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Stratosphere-troposphere Processes And their Role in Climate

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# Future Arctic Temperature and Ozone: The Role of Stratospheric Composition Changes

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Stratospheric Change and its Role for Climate Prediction
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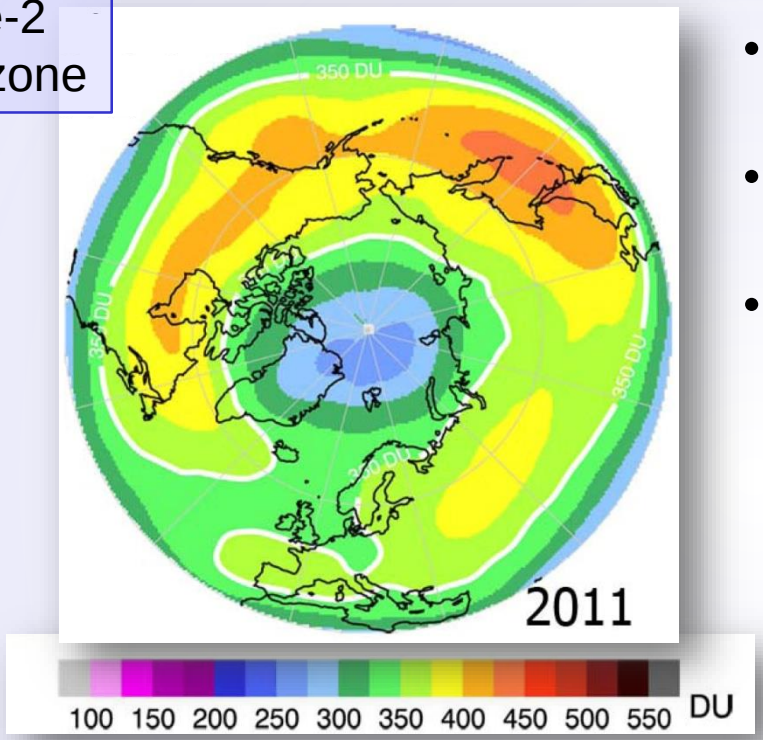
# Arctic Ozone in March 2011

Gome-2
Total Ozone




courtesy Mark Weber, Uni Bremen

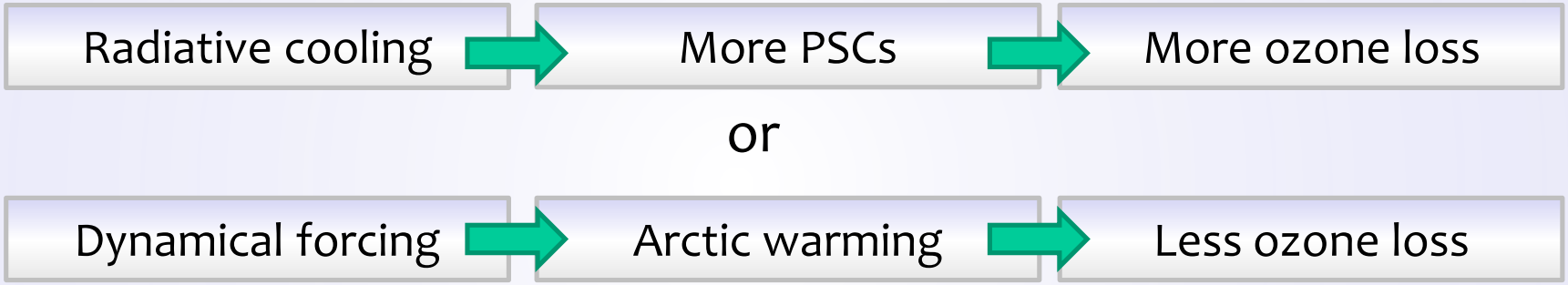
- Unprecedented Arctic ozone loss
- Comparable to Antarctic ozone hole
- Due to
  - persistent cold lower stratosphere from early winter into spring
    - early onset of denitrification
    - long-lasting enhanced chlorine activation
  - large $V_{PSC}$

Manney et al., 2011

Is there a risk that such extreme Arctic ozone-hole-like events will become more frequent in a future with climate change?

# Questions

- What is the effect of increasing GHG concentrations on the Arctic polar lower stratosphere?




- How will the meteorological conditions in the Arctic lower stratosphere change with rising GHGs?
- How will ozone be affected?
- How do GHG increases modify the ODS effect on ozone?

# Method

Analysis of chemistry climate model (CCM) data from 1865 to 2100

# Model


## EMAC

- ECHAM-MESSy Atmospheric Chemistry model (EMAC) (Jöckel et al., 2006; Röckner et al., 2006)
- Interactive chemistry model MECCA (Sander et al., 2005)
- Improved shortwave radiation scheme FUBRad (Nissen et al., 2007)
- Resolution: T42 (2.8°x2.8°) , L39 ( top at 0.01 hPa, ~80 km)
- Contributed to CCMVal-2

# Simulations

- transient, 1960-2100

| | Scenario | Period | Greenhouse Gases | ODSs | SSTs/SICs | Background & Volcanic Aerosol | Solar Variability | QBO | Ozone and Aerosol Precursors |
|---|---|---|---|---|---|---|---|---|---|
| NCC | SCN-B2c NCC | 1960-2100 | Fixed GHG | Obs + A1 WMO (2007) | 1955-1964 average of values used in REF-B2, repeating each year | Same as in REF-B2 | Same as in REF-B2 | Same as in REF-B2 | Same as in REF-B2 |
| REF | SCN-B2d Natforcing QBO | 1960-2100 | Obs + SRES A1b | Obs + A1 WMO (2007) | Same as in REF-B2 | **OBS in the past and background aerosol in the future** | **OBS repeating in future** | **OBS / repeating in future or internally generated** | Same as in REF-B2 |

