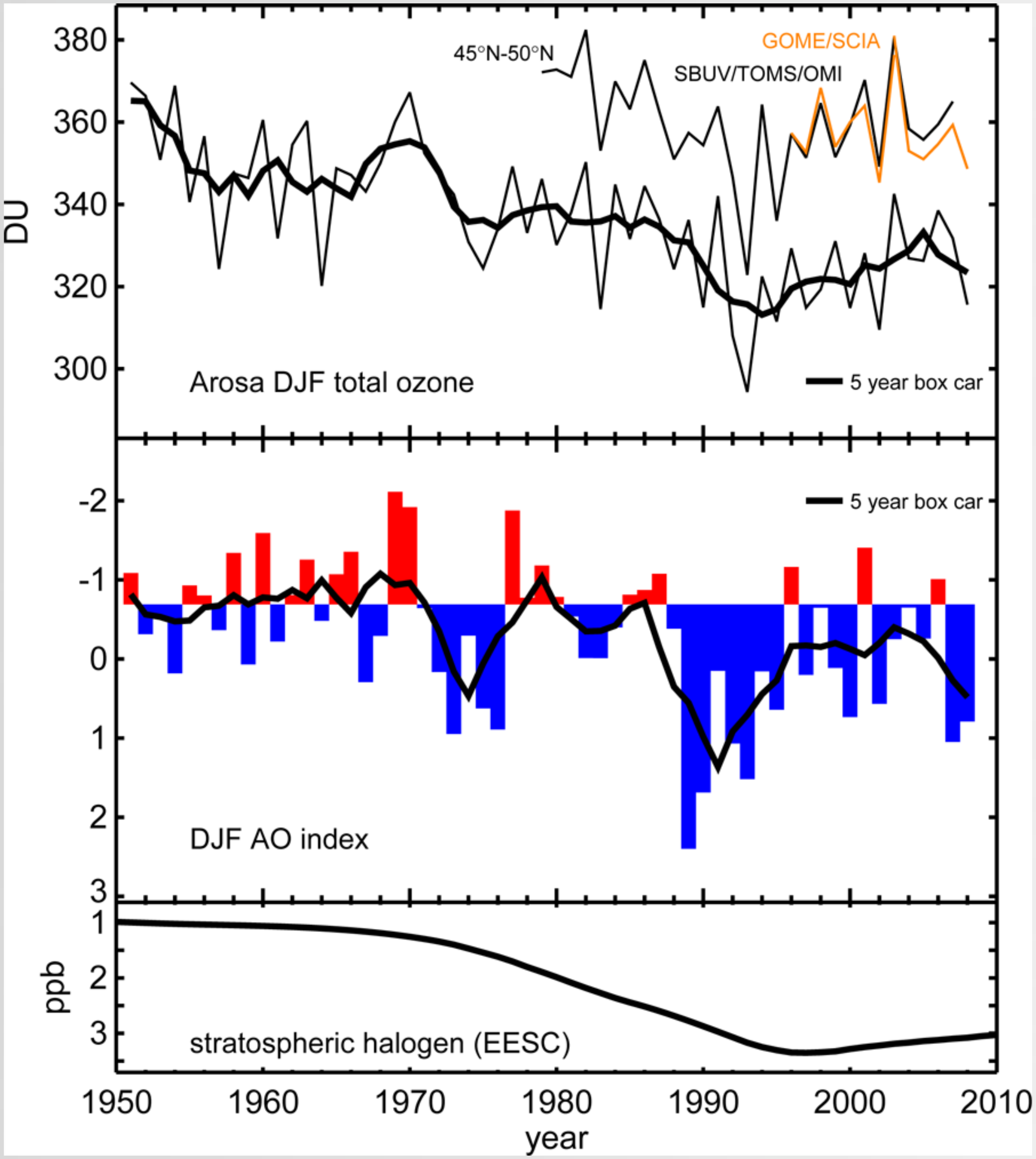
Decadal ozone variations: groundbased & satellite data



- Longterm time series e.g. Arosa (47°N) DJF show decadal variations that are correlated with
  - ➔ changes in climate patterns here the Arctic oscillation (see Appenzeller et al. 2000)
  - ➔ changes in stratospheric halogen (chemistry)

Decadal ozone variations: groundbased data & satellite data



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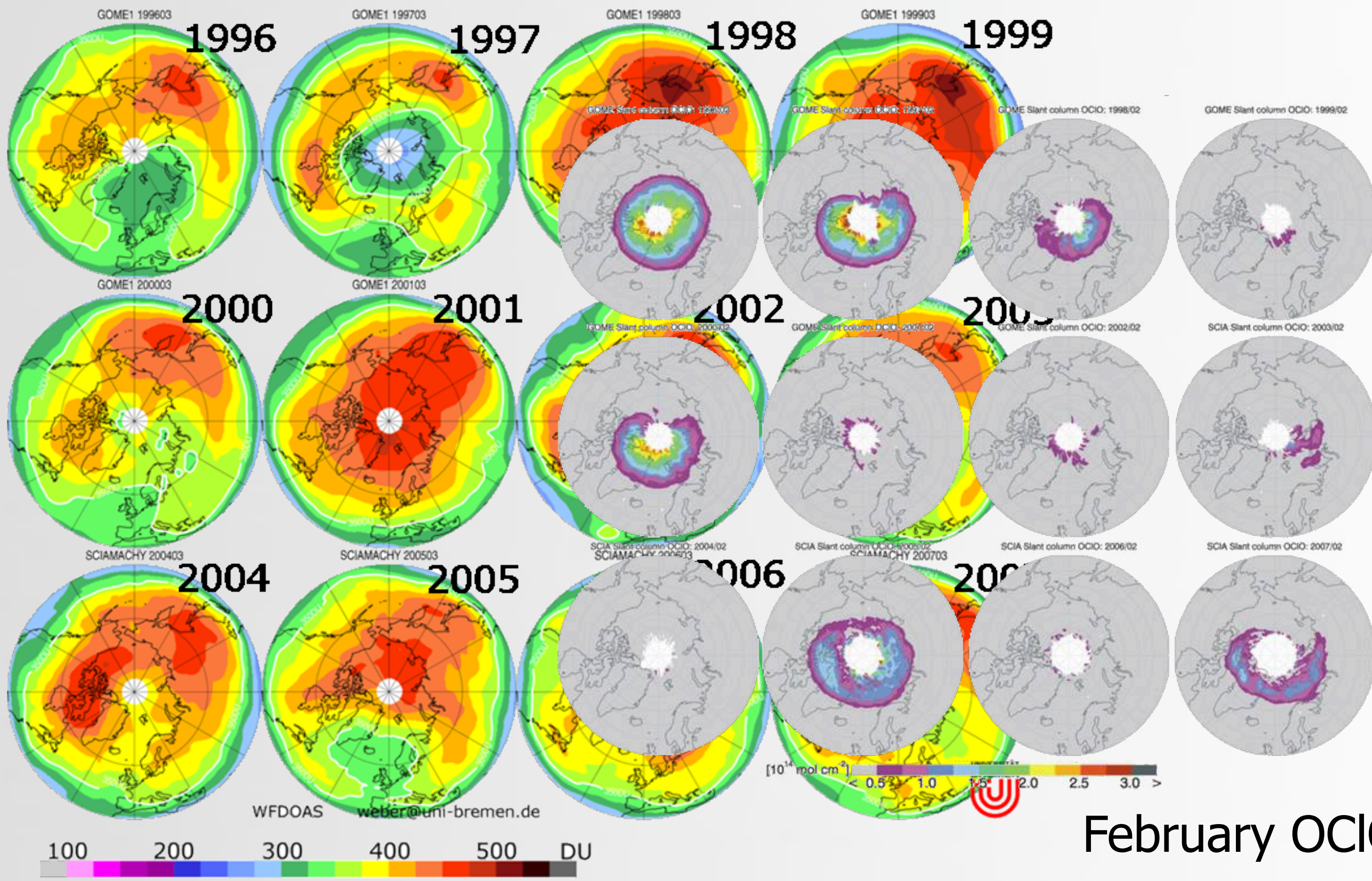
Cautionary note:

thirty years of satellite data still appear quite short with respect to decadal and longer term variations

NH March total ozone and February OClO from GOME/SCIAMACHY

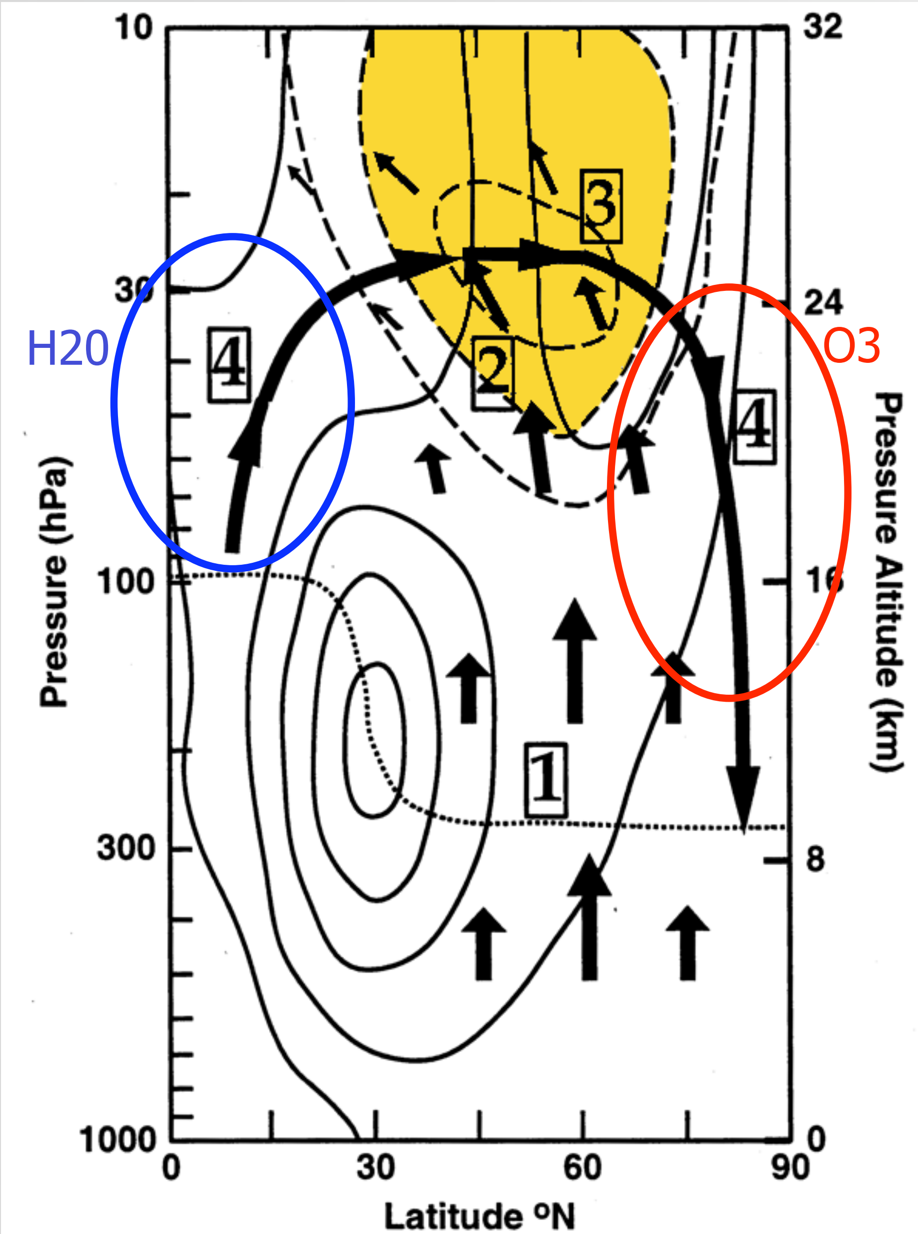


March O3

February OClO

- ▶ Inter-annual variability in PSCs, chlorine activation, and ozone transport
- ▶ About half of the Arctic winters show low ozone and high chlorine activation („cold" winters), the other half high ozone and little or no chlorine activation („warm" winters)

Planetary waves and residual (Brewer-Dobson) circulation



Newman et al. 2001

Ozone transport in winter hemisphere is driven by the BD circulation:

▶Propagation of planetary waves into stratosphere **(1)**

Eddy heat flux $\overline{v'T'}$

▶Deposition of easterly momentum **(2)**

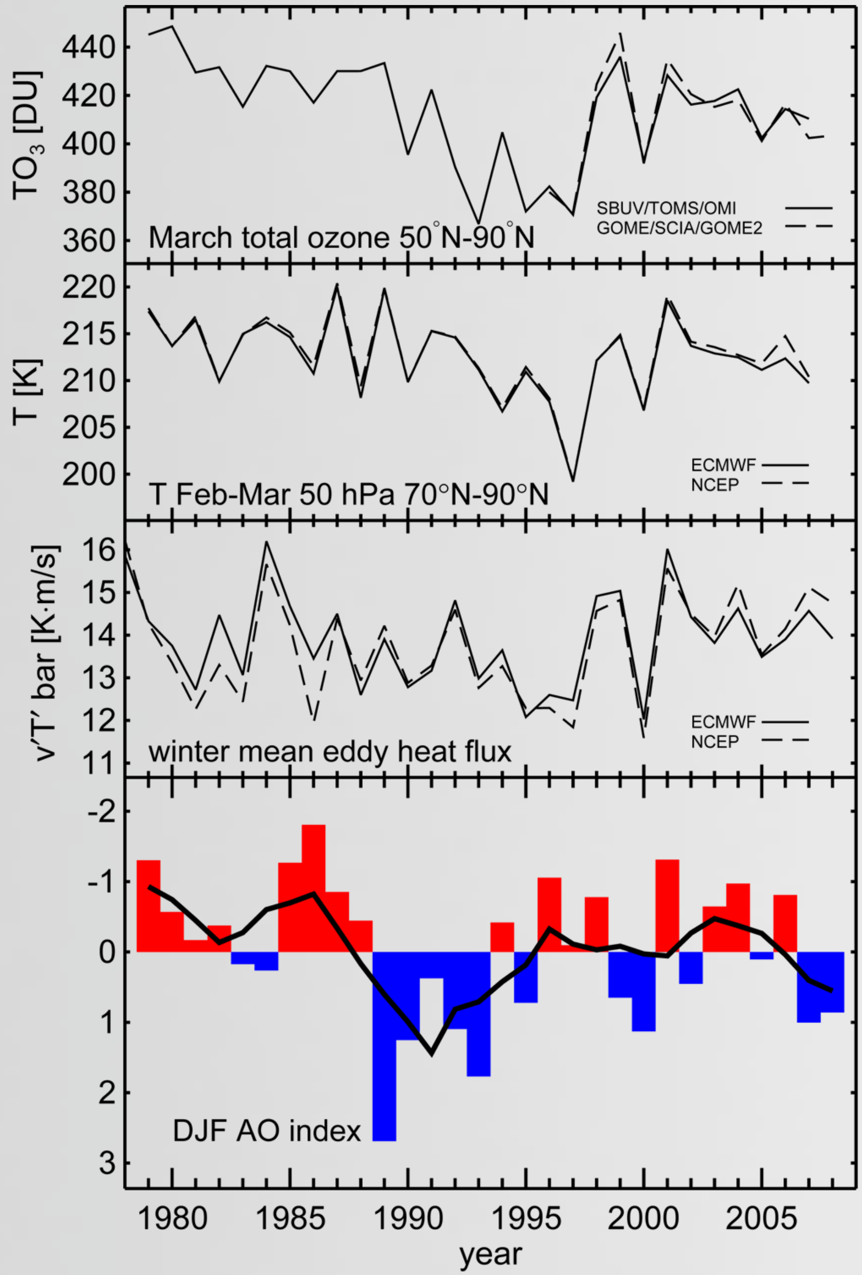
$-\vec{\nabla} \cdot \vec{E}$

EP flux convergence

▶deceleration of stratospheric westerlies/geostrophic balance requires then a small meridional (residual) wind component **(3)**

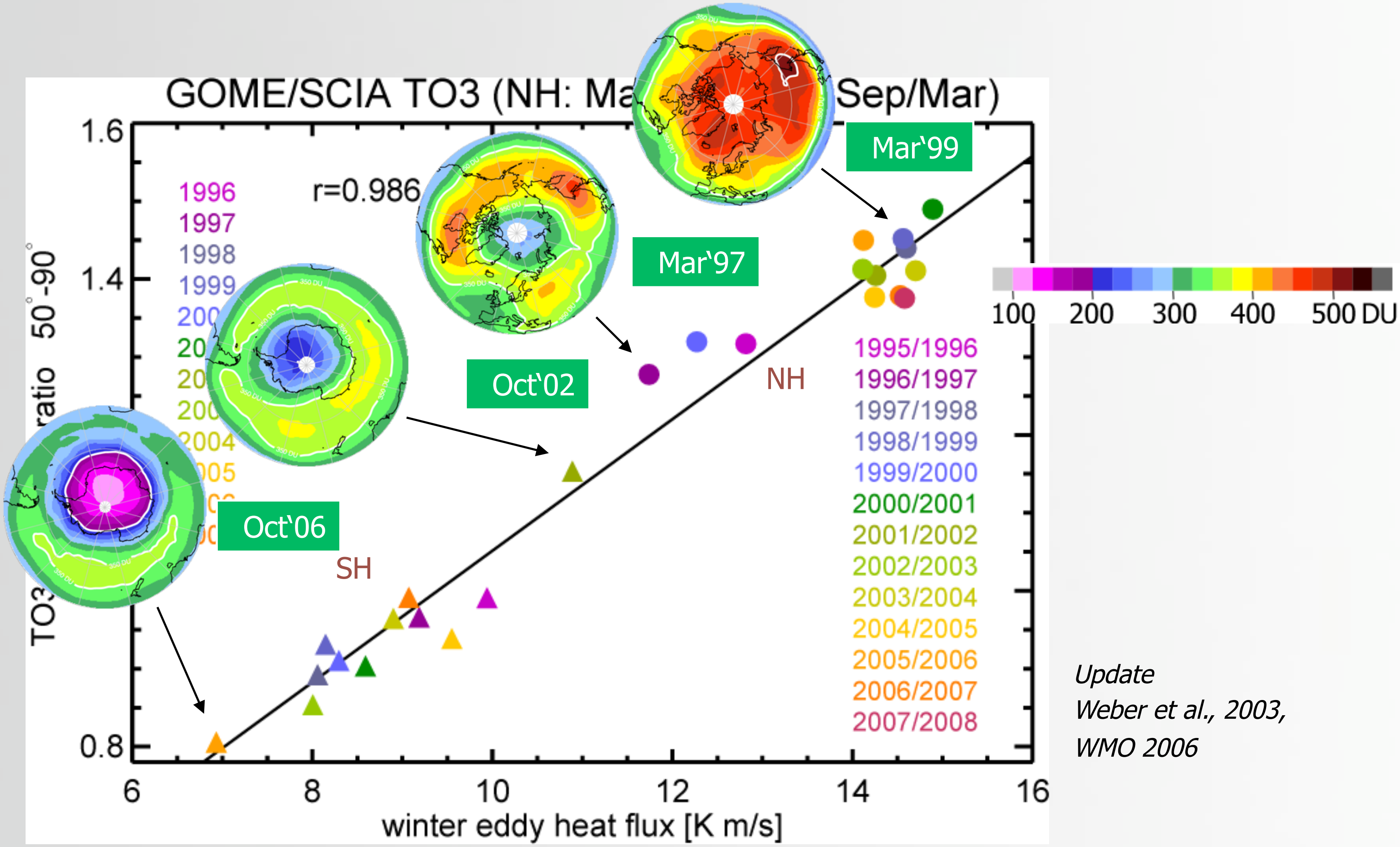
▶residual circulation causes uplifting in tropics (cooling) and descent in polar region (warming) **(4)**

Polar ozone, stratospheric temperatures, and planetary waves



- ▶ Inter-annual variability of NH polar spring ozone, polar temperature, and planetary wave activity (eddy heat flux)
- ▶ Connection between NAO, planetary wave propagation, and polar vortex strength (Hartmann et al., 2000)

Coupling of transport and chemistry

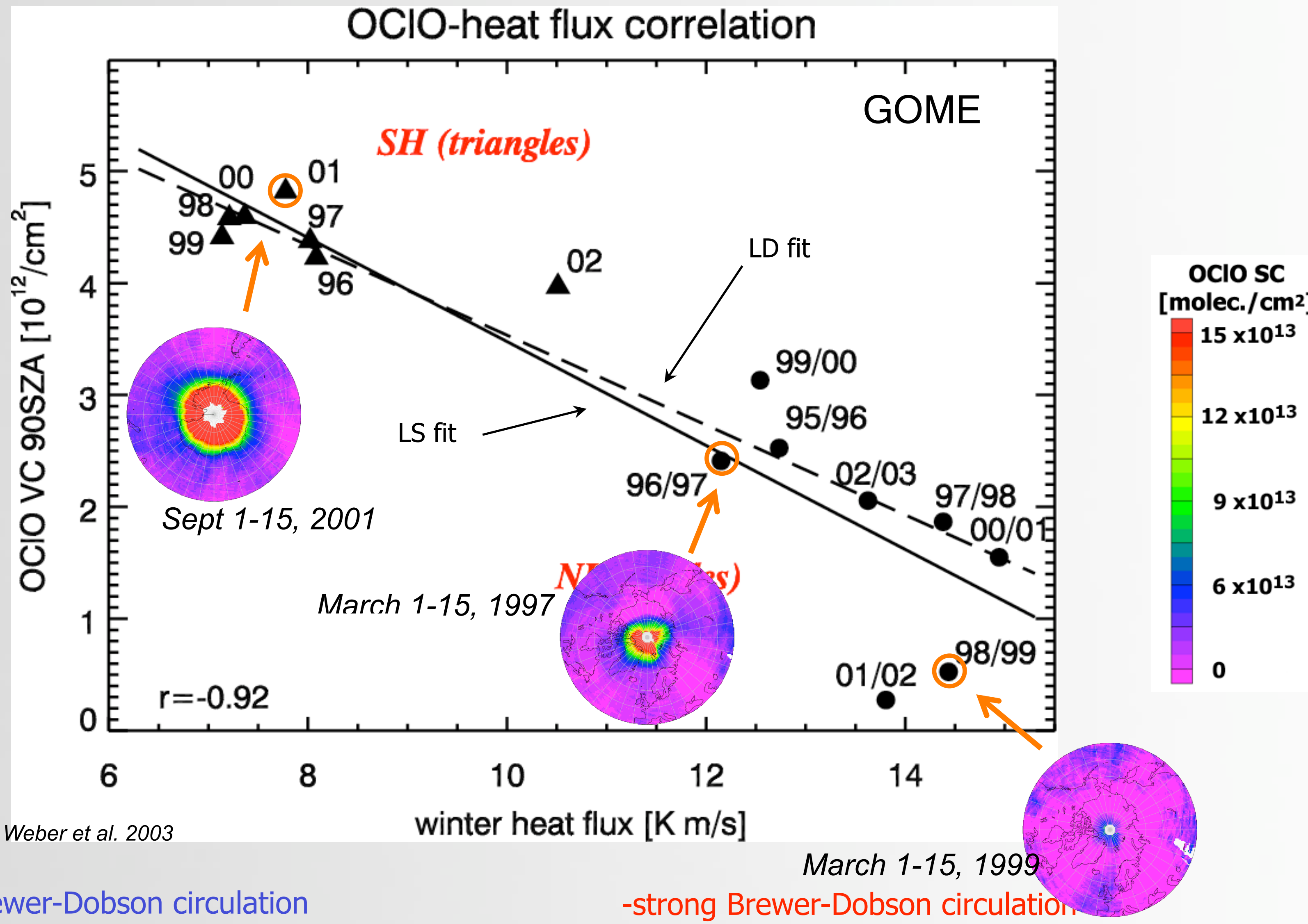


Update
Weber et al., 2003,
WMO 2006

-weak Brewer-Dobson circulation
-low T
-high polar ozone loss

-strong Brewer-Dobson circulation
-high T
-enhanced ozone transport

Dynamical control of ozone chemistry: chlorine activation



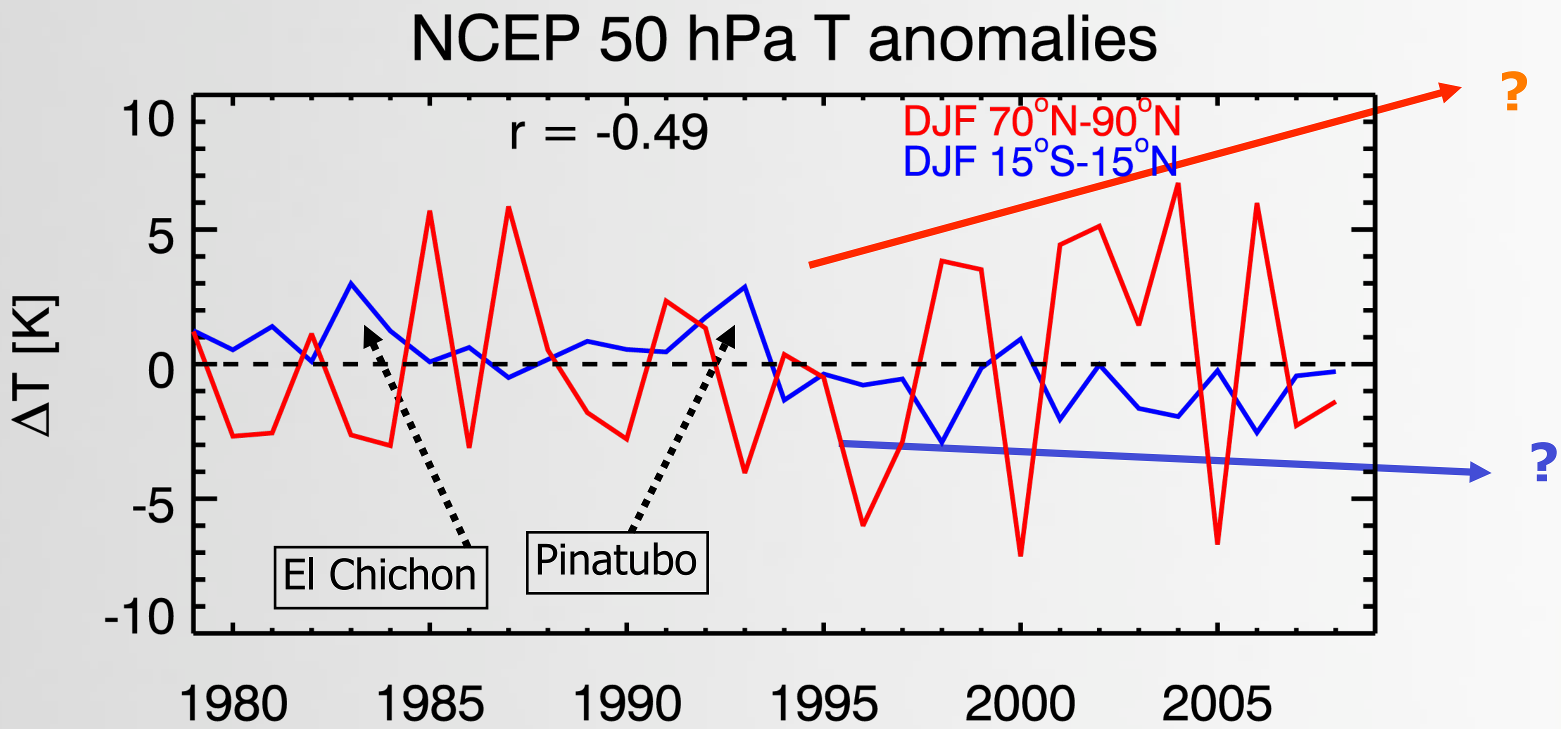
Update Weber et al. 2003

March 1-15, 1999

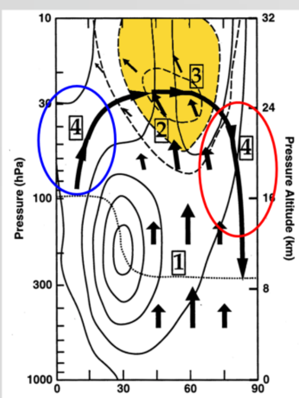
- -weak Brewer-Dobson circulation
- -low T/high PSC volume
- -high chlorine activation

- -strong Brewer-Dobson circulation
- -high T/low PSC volume
- -low chlorine activation

Stratospheric temperature, volcanic aerosols, and BD circulation

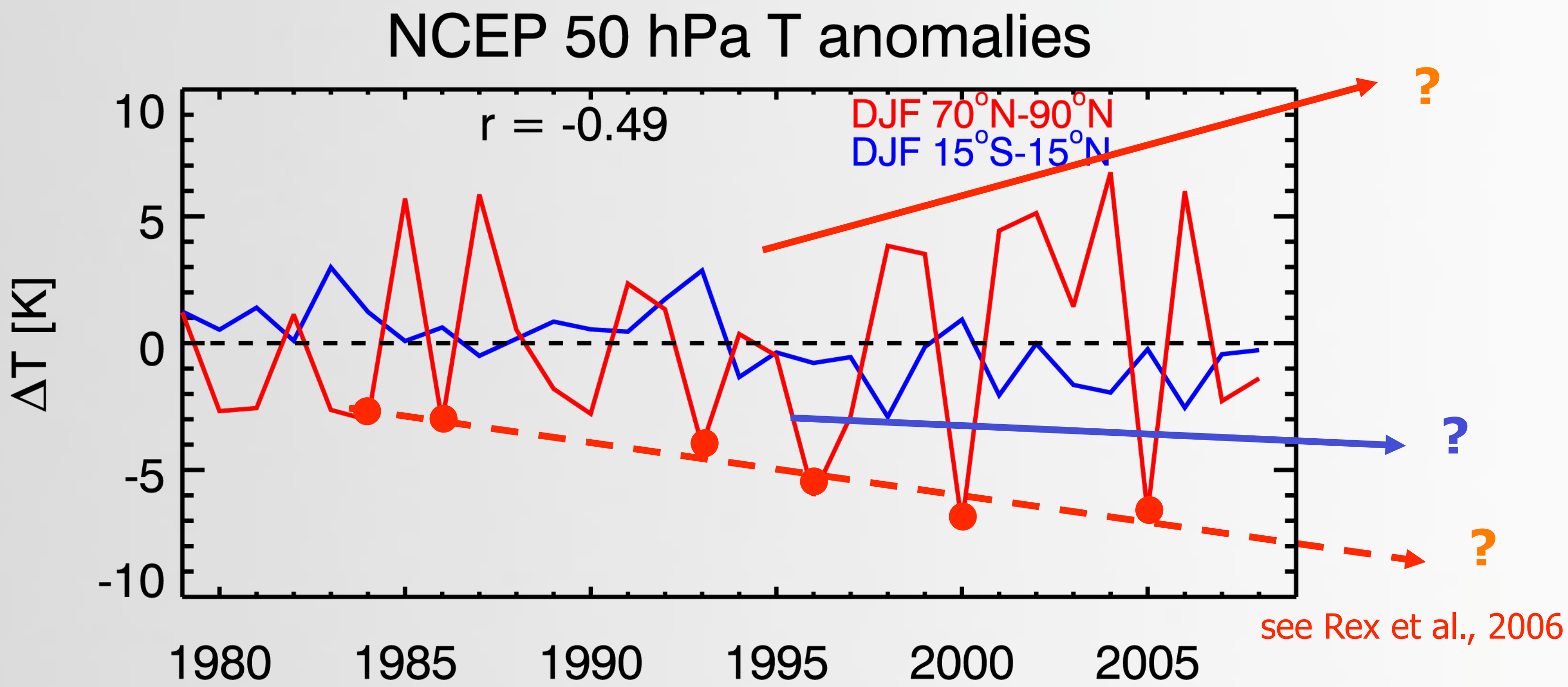


Update from Dhomse et al., 2006



- See-saw pattern between tropical and polar stratospheric temperatures (r=-0.49)
- Impact of El-Chichon and Pinatubo (2-3 K)
  - ➔ aerosol effect on Brewer-Dobson circulation & polar chemistry (El Chichon, Mt. Pinatubo)
- Intensification of BD circulation?

Stratospheric temperature, volcanic aerosols, and BD circulation

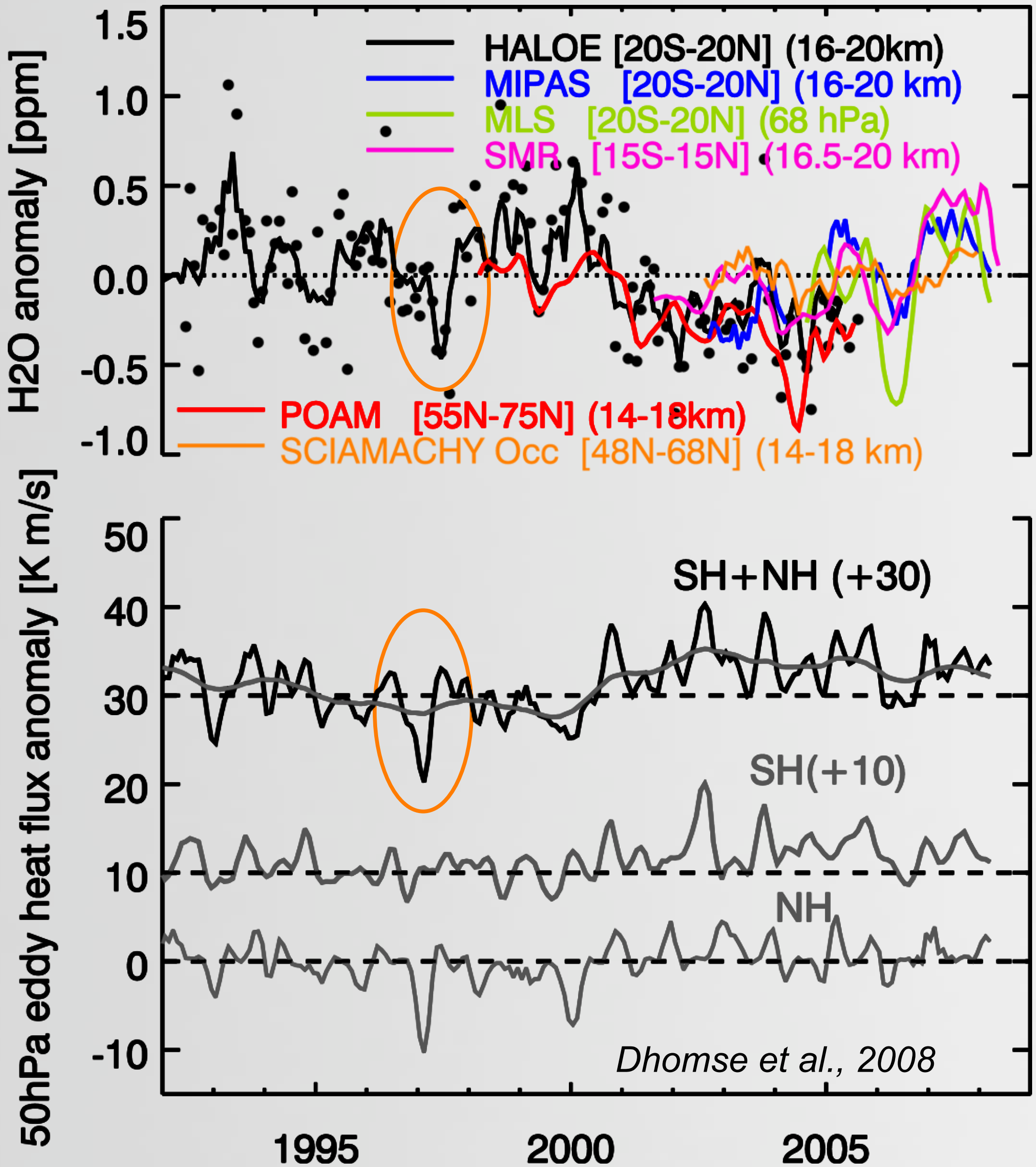


Update Dhomse et al., 2006

- „cold“ Arctic winters are still getting colder?
- larger spread in polar temperatures?

see poster Grunow et al. (Session A)

Stratospheric water vapor and BD circulation

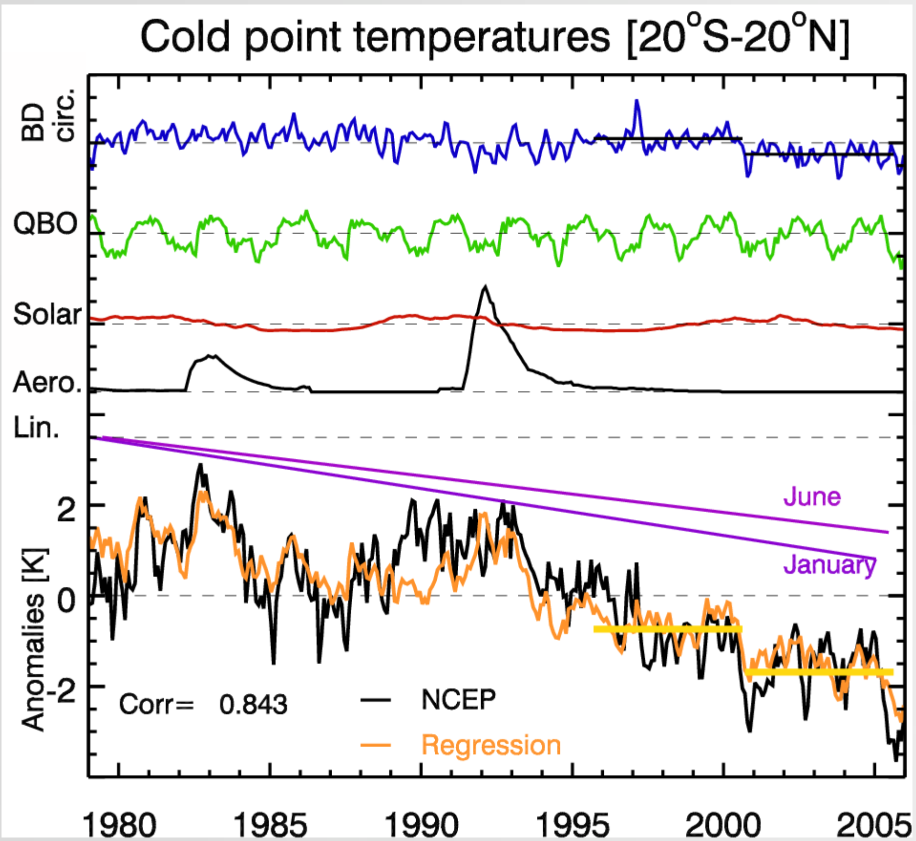


SCIAMACHY results preliminary!

- Water vapor anomaly above tropical tropopause
  - ➔ Persistent low H2O since 2001 related to a drop in cold point temperatures
  - ➔ increase in tropical upwelling (Randel et al., 2006)
  - ➔ Increase in summed eddy heat flux from both hemispheres (Dhomse et al., 2008)
- Other processes may also be relevant for tropical LS water vapor changes (tropical convection, equatorial waves, e.g. Norton et al. 2006, Kerr -Munslow 2006, Rosenlof & Reid 2008)

see poster by Stiller et al. (B)
see poster by Urban et al. (B)

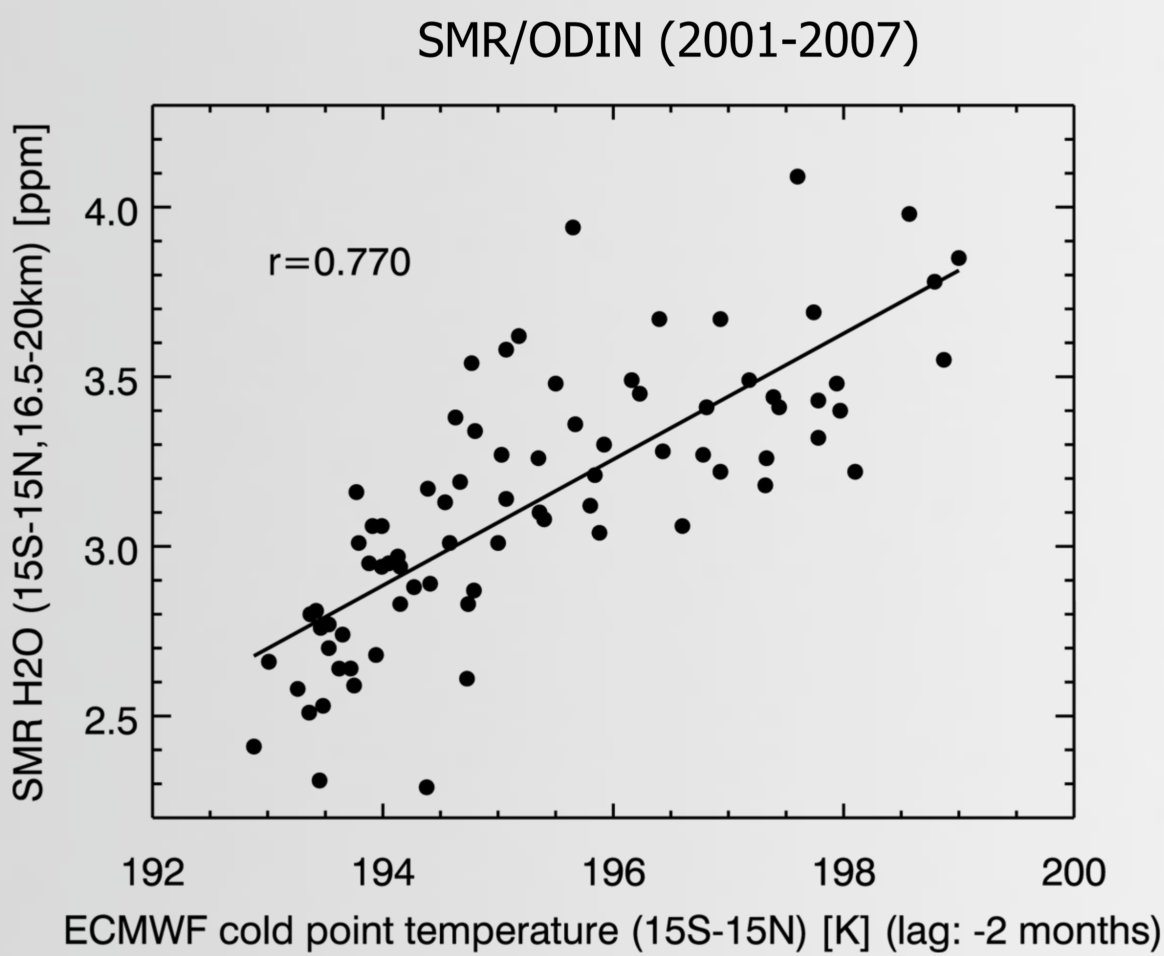
Tropical cold point temperature and BD circulation



Dhomse et al., 2008

- BD circulation changes since 2001 contributed to a ~0.4 K cooling in the cold point temperature
  - ➔ Consistent with observed water vapor change (-0.2 to -0.3 ppm) and Haynes & Füglistaler (2005) estimate of a 0.5ppm H2O change /1K from Lagrangian model calculation
- Analysis data (NCEP, ECMWF) show apart from the 2001 jump, a linear downward trend (~1K /decade)
  - ➔ not consistent with trends in water vapor observations
- Larger uncertainties of radiosonde measurements and met analyses in TTL (e.g. Randel et al. 2004, Lanzarote et al. 2003, Seidel et al., 2001)

Cold point temperature and water vapor



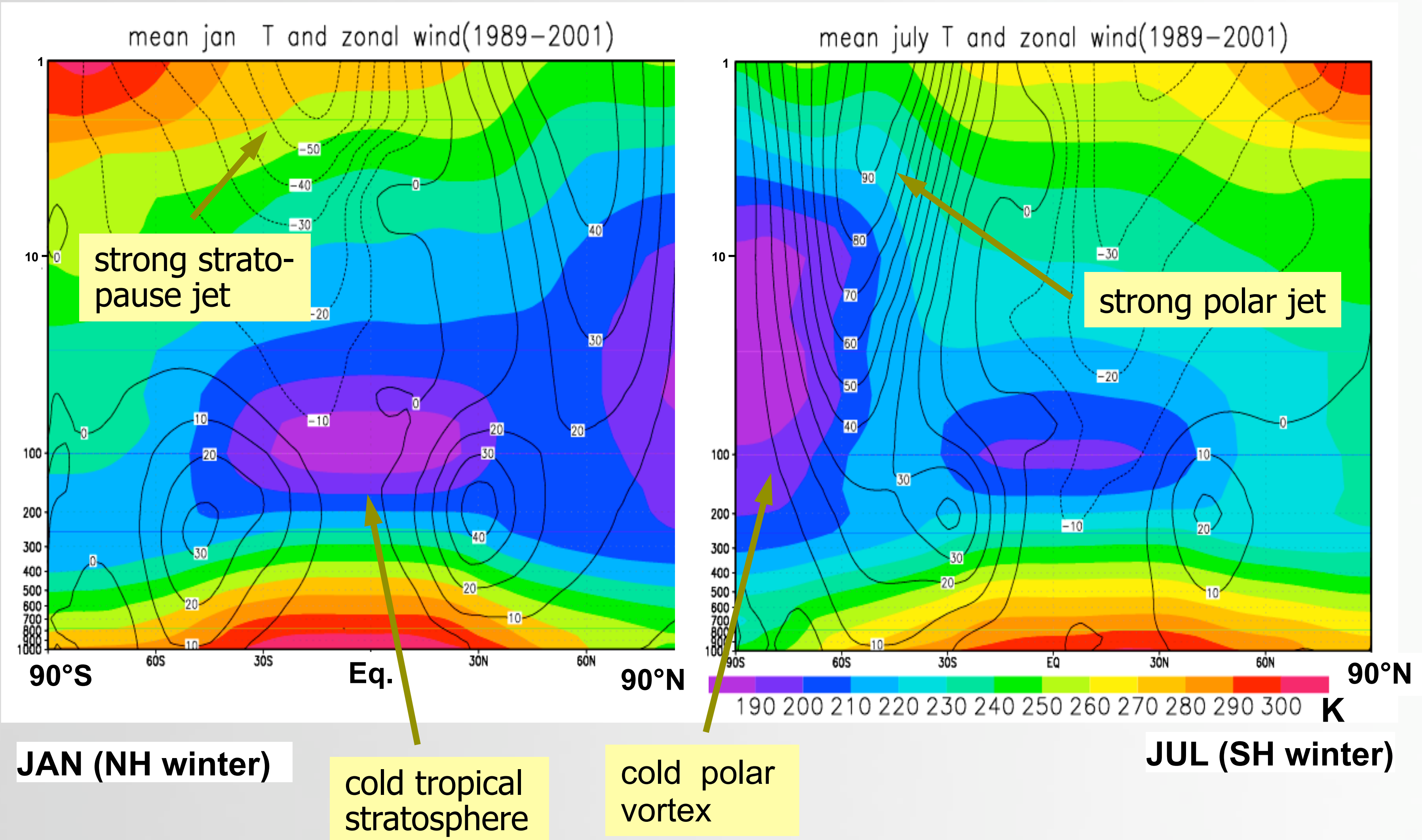
- Tropical LS water vapor (~18 km) is consistent with ECMWF cold point temperatures (CPT) with time lag of 2 months
- Recent increase in tropical LS H2O are therfore consistent with CPT increases

Summary/Conclusions

- Interannual variability in and coupling of ozone transport (BD circulation) and chlorine activation (polar ozone loss) in both hemispheres
- Link of extratropical planetary wave activity (BD circulation) to stratospheric water vapor changes explain drop in tropical LS H2O after 2000.
- There are some inconsistencies between TTL temperature (NCEP) and observed tropical LS water vapor trends.
- Continuous intensification of the BD circulation is not evident in the observational record (eddy heat flux, water vapor/tropical CPT change) see also poster by Möbius et al. (B) regarding mean strat. age-of-air trends
  - ➔ Strenghtening of the BD circulation may lead to accelerated (lower stratospheric) ozone recovery as models seem to suggest (e.g. Schnadt et al., 2002, Butchart et al. 2006, Eyring et al., 2007, Li et al., 2007, Garcia et al., 2008)
- Continuation of water vapor satellite observations (MIPAS, MLS, SCIAMACHY, SMR, ACE/MAESTRO) is important
  - ➔ water vapor analysis of SCIAMACHY limb data (with global coverage) is in preparation

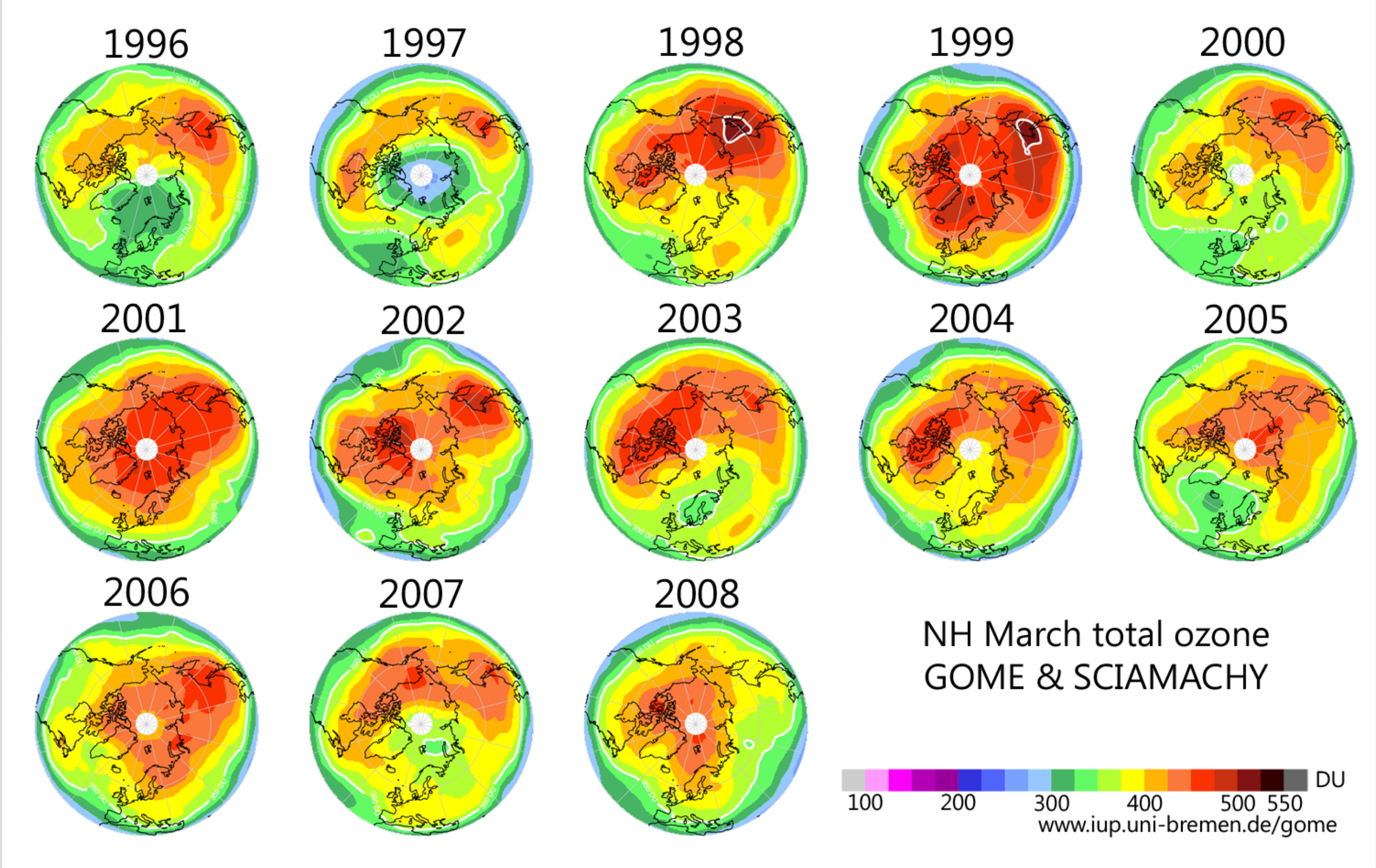
Addditional slides

seasonal variability in temprature



▶ Link of T variability in tropics (Yulaeva et al. 1994) and in polar region (Newmann et al. 2001) to planetary waves

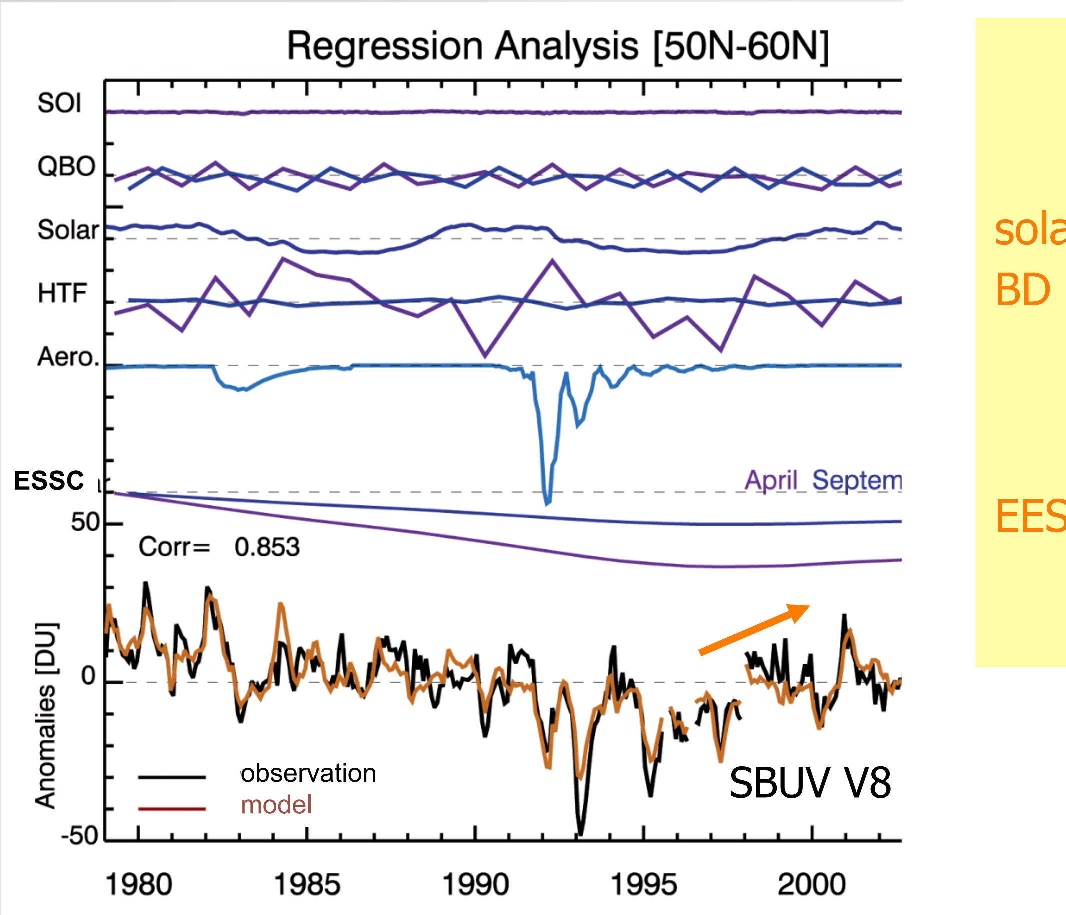
NH March total ozone from GOME/SCIAMACHY



- inter-annual variability in ozone during NH winter/spring
- combined effect from **ozone transport/dynamics** and **chemical ozone loss**

Stratospheric ozone trends, solar cycle, BD circulation and stratospheric chlorine

Total ozone anomalies 1978-2003



Dhomse et al. 2006

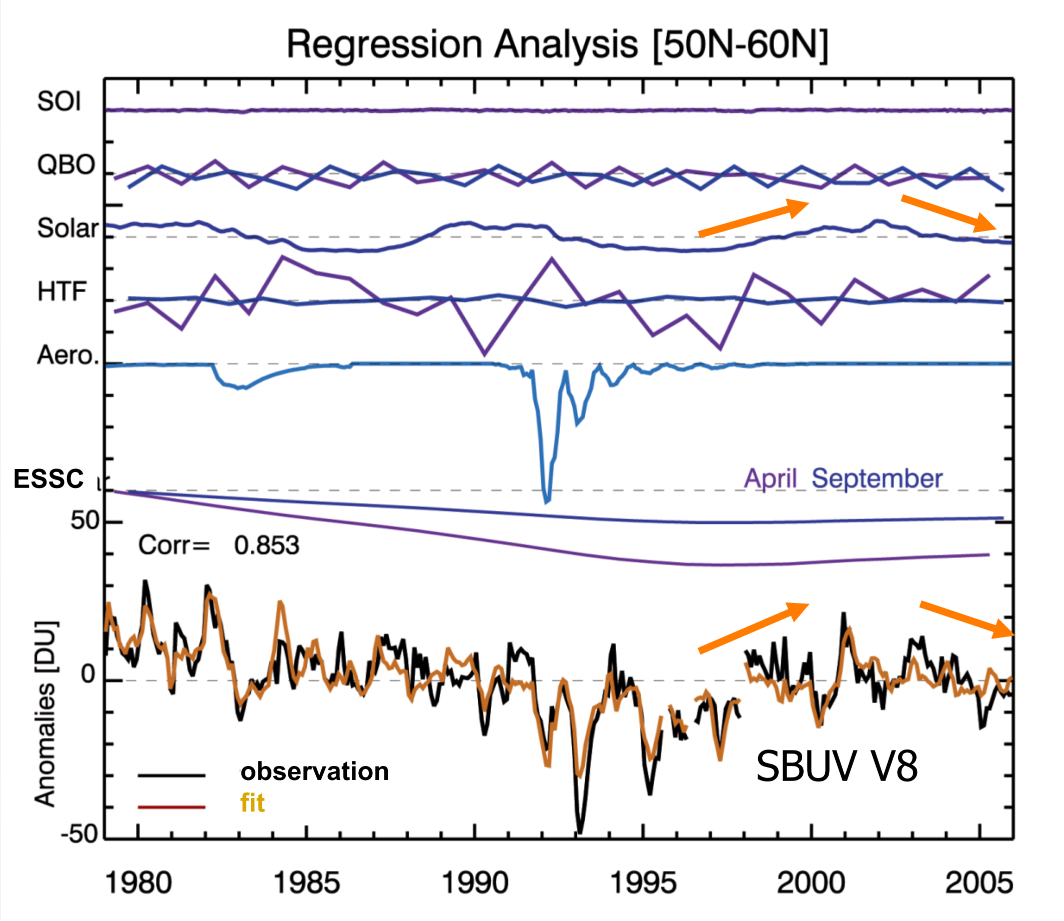
trends
since mid nineties

solar →
BD circulation/HTF →
EESC (halogens) →

- Solar activity and BD circulation change explain large part of the increase from the mid 1990s.

Stratospheric ozone trends, solar cycle, and stratospheric chlorine

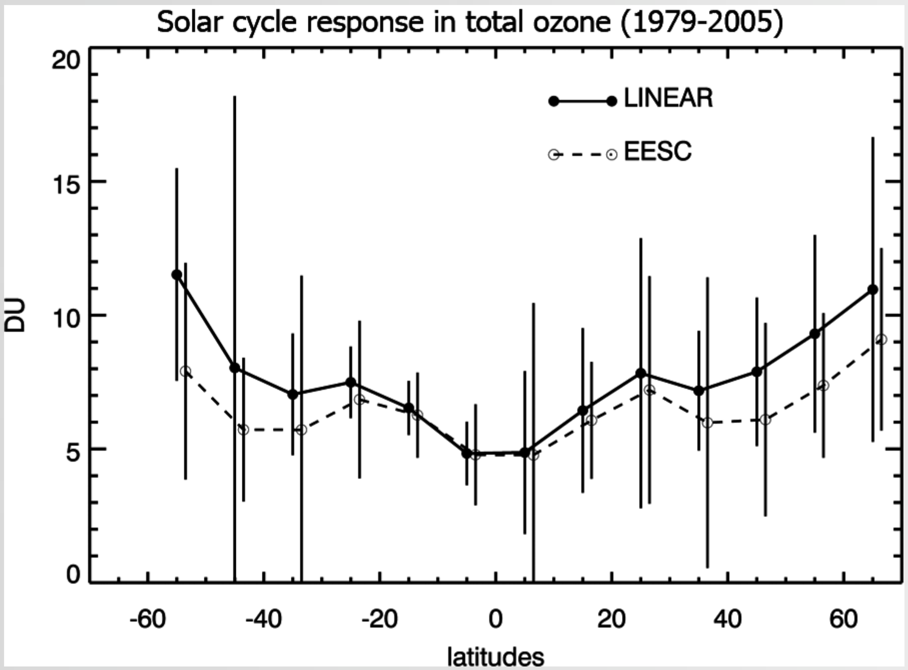
Total ozone anomalies 1978-2005

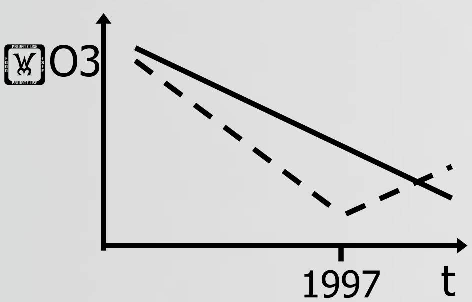


- ▶ Solar cycle plays also an important role
- ▶ Is there a connection between circulation changes and solar activity?

solar cycle response on column ozone

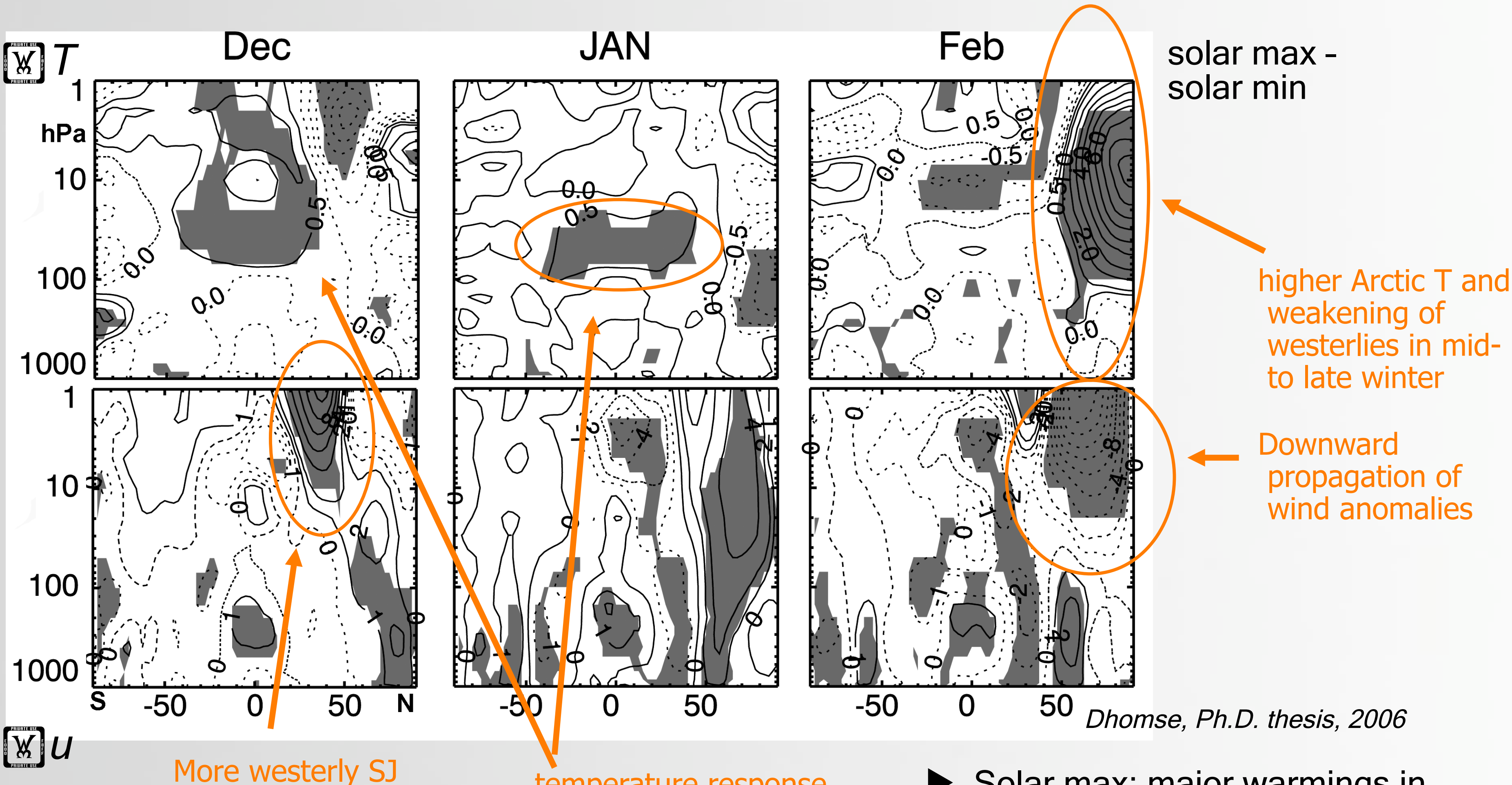
solar max –
solar min





- Solar cycle response up to 12 DU when assuming a linear downward trend until 2005
- Accounting for EESC trend, solar cycle response varies from 5 DU (tropics) to 9 DU (high latitudes)
- high latitude solar response via dynamics
  - ➔ Changes in planetary wave propagation (Kodera and Kuroda 2002)
  - ➔ Occurence and timing of NH major warmings (Grey et al. 2003)

NH u and T response to solar cycle



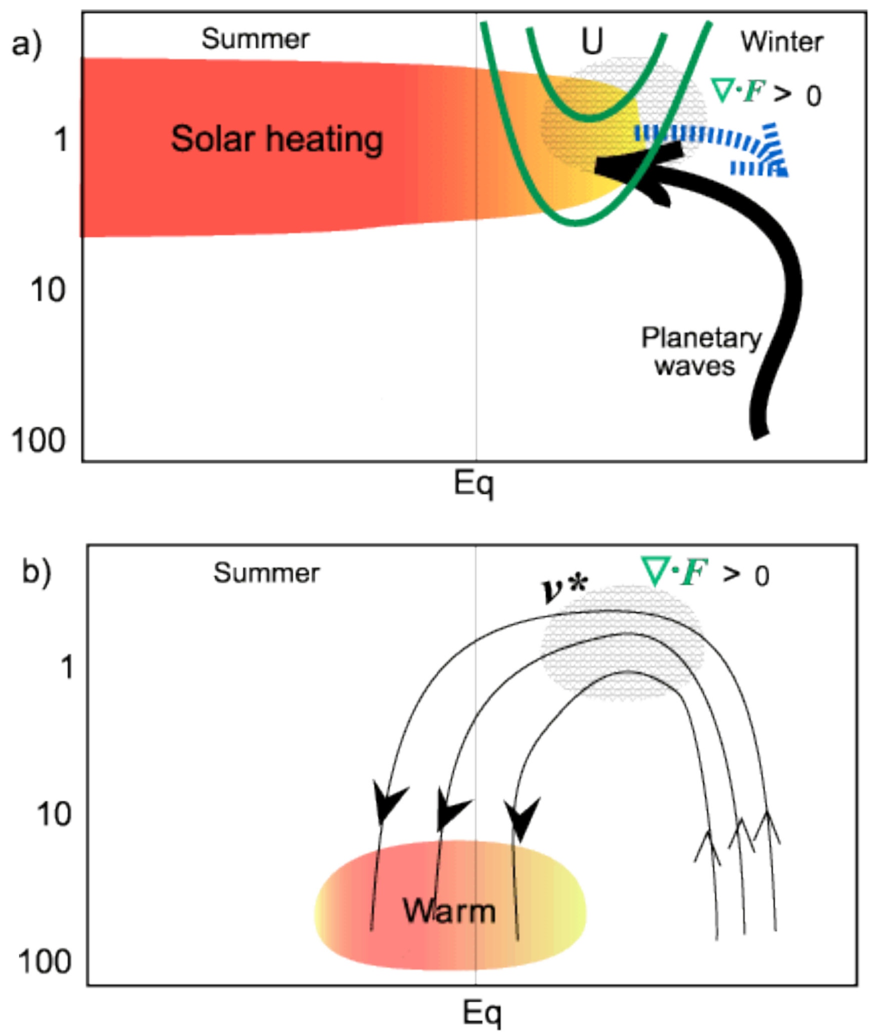
Dhomse, Ph.D. thesis, 2006

Change in zonal mean wind (u) in m/s and zonalmean temperature (T) in K for a change of 113 solar flux units (F10.8 units) from a multi -variate regression of ERA40/ECMWF (1979-2005)

- Solar max: major warmings in late winter/weak polar vortex in late winter
- Solar min: major warmings in early winter/strong polar vortex in late winter

see also Grey (2003)

Solar variability, planetary waves, polar O3 loss



Kodera and Kuroda (2002)

- ▶ extra solar heating during solar max strengthens subtropical stratopause jet (SJ) in early winter

  → **radiative response**

- ▶ Strengthening of westerlies (SJ) means reduced wave progation and reduced BD circulation /warming of tropical tropopause region in early winter

  → **dynamical response**

  → **weak BD circulation in early winter**

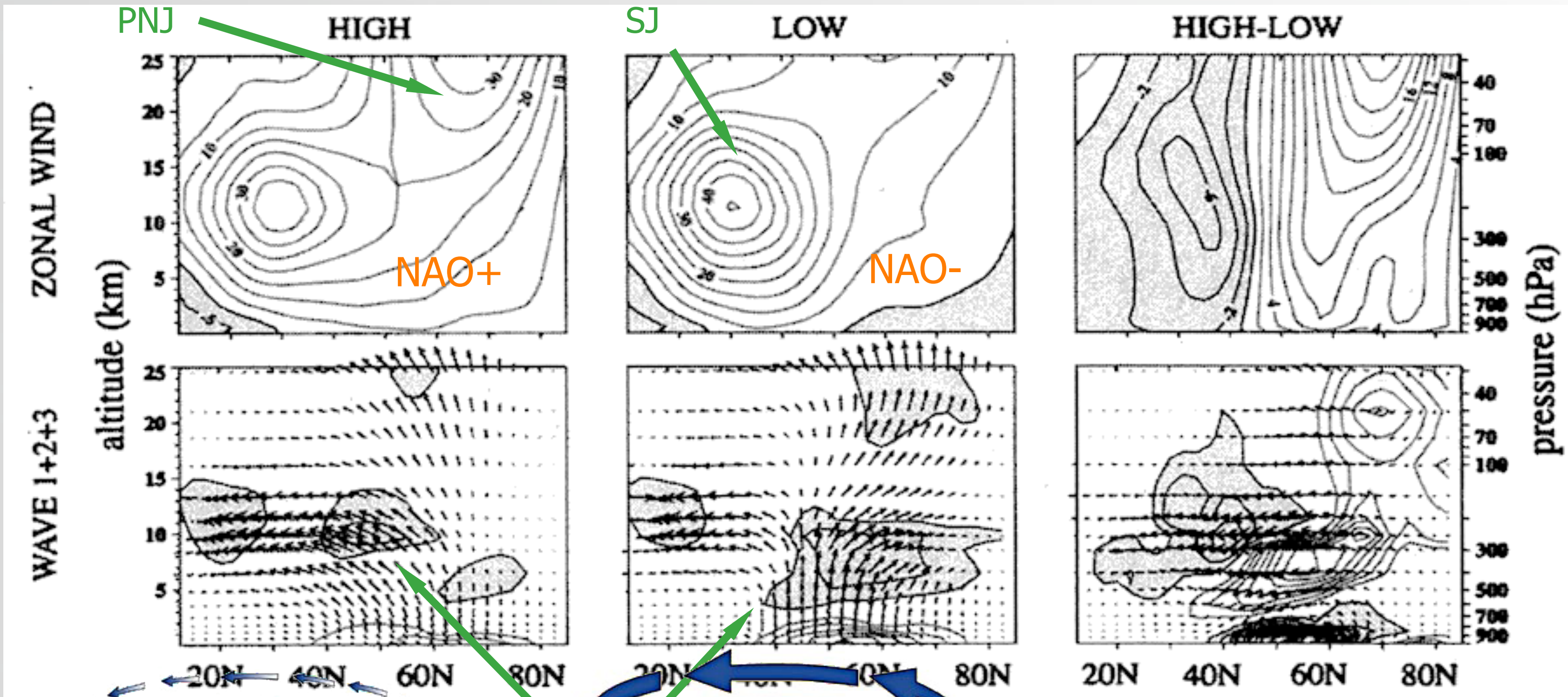
- ▶ Deflection of planetary waves away from subtropics (towards pole) while SJ descends downwards and polewards, leading to weakening of polar night jet (polar vortex) in mid- to late winter

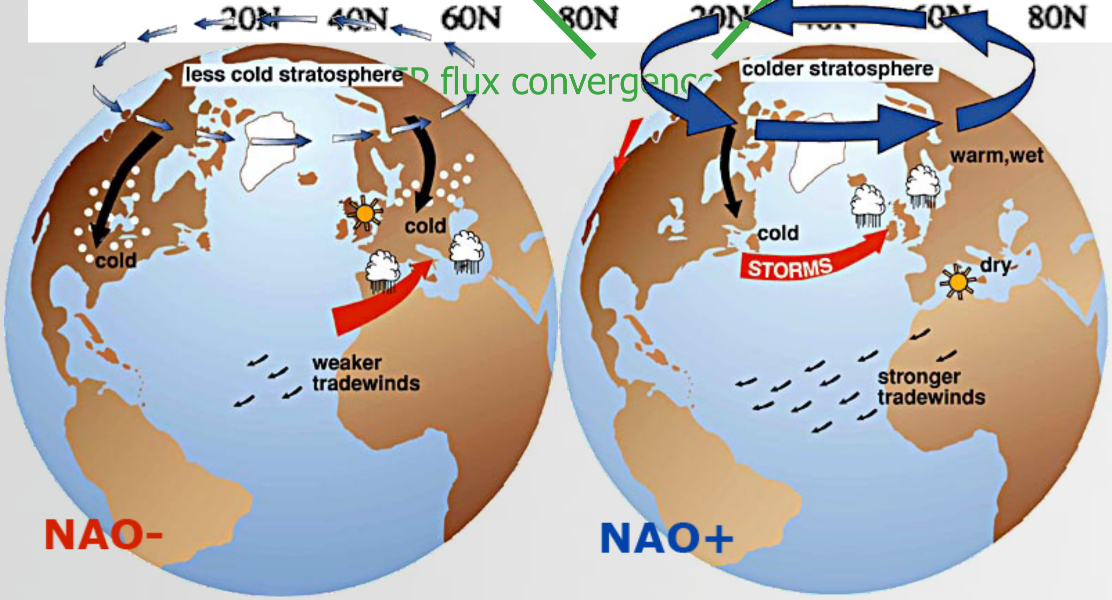
  → **strong BD circulation**

- ▶ warmer polar stratospheric temperatures with reduced polar ozone loss in late winter

  → **chemical response**

NAO and planetary wave propagation





Hartmann et al. 2000

- NAO+: strong polar vortex (high PNJ speed)
- NAO – : weak polar vortex (low PNJ wind speed, strengthening of SJ)

Additional notes

- Water vapor accounts for 60% of the natural green house gases under clear sky condition (Kiehl & Trenberth, 1997), largest feedback in climate change
- HOx is the dominant ozone loss cycle in the lowermost stratosphere, increase in 1ppmv H2O is as effective as an PSC enhancement due to an additional 1K cooling (Tabazadeh, 2000), increase in H2O will extend the PSC existence period (Stenke & Grewe, 2005)
- Inconsistency in trends between Boulder water vapor measurements and Haloe (Oltmanns 2000, Randel 2004)
- Water vapor stratospheric input governed by tropical cold point temperatures („cold trap“ Holton and Gettelman 2001)
  - ➔ Increase in water vapor (Boulder) requires positive temperature trend, but the temperature trend is negative
- Füglistaler et al. 2004, 2005a,b found good agreemment of H2O observations and cold point temperatures in Lagrangian trajectory models

Additional notes

- Convective overshooting (Kuang et al. 2003), e.g. in SA and Africa (e.g. Ricaud et al., 2007) and cold-trap dehydration may be distinguished by location of the bottom boundary of the tape recorder (above or below the cold point temperature altitude, Schoeberl et al., 2006)
- Role of cirrus clouds formed by Kelvin waves for dehydration in TTL (e.g. Immler et al., 2007)
- Bypassing of TTL through Asian monsoon over Tibetan plateau (Fu et al., 2006; Gettelman et al., 2004; Park et al, 2004; Park et al., 2007; Park et al., 2008)
- Convective overshooting should bring heavier water up into the stratosphere (Moyer et al., 1996; Hanisco et al., 2007; Kuang et al., 2003; Schoeberl et al., 2006; Dessler et al., 2007; Gettelman and Webster, 2005; Read et al., 2008)
- Anti-correlation between SST in the W Pacific and stratospheric water vapour (Rosenlof and Reid, 2008)
- Widening of the tropical belt and change in the Hadley cell (Seidel et al., 2007a, b; Hu and Fu, 2007

Additional notes

- Oxydation of methane is source for 1/3 of stratospheric water vapor
- Methane oxydation efficiency is dependent on OH levels, H2O input and upper stratospheric ozone column (O1D production) (Saueressig et al., 2001)
- Methane oxydation efficiency increases when more chlorine, less ozone, and more H2O input (Röckmann et al., 2004), compensation by future methane increases