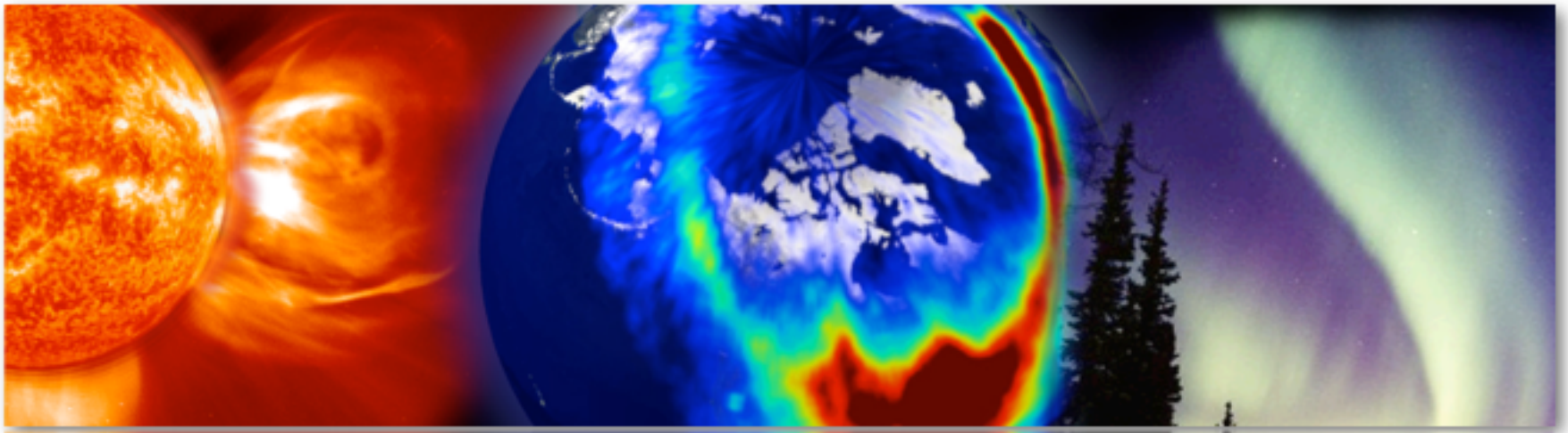
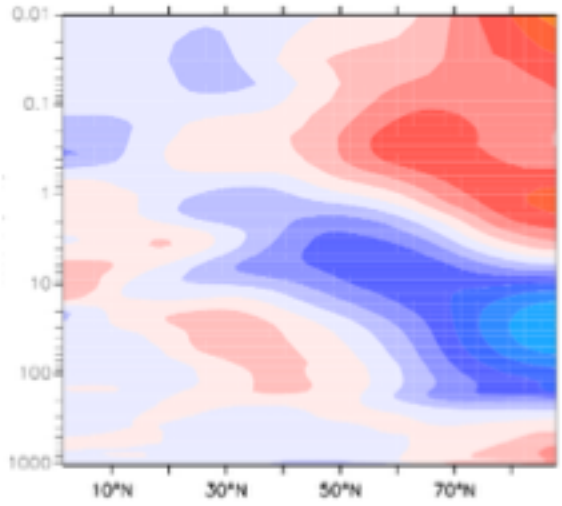
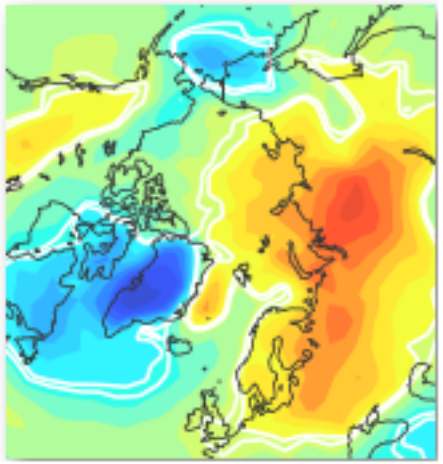


EPP contribution to stratospheric and tropospheric variations (chemistry - indirect effects - dynamics)

Annika Seppälä





ISSI, March 24-28, 2014

About the so-called indirect effect

Impact on the neutral atmosphere

Precipitation into the polar atmosphere (30 - 100 km) increases ionisation.

Protons and electrons from the Sun/magnetosphere

Enhanced production of NO_x and short-lived HO_x through ion chemistry.*

*Ionisation is the main source during winter

NO_x lifetime long during polar winter → Contained/ transported in polar vortex

Important contribution to ozone balance.

$2(NO + O_3) \rightarrow 2(NO_2 + O_2)$

$NO_2 + h\nu \rightarrow NO + O$

$NO_2 + O \rightarrow NO + O_2$

Total: $2O_3 \rightarrow 3O_2$

Effect on LW & SW radiative heating and cooling

Natural forcing to the atmosphere. Regional scale effects.

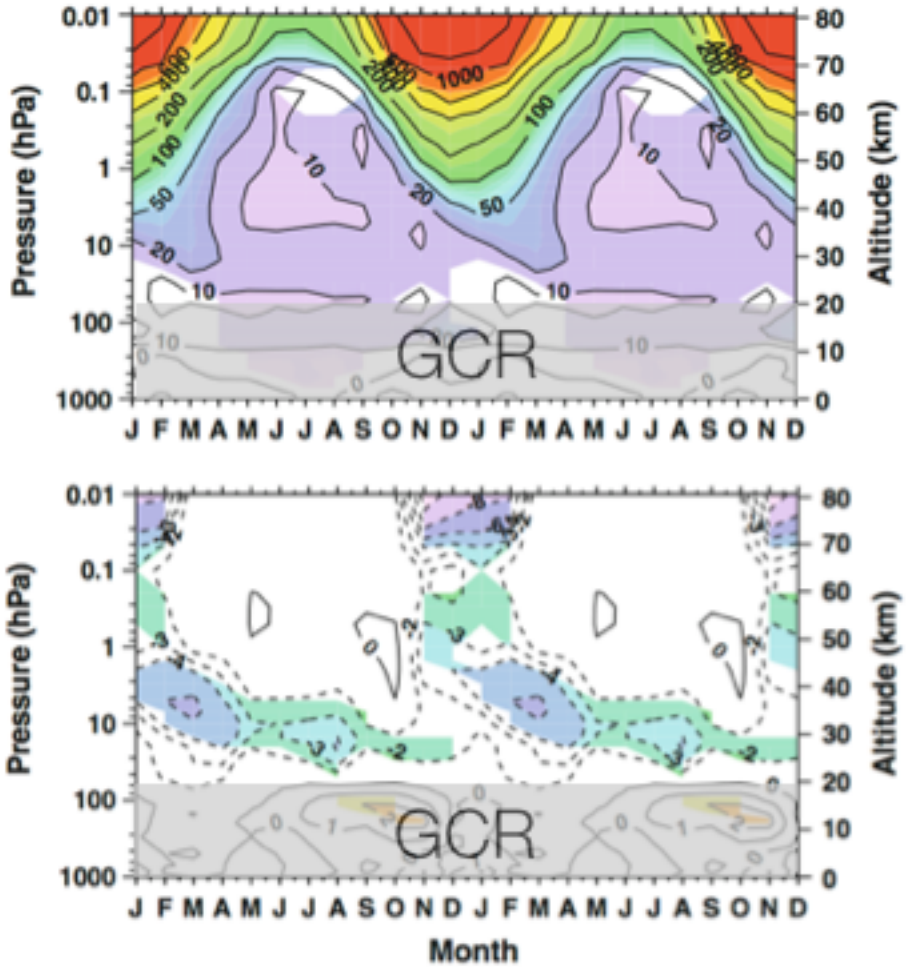
Atmospheric Dynamics

About the so-called indirect effect

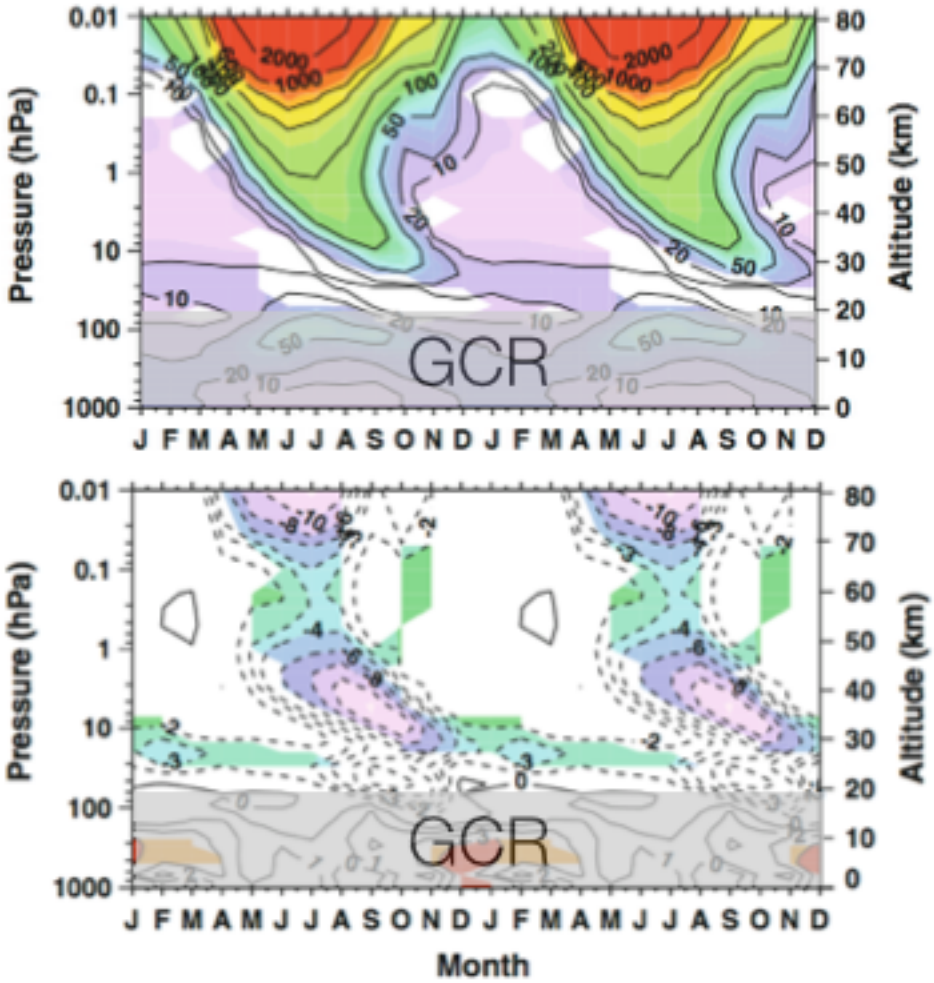
Model simulations: 3D chemistry-climate model

*Electron precipitation included through a proxy

60N-90N Monthly mean NO_x and O_3 response [%] to SPEs, EEP*, and GCR. 1960-2005 average.



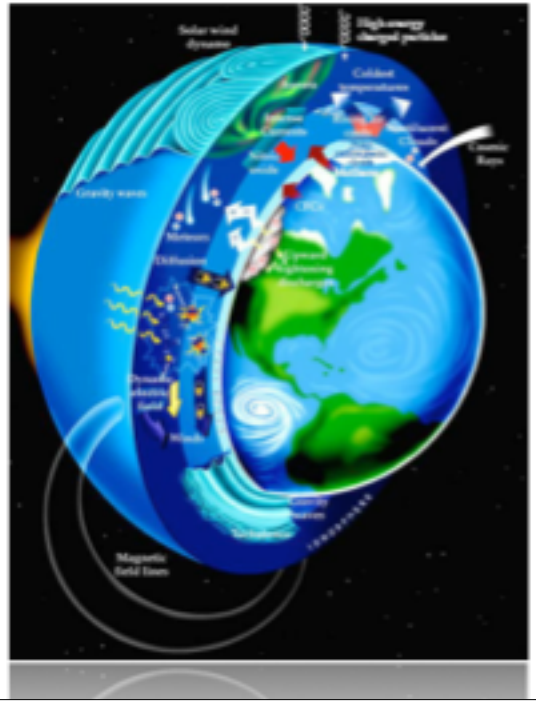
60S-90S Monthly mean NO_x and O_3 response [%] to SPEs, EEP, and GCR. 1960-2005 average.



Rozanov et al., 2012

Continued from morning session…

- Pekka's presentation: EPP initial effects on middle atmosphere chemistry relatively well known.
- We have also learned more about indirect effects on stratospheric chemistry, thanks to satellite observations.
  - *Indirect* - as a result of air masses transported from higher altitudes
- EPP effects on dynamics and lower altitudes less clear.
  - Mesospheric dynamical changes from SPE.
    - *Jackman et al., 2007*
  - What about the stratosphere and troposphere?

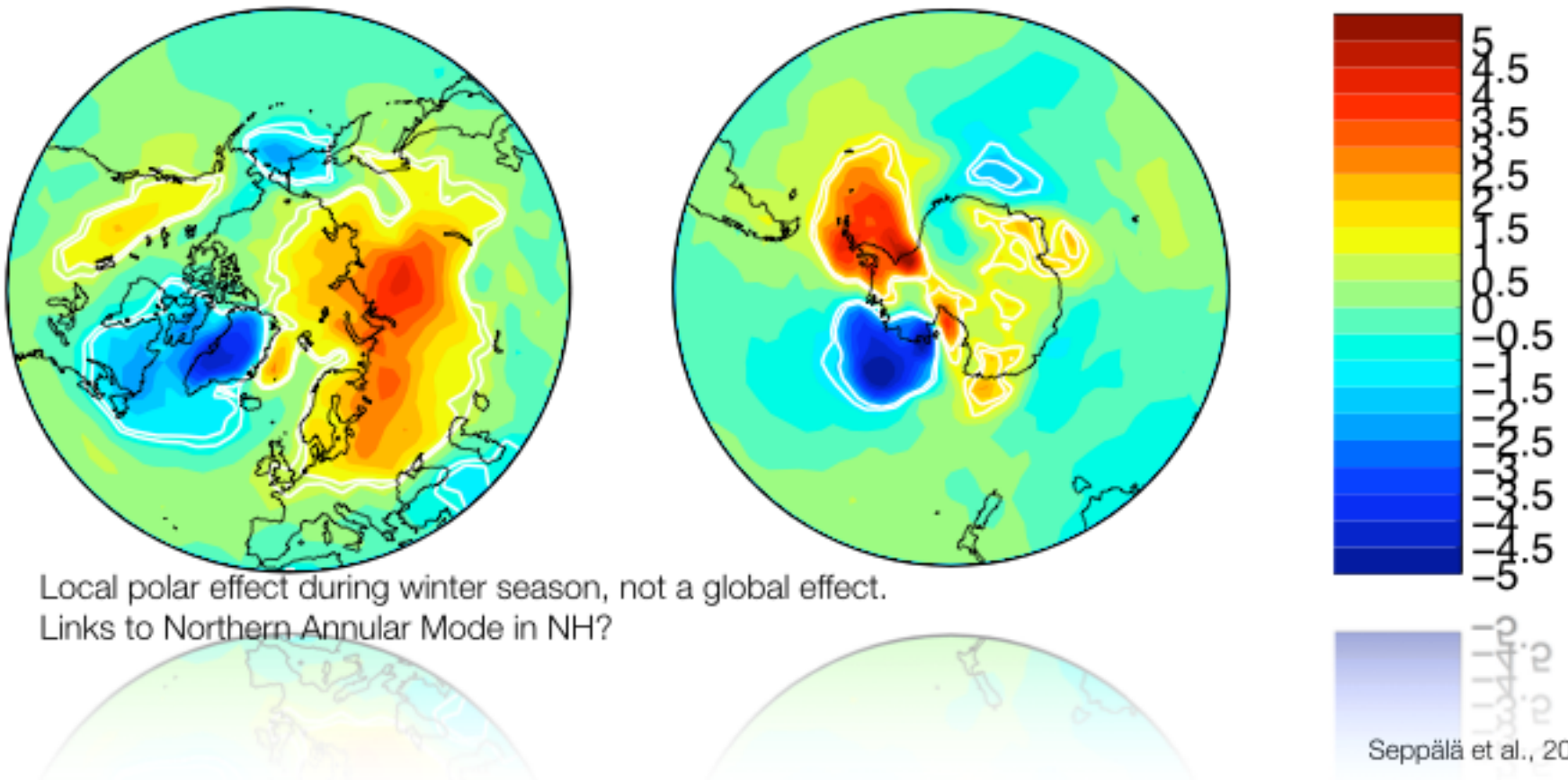


EPP and tropospheric temperatures (Surface Air Temperature)

>40 years of re-analysis data

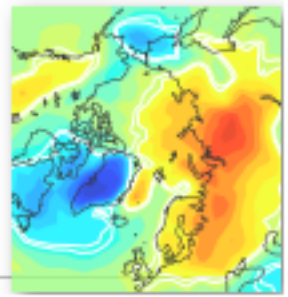
NH: High EPP - Low EPP

SH: High EPP - Low EPP



Local polar effect during winter season, not a global effect.
Links to Northern Annular Mode in NH?

Continued from morning session…

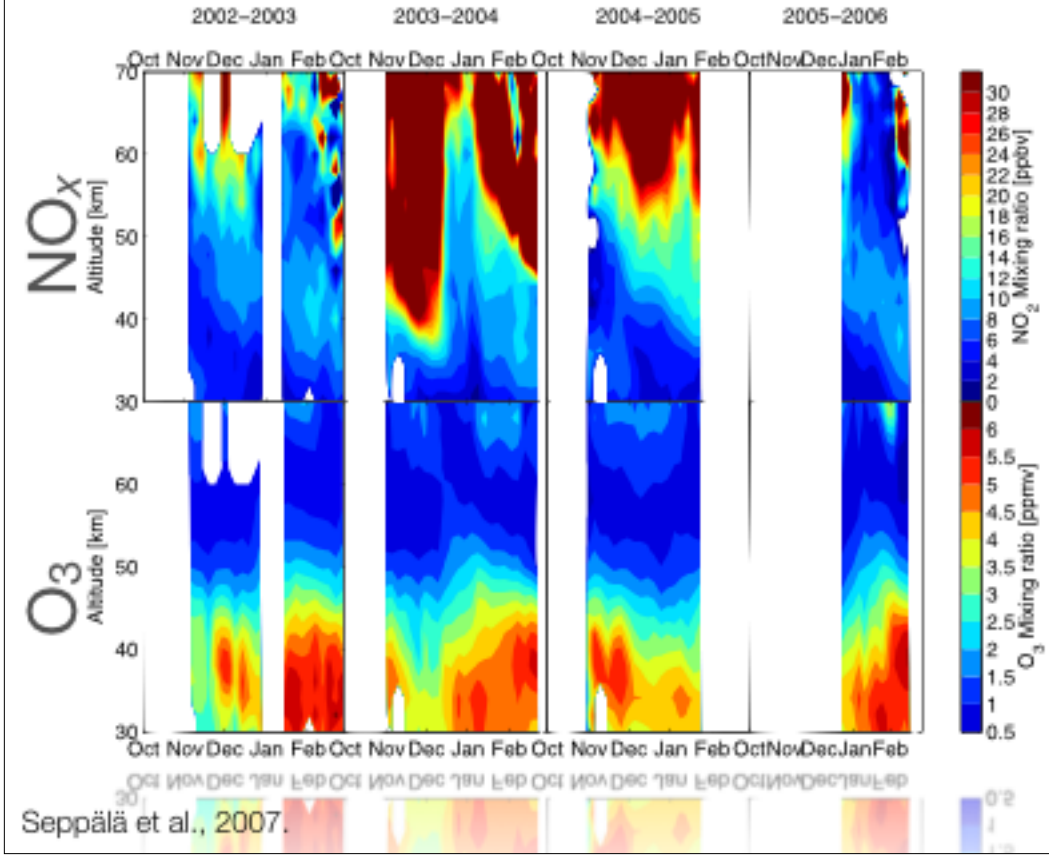


- Energetic Particle Precipitation (EPP) initial effects on middle atmosphere chemistry relatively well known. We have also learned more about indirect effects on stratospheric chemistry, thanks to satellite observations.
- EPP effects on dynamics and lower altitudes less clear.
  - Mesospheric dynamical changes from SPE. *Jackman et al., 2007.*
  - What about the stratosphere and troposphere?
    - Connection between solar wind/geomagnetic activity/EPP and the NAM/NAO/AO? Several studies including *Boberg and Lundstedt, 2002, Thejll et al., 2003, Lu et al., 2008, Seppälä et al., 2009, Baumgaertner et al., 2011.*
    - How does the signal propagate from MLT altitudes to the troposphere? What happens in the stratosphere?

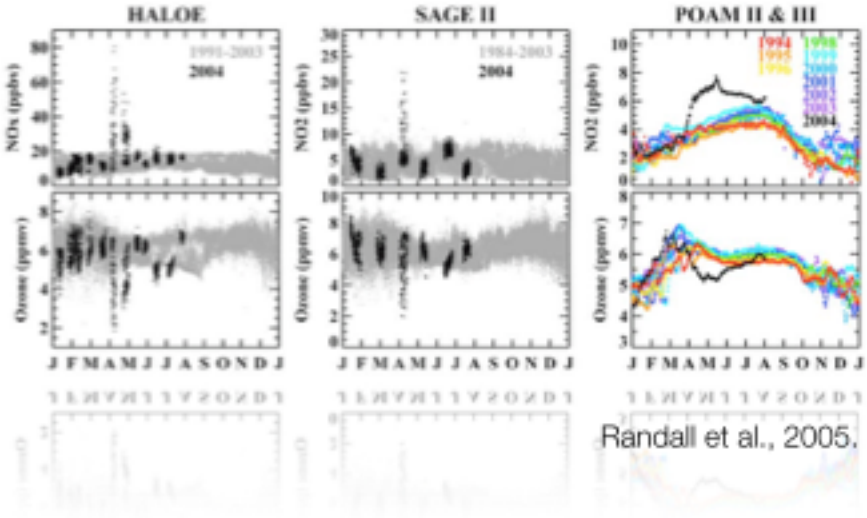
EPP and chemistry

Long lived chemical changes during *winter and progressing into spring.*

Chemical changes limited to the mesosphere and stratosphere, above about 30km.
How is the troposphere influenced?



Seppälä et al., 2007.



Randall et al., 2005.

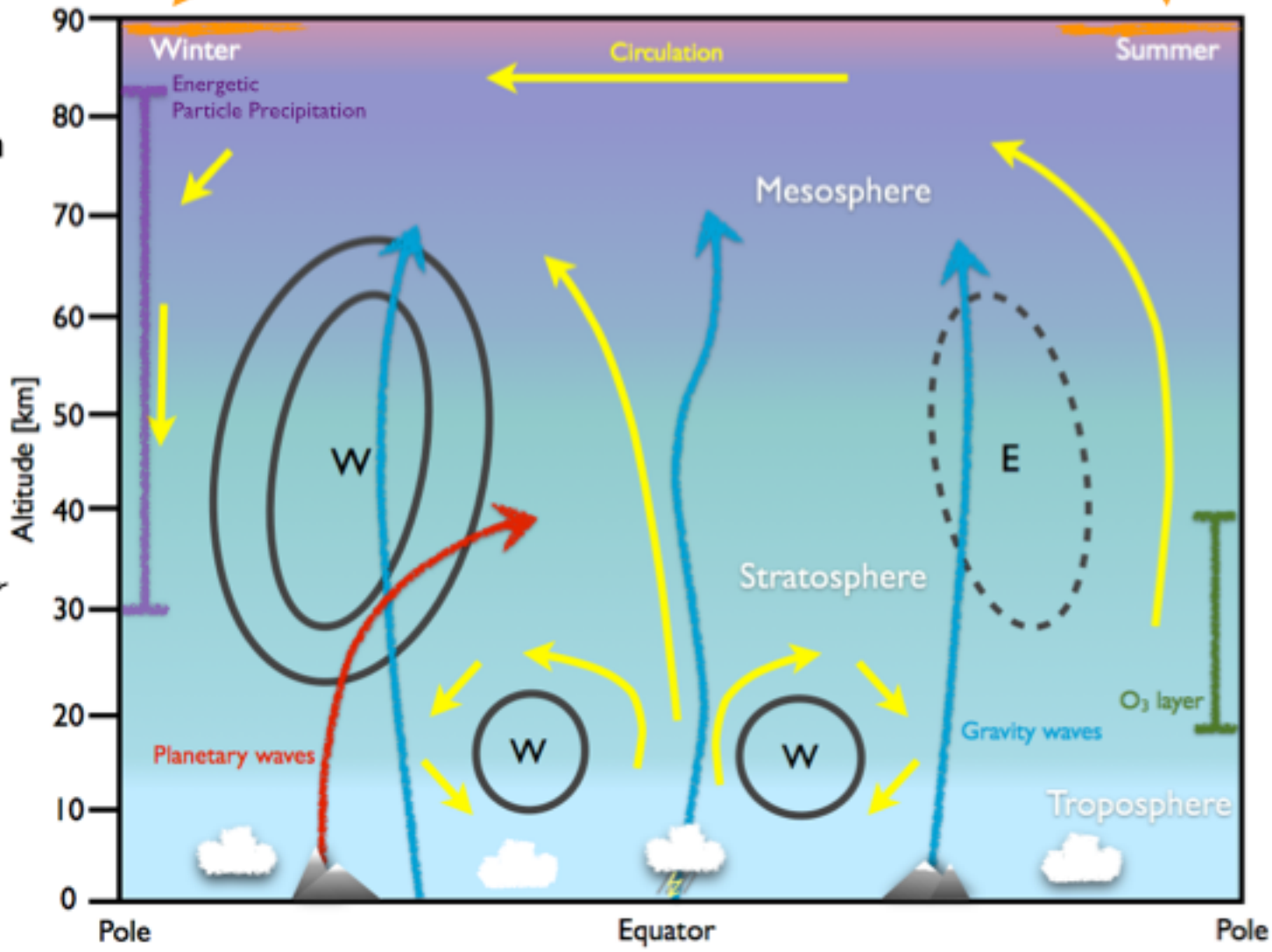
If the NO_x reaches the stratosphere before spring, effects on stratospheric ozone significant. Possibility for effects until summer? Is this the pathway to influencing troposphere?

Middle atmosphere dynamics

Polar regions: Access for particles. Location of chemical changes.

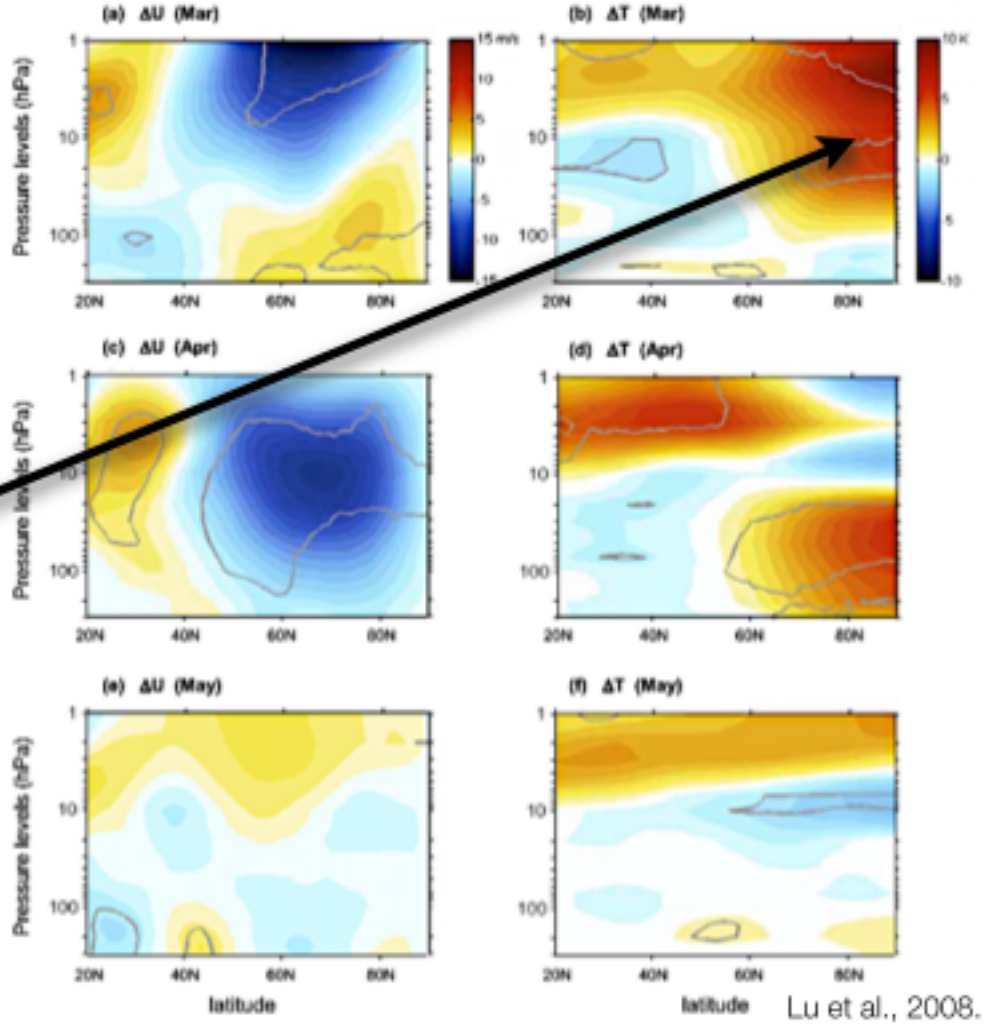
Active dynamics through interaction with atmospheric waves takes place in the winter hemisphere.

Strong winds around the winter pole form the *polar vortex*. Maintains air in the polar region, enhances downward transport.

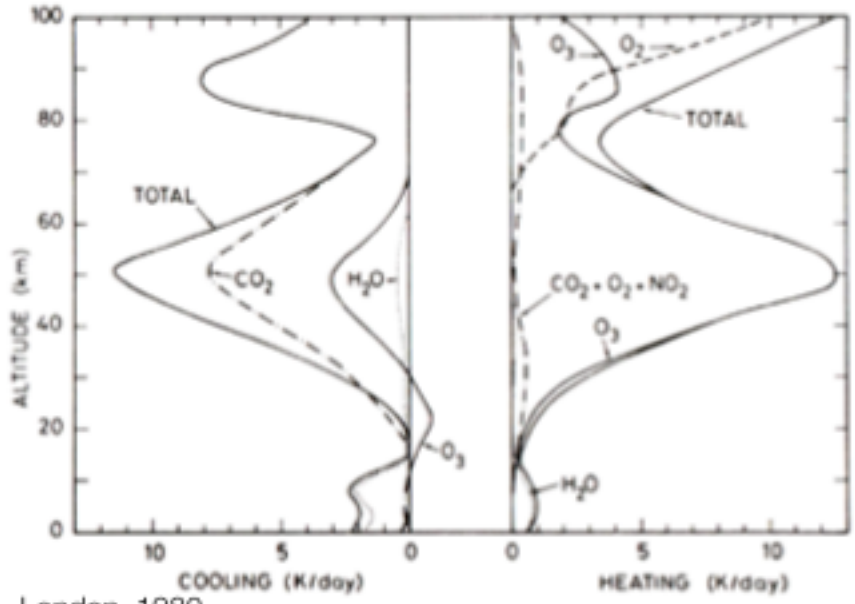


EPP and dynamics

- Hypothesis: EPP leads to reduction on stratospheric ozone in the SPRING.
- Less O_3, less long wave heating from O_3 → Cooling.
- Lu et al. 2008: Opposite T signal.



Lu et al., 2008.



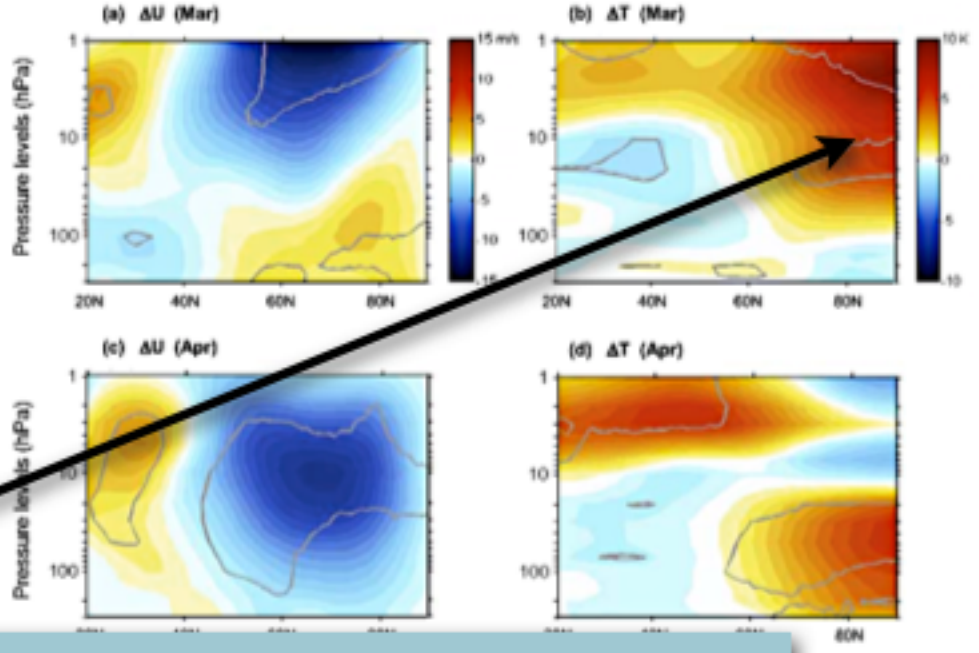
London, 1980.

Similar spring time zonal mean zonal wind results from WACCM presented by Kvissel et al., 2012.

SPRING

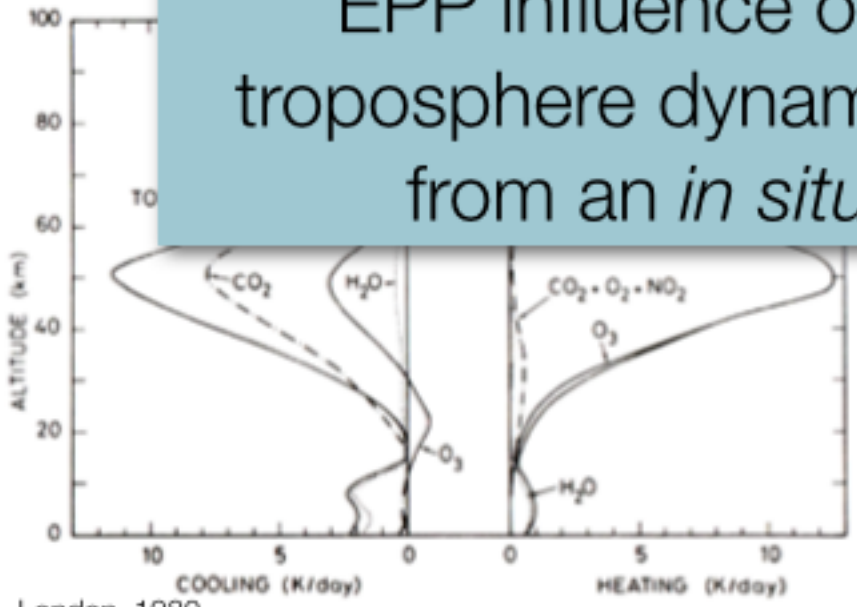
EPP and dynamics

- Hypothesis: EPP leads to reduction on stratospheric ozone in the SPRING.
- Less O_3, less long wave heating from O_3 → Cooling.
- Lu et al. 2008: Opposite T signal.



Lu et al., 2008.

EPP influence on stratosphere and troposphere dynamics in spring likely not from an *in situ* chemical effect.



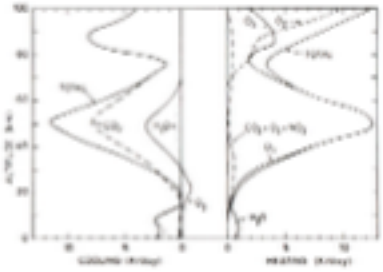
London, 1980.

Similar spring time zonal mean zonal wind results from WACCM presented by Kvissel et al., 2012.

WINTER

EPP and dynamics
What have we learned from models?

- ✓ EPP impact on chemistry.
- Model experiments: Chemistry-General Circulation Models forced with EPP-NO_x source. (*Rozanov et al., 2005, 2012, Baumgaertner et al., 2011, Kvissel et al., 2012*)
- Similar surface temperature results to re-analysis data during WINTER.
- *Baumgaertner et al. (2011)*: Ozone loss → Reduction in *long wave radiative cooling* in WINTER polar upper stratosphere-mesosphere → Positive WINTER temperature anomaly.
  - Decreased mean meridional circulation → Cooling the polar stratosphere.
- Chemistry coupling to dynamics already during winter



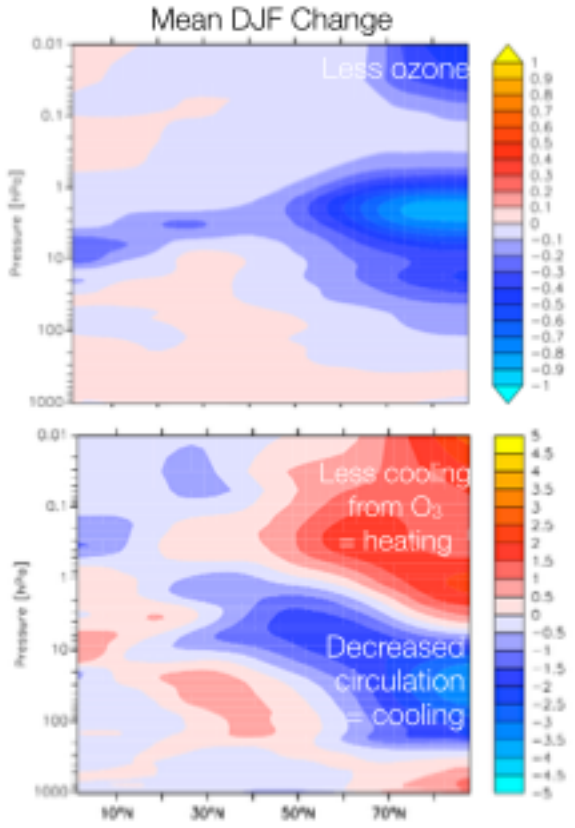
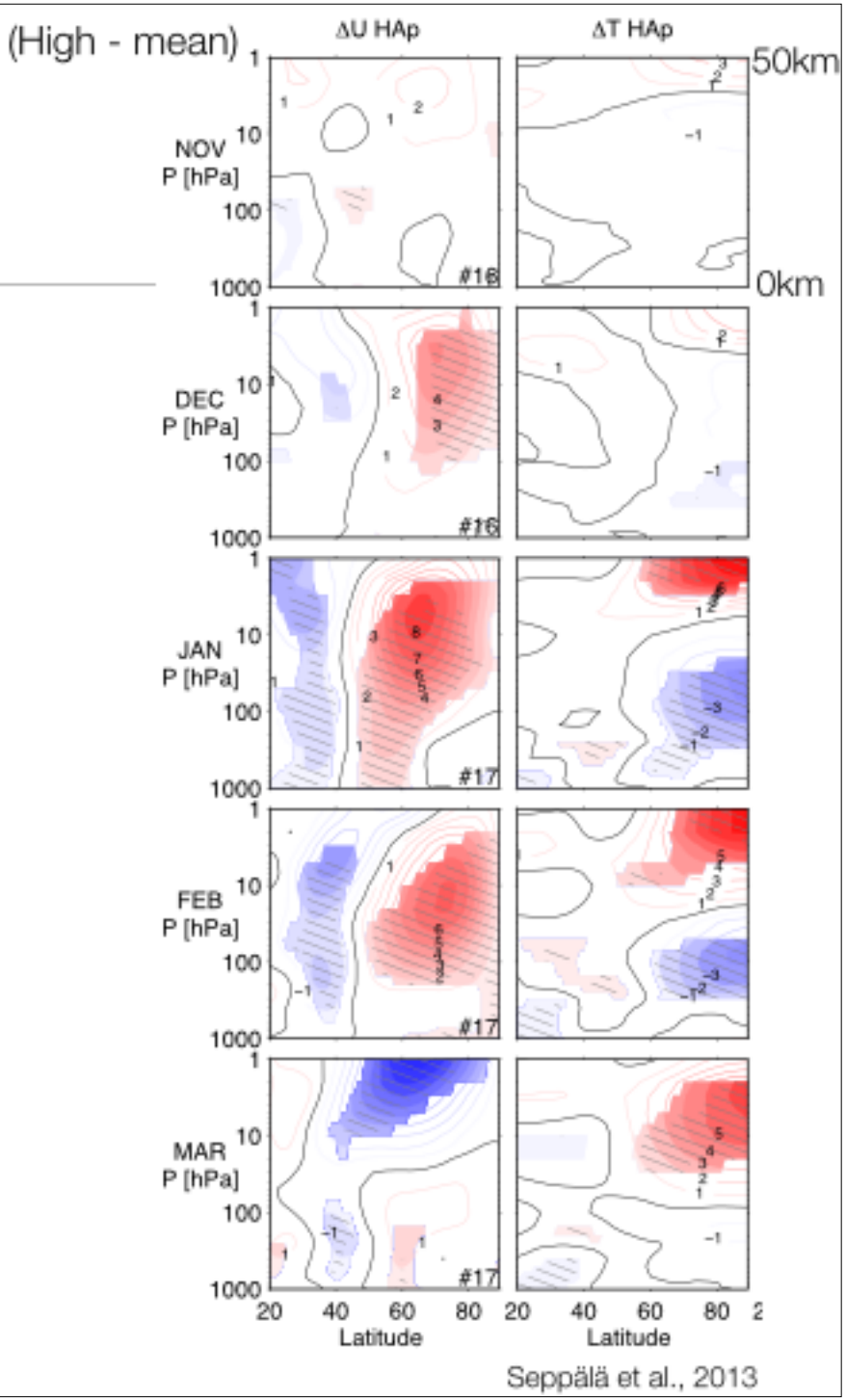


Fig. 9. Climatological DJF change of temperature (K), $\Delta T = T^{S-EPP} - T^{S-noEPP}$. Red-yellow/blue colours indicate positive/negative differences.

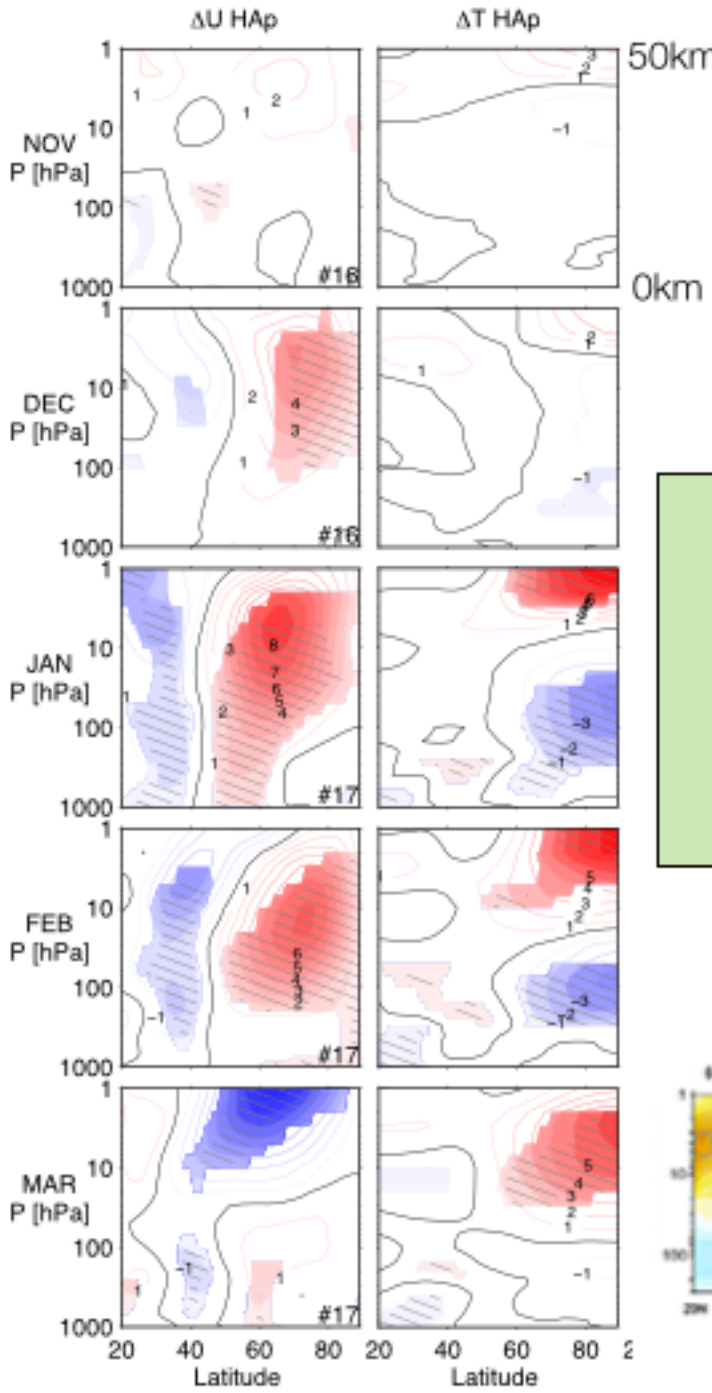
Baumgaertner et al., 2011

EPP and dynamics: A closer look

- 50 years of ERA re-analysis data
- Monthly means of zonal mean zonal wind, temperature and Eliassen-Palm flux.
- All data divided into High EPP and low EPP based on the A_p index.
- Looking at deviations from the dataset mean.

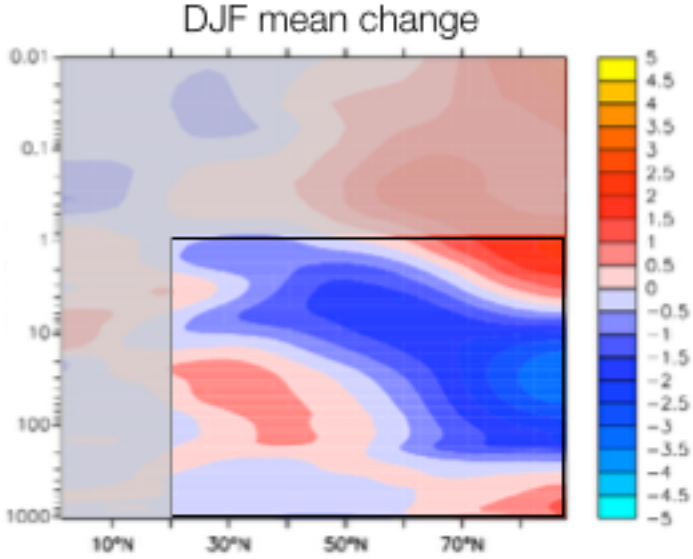


Seppälä et al., 2013

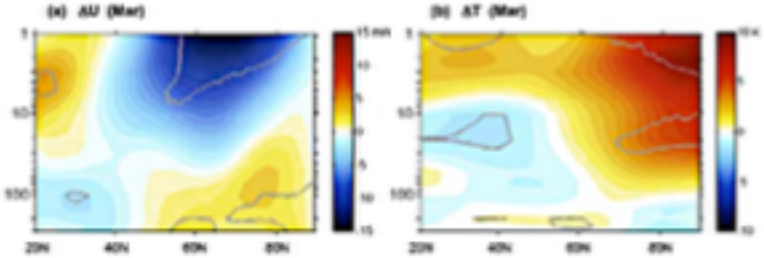


Seppälä et al., 2013

The results agree fairly well with previous studies for the polar region.



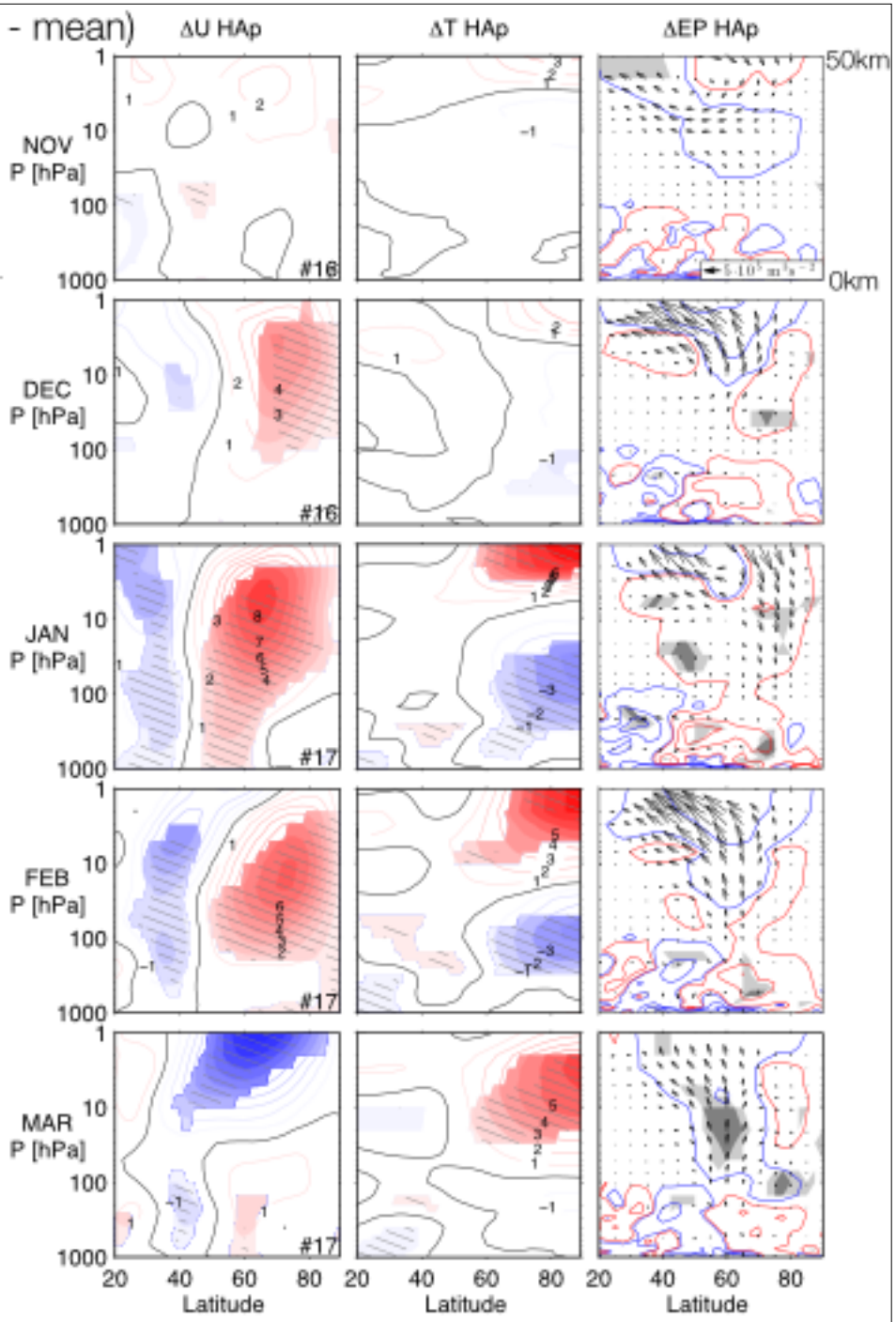
Baumgaertner et al., 2011



Lu et al., 2008.

EPP and dynamics
Wave forcing

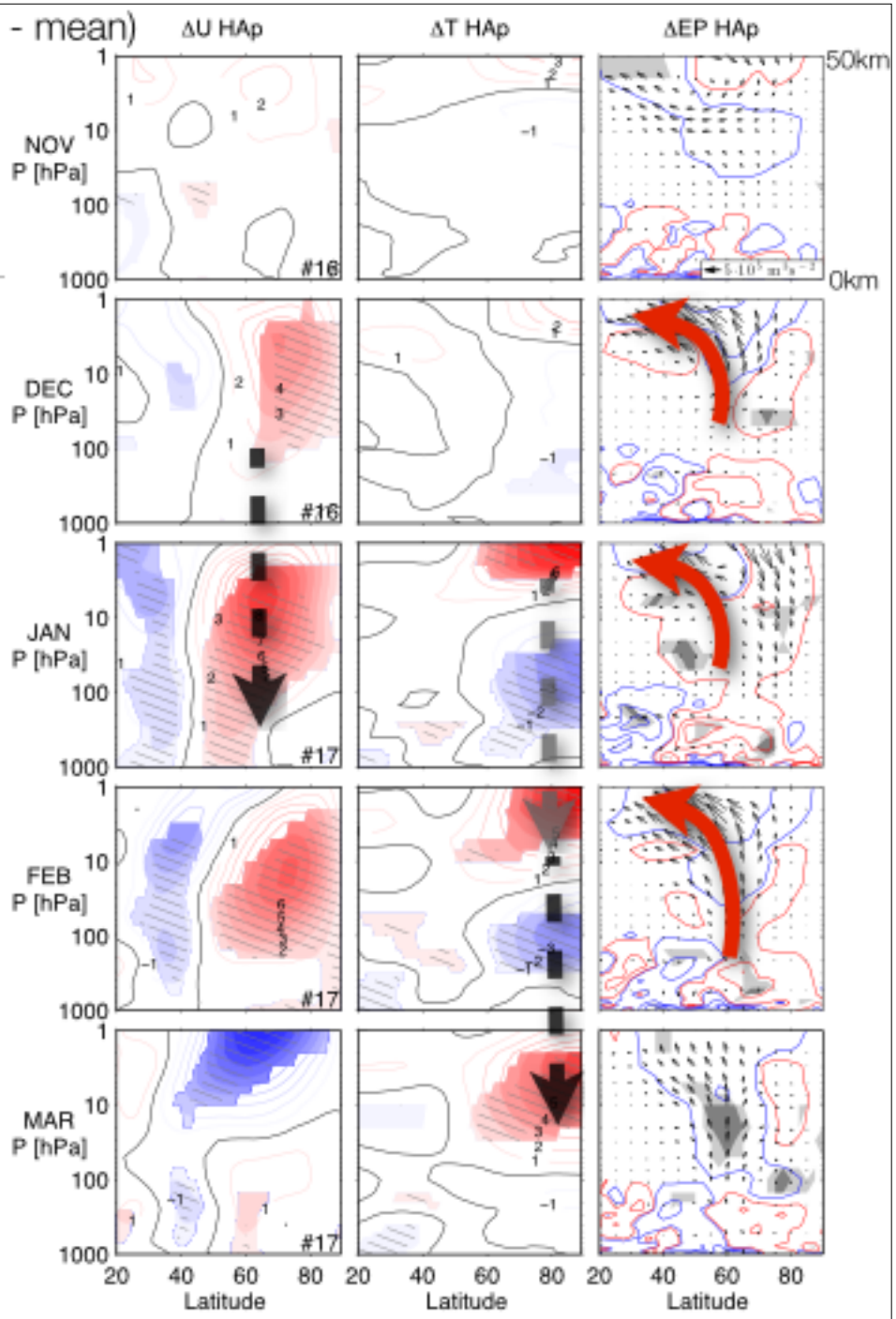
- Eliassen-Palm flux (EP flux), a measure of wave activity (energy transfer).
- Arrows: Direction of wave propagation
- Contours: Zonal flow acceleration or deceleration from wave breaking.



Seppälä et al., 2013.

EPP and dynamics
U, T, EP

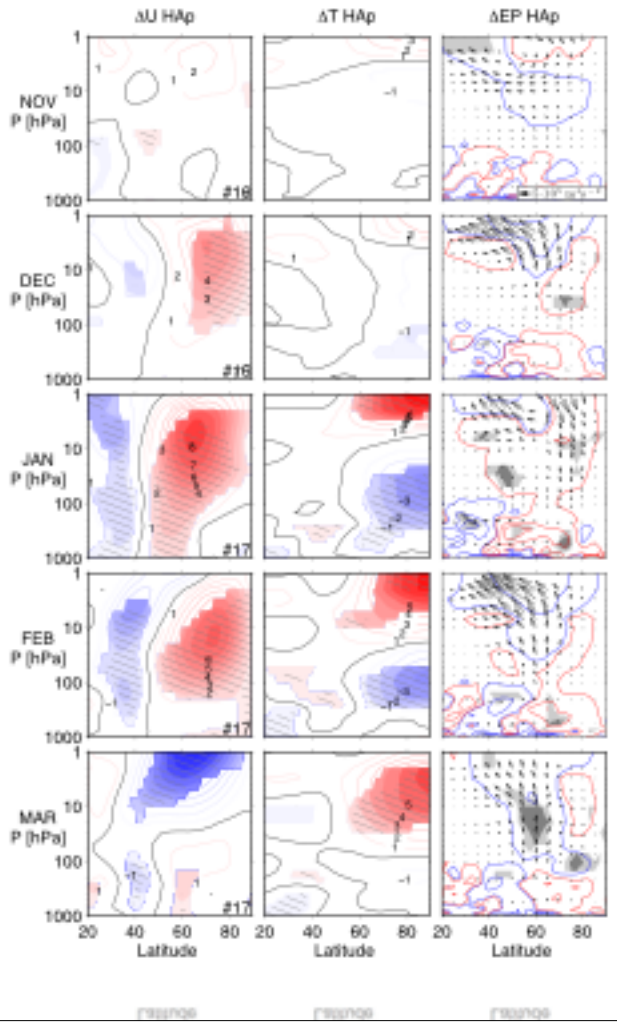
- Dec-Feb: More waves are reflected towards the equator and away from the polar region under high EPP.
- Less waves disturbing the polar vortex → stronger vortex, until Mar.
- Winds and temperatures show downward movement with time. Waves play a significant role in transferring the EPP signal from the stratosphere to the troposphere.
- ⇒ Coupling through wave-mean flow interaction important.



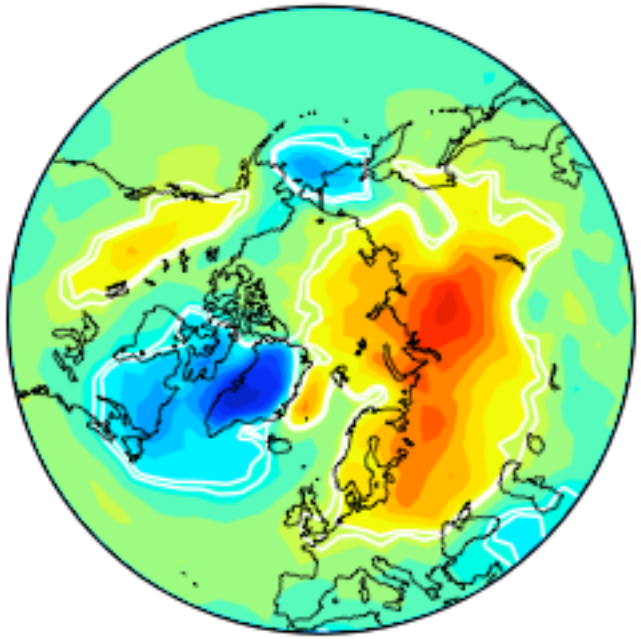
Seppälä et al., 2013

How are these linked to the surface level signals?

From Here