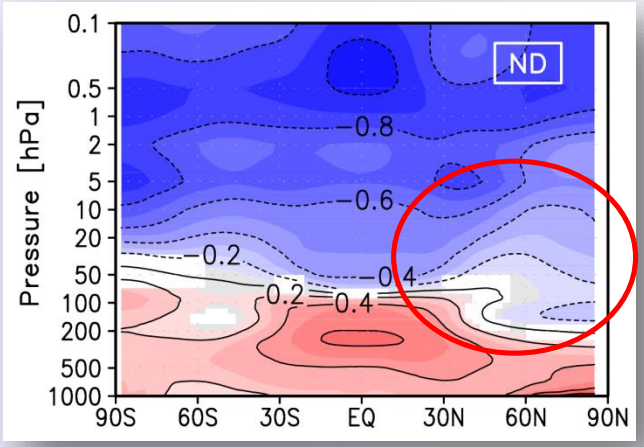
- timeslices (40 years)

| | R1865 | R1960 | R2000 | R2045 | R2095 | S2045 | S2095 |
|---|---|---|---|---|---|---|---|
| **GHGs** | 1865 | 1960 | 2000 | 2045 | 2095 | 2045 | 2095 |
| **ODSs** | 1865 | 1960 | 2000 | 2045 | 2095 | **2000** | **2000** |

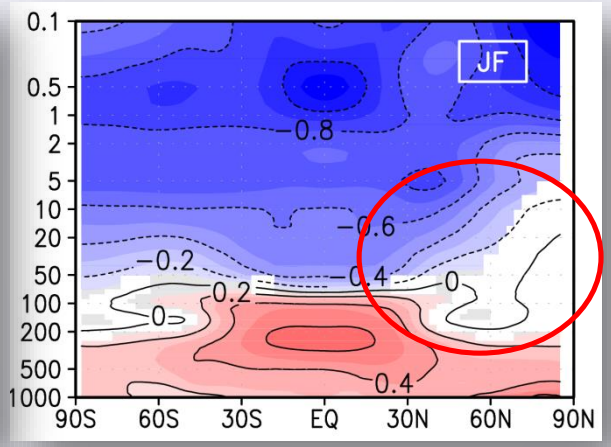
# Stratospheric cooling due to GHG increases?

Temperature change 1960-2099
[K/decade]

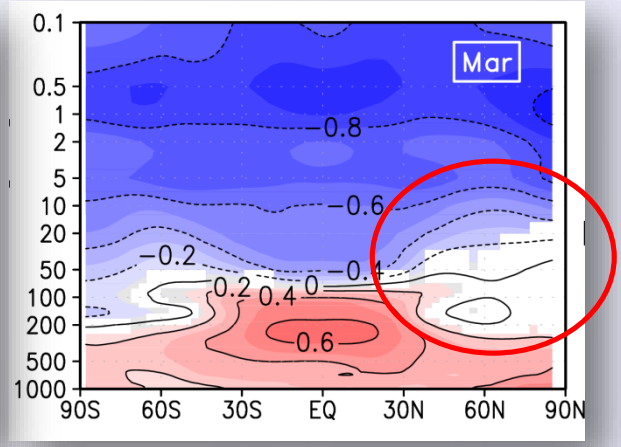
November/December




January/February



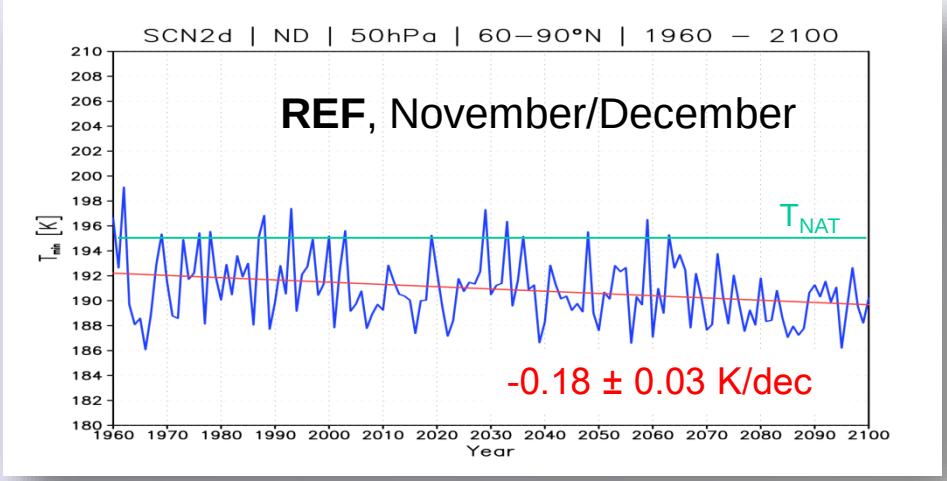

March

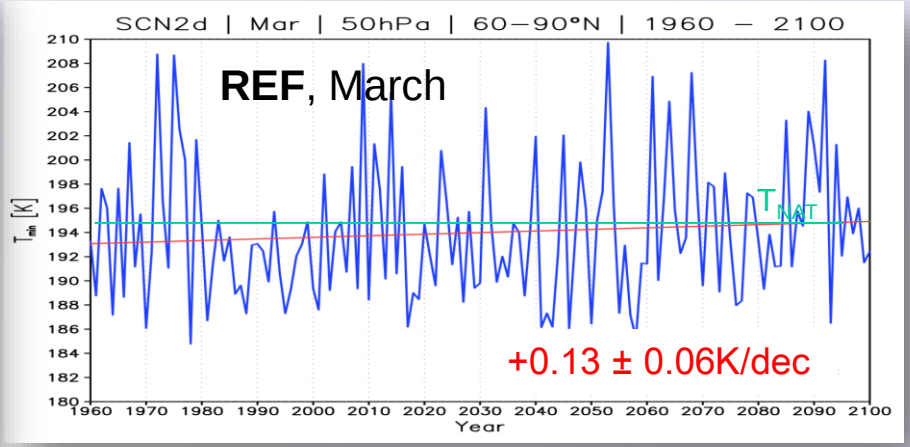


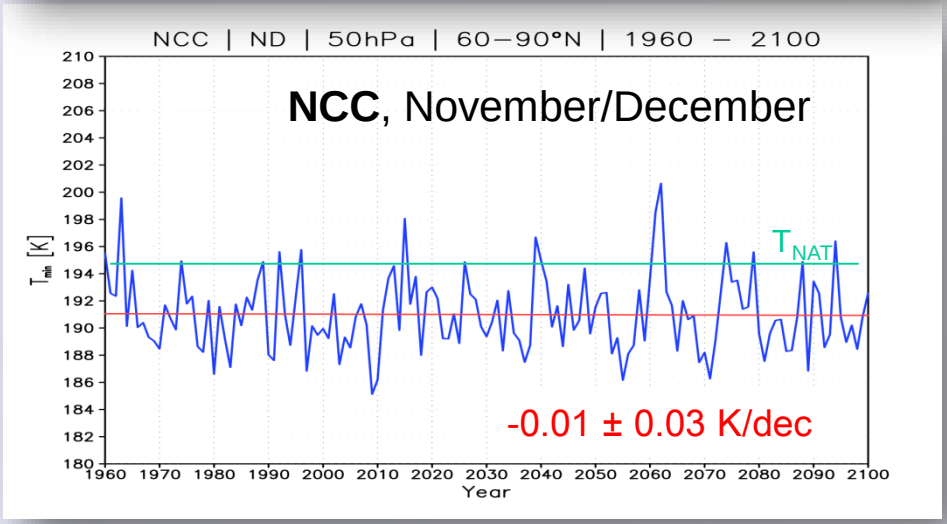

- Cooling in early winter, but no significant change in mid-winter and spring
- Due to GHG increase (as no change in NCC simulation)

# More future cold Arctic winters?

## Arctic minimum temperatures



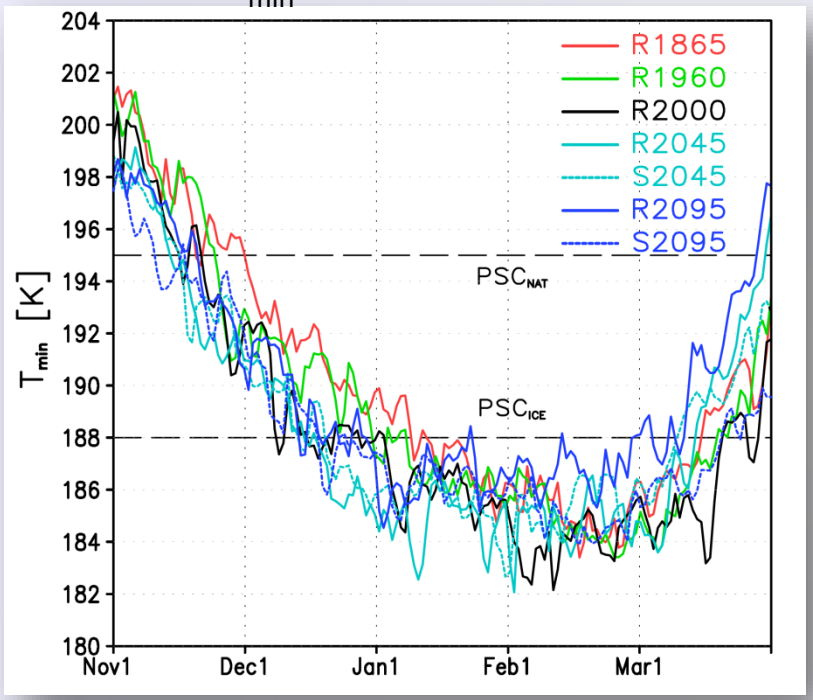




Future decrease in minimum temperature only in early winter

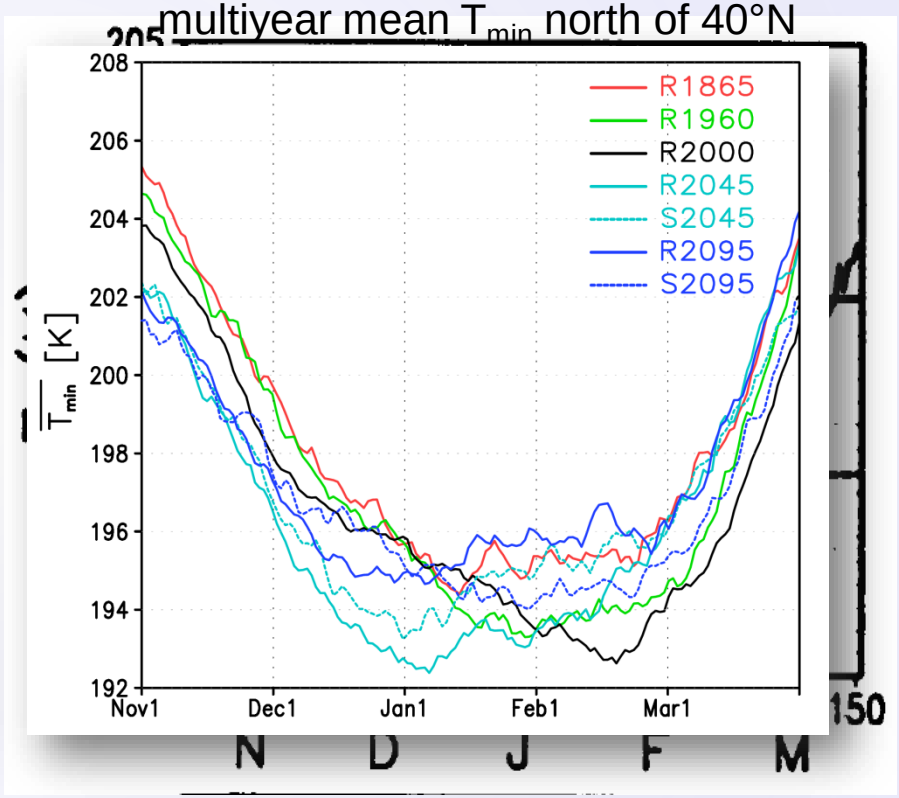
# Seasonal evolution of Arctic minimum temperatures

## for individual forcings

absolute $T_{min}$ north of 40°N at 50 hPa




multiyear mean $T_{min}$ north of 40°N




Pawson and Naujokat, 1997

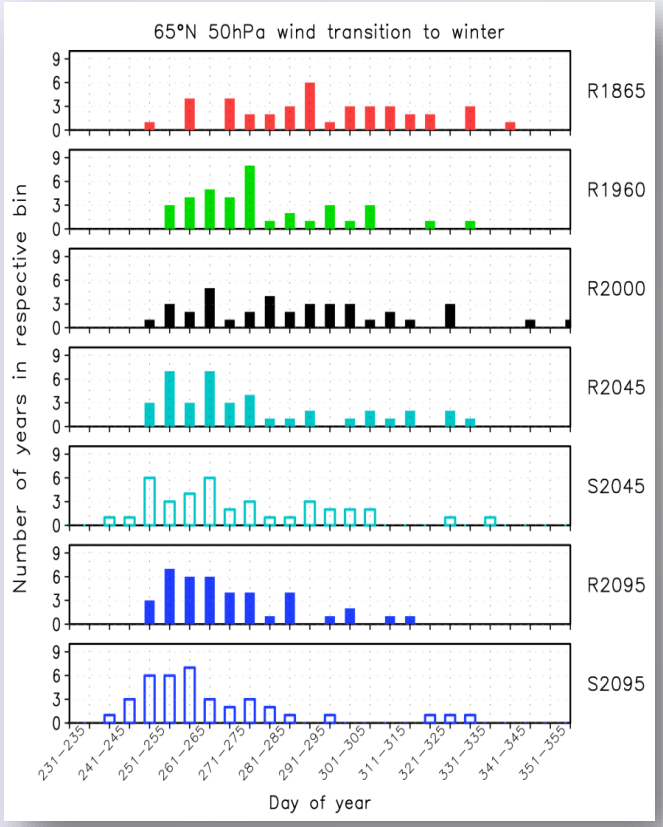
Range of $T_{min}$ in EMAC agrees with observations

ODS lead to lower $T_{min}$ in late winter; GHGs in early winter

# Arctic polar vortex persistence I

Zonal wind transition, 65°N, 50 hPa

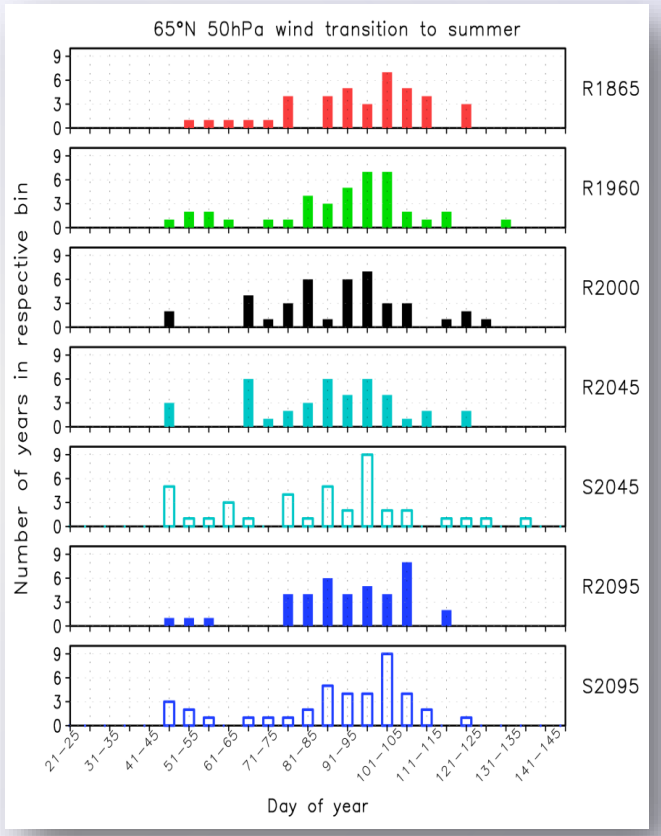
summer ➔ winter




**REF**: -1.12 ± 0.45 days/dec.

Earlier buildup of polar vortex with increased GHGs

winter ➔ summer

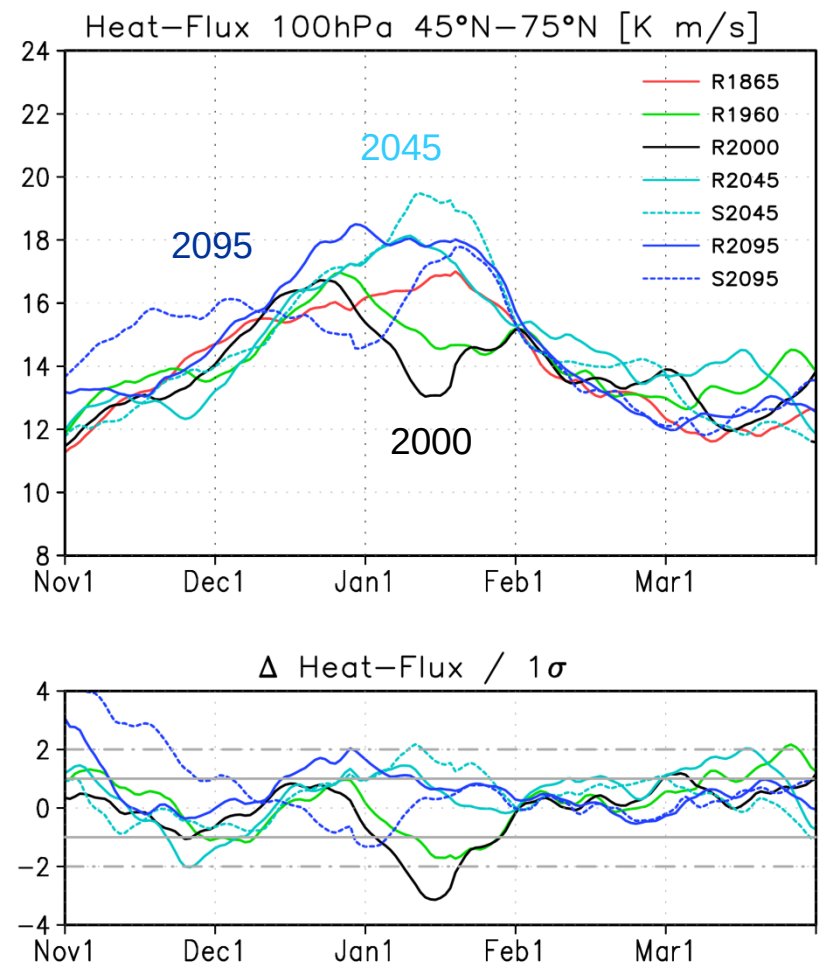



**REF**: -0.18 ± 0.44 days/dec.

Individual late breakdown with high ODS, but no significant change

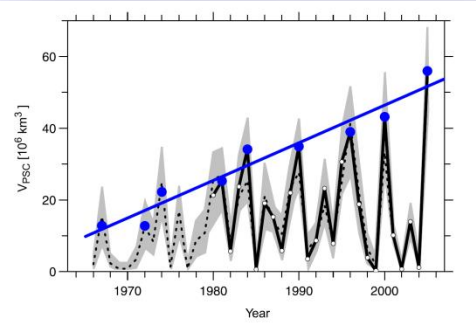
# Stronger dynamical forcing of the stratosphere?

## 100 hPa eddy heat flux



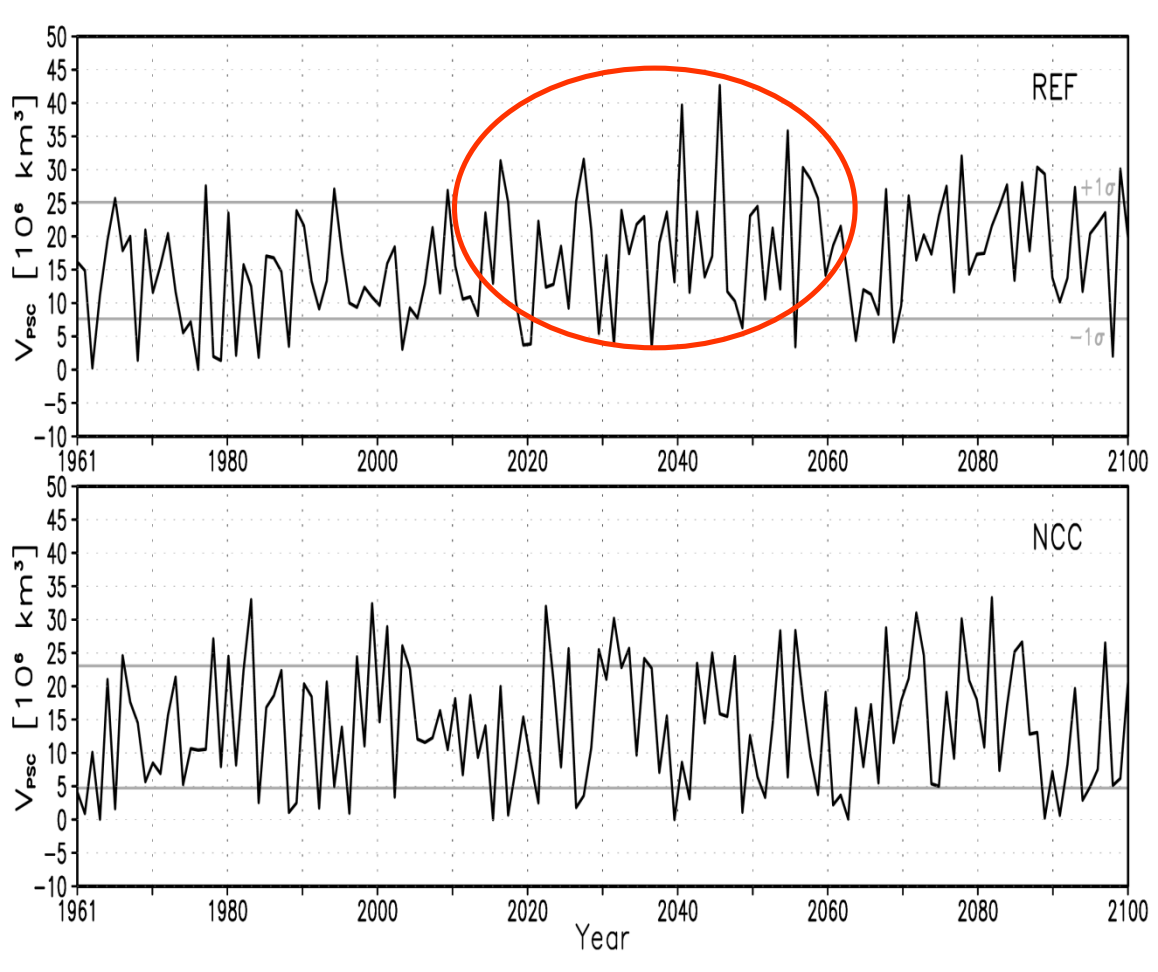

Enhanced planetary wave forcing from troposphere in mid-winter due to GHG increase

# What is the effect on Arctic total ozone?




Rex et al., 2006

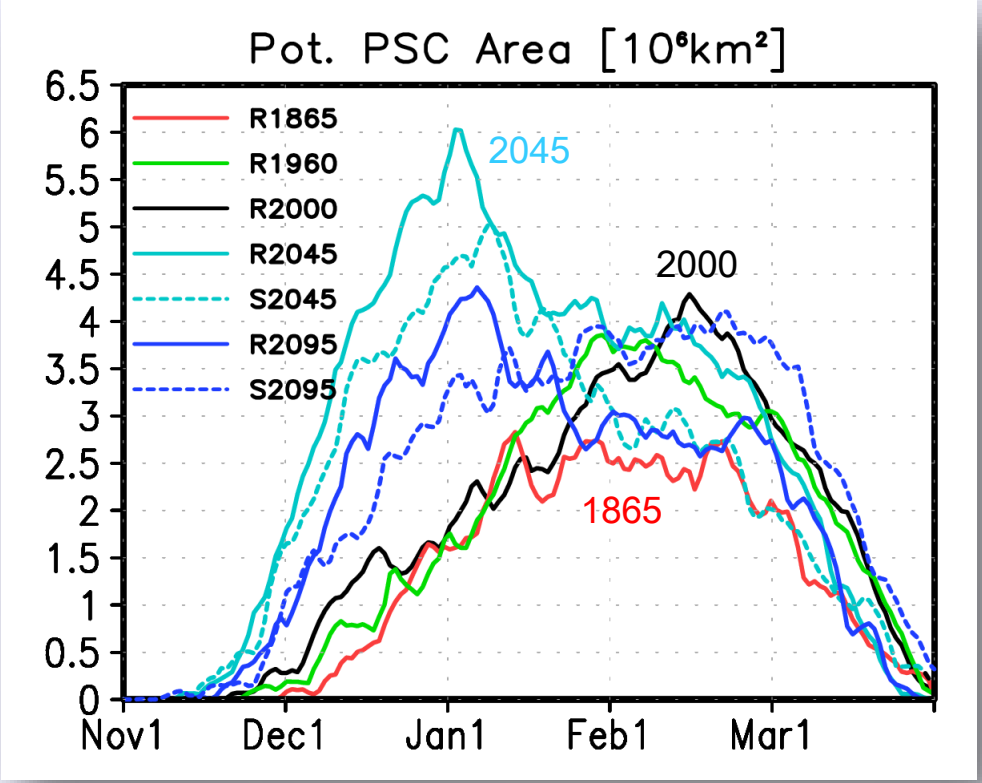
$V_{PSC}$




Maximum $V_{PSC}$ with climate change during 1st half of 21st century

# Potential PSC area with $T < T_{NAT, mod}$

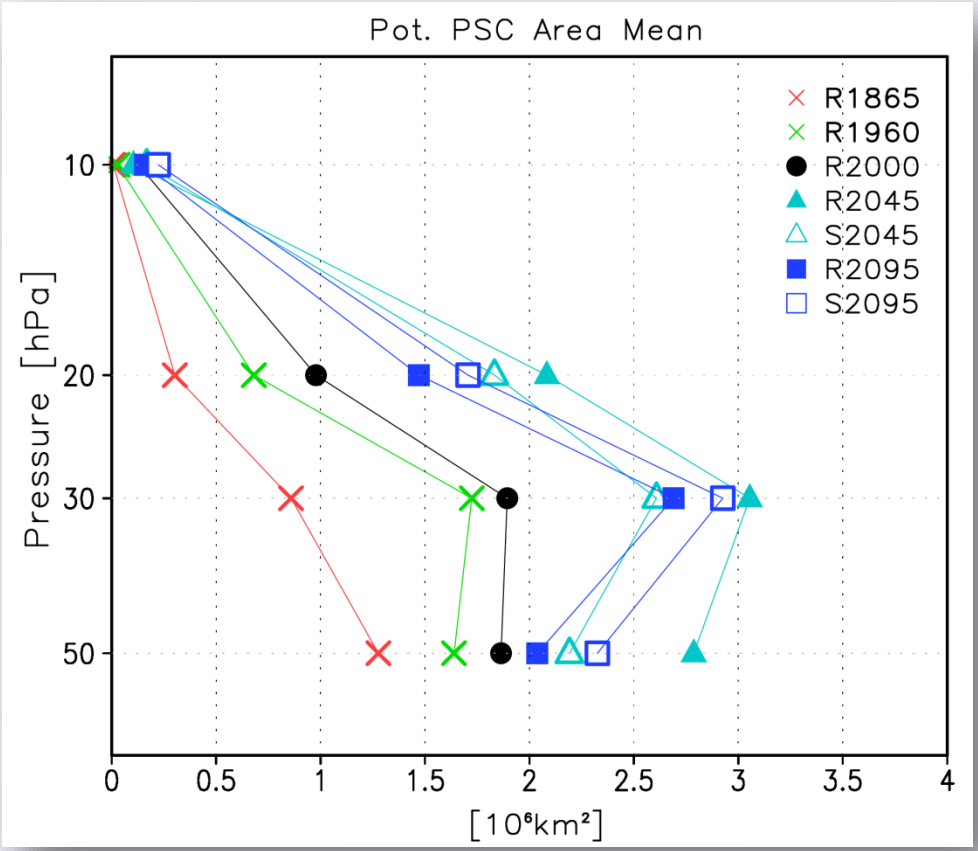
50 hPa, 40°-90°N




Enhanced PSC formation potential in early winter due to GHGs

# Potential PSC area with $T < T_{NAT,mod}$ as a function of height

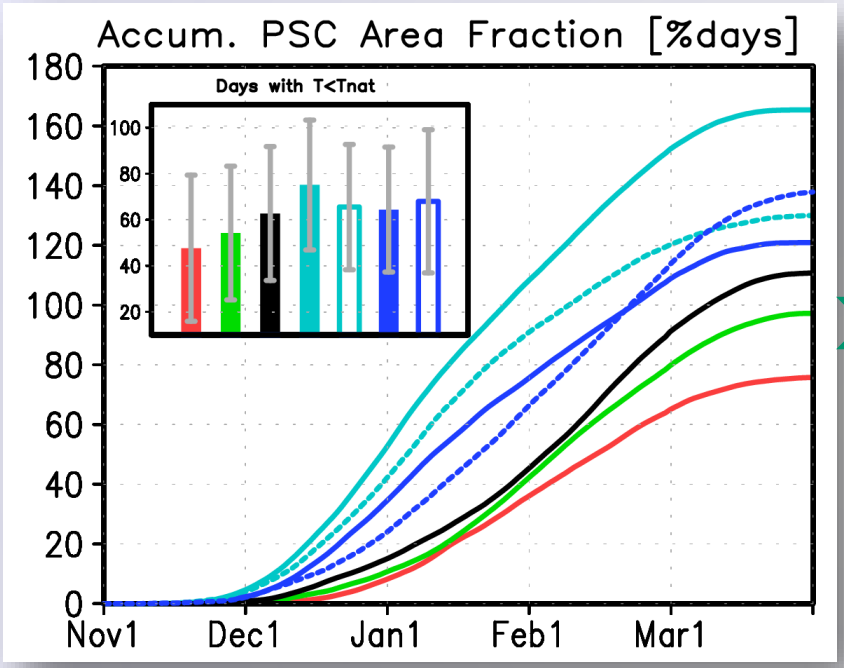
40°-90°N

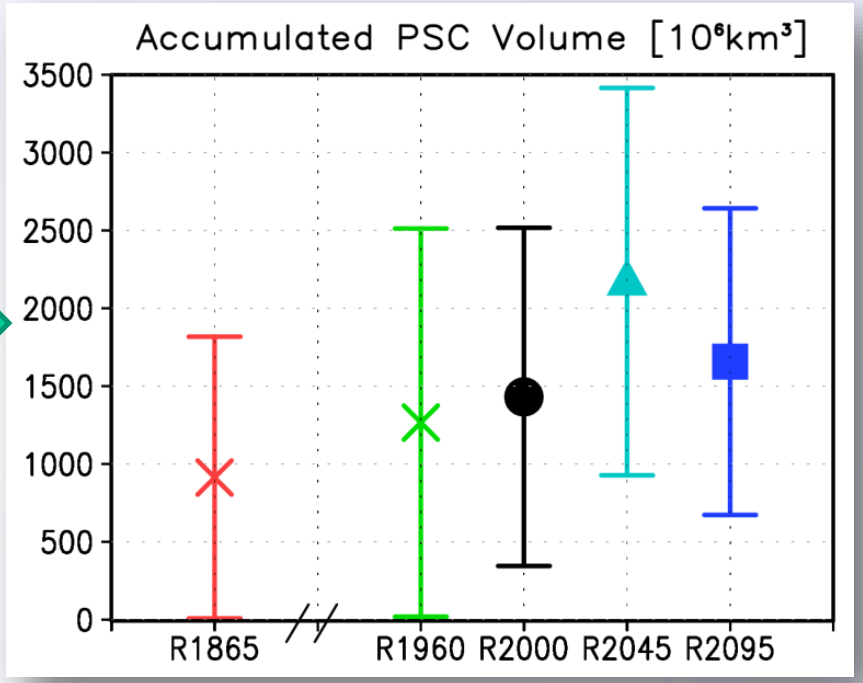



Improved conditions for PSC formation in the middle stratosphere due to GHG induced cooling

# Accumulated potential PSC area fraction

50 hPa, 40°-90°N



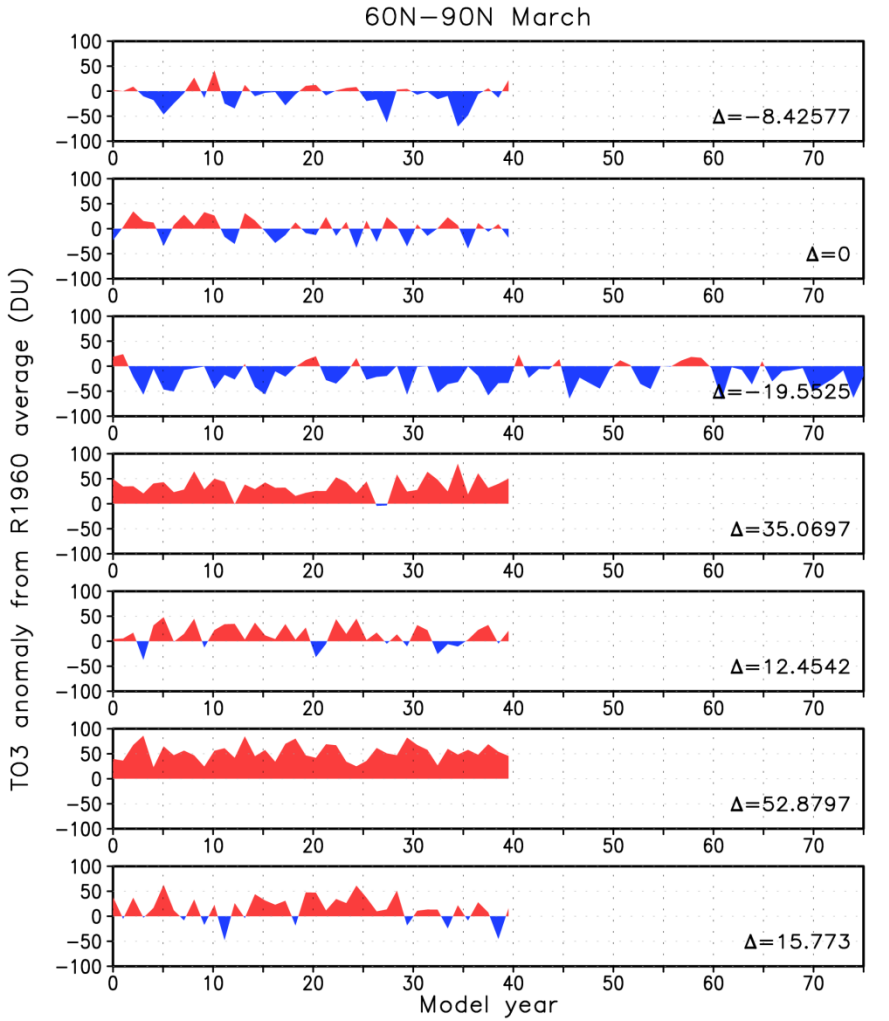




Strong increase by ODS in **late** winter
Strong increase by GHG in **early** winter

Maximum accumulated $V_{PSC}$ in 2045

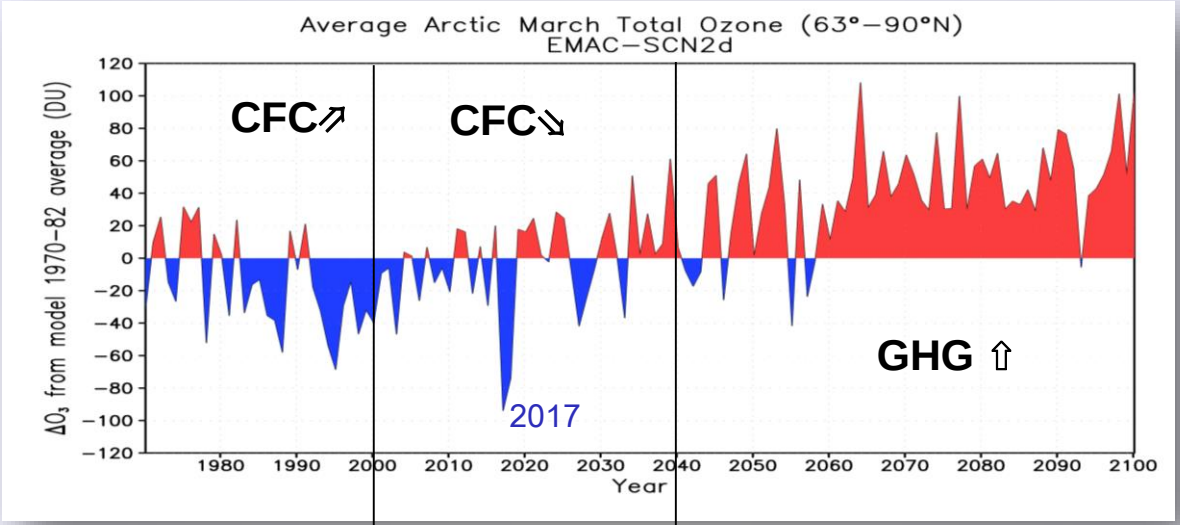
# Arctic total ozone in March

Anomalies from 1960 average

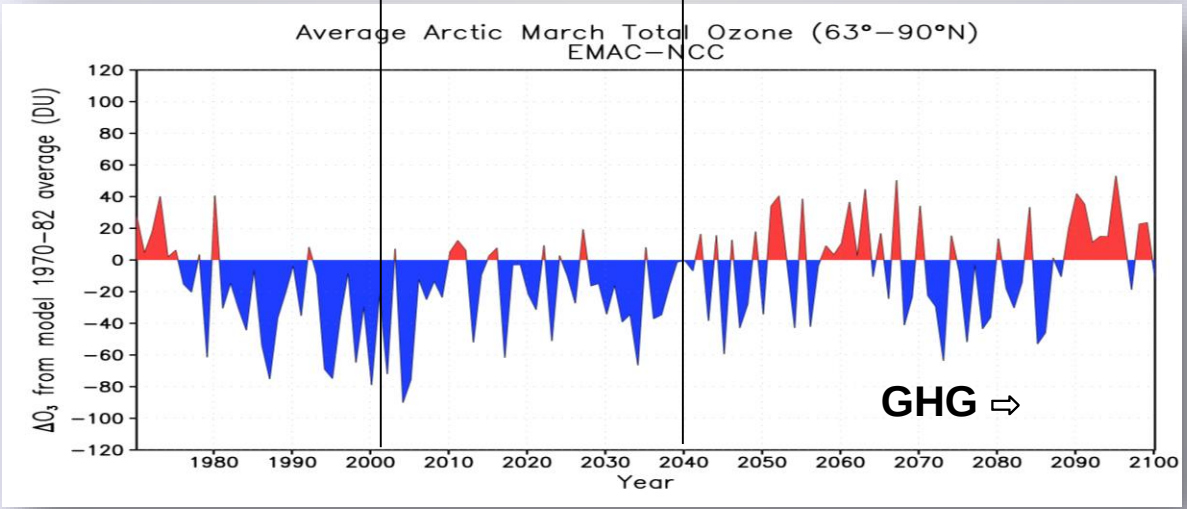


# Arctic total ozone in March

SCN2d




NCC



# Conclusions

- Future cooling of Arctic lower stratosphere in early winter, but no significant change in mid-winter and March
- Extended future lifetime of Arctic polar vortex due to earlier build-up
- Enhanced future dynamical forcing of the stratosphere in mid-winter
- Future decrease in minimum temperature only in early winter
- Lower early winter temperatures lead to higher PSC formation potential in future, however no enhanced Arctic spring ozone losses due to dynamical impact
- Increase of future increase in $V_{PSC}$ not confirmed for 2nd half of 21st century
- **No tendency to future Arctic ozone holes, but individual events possible**

Funded by DFG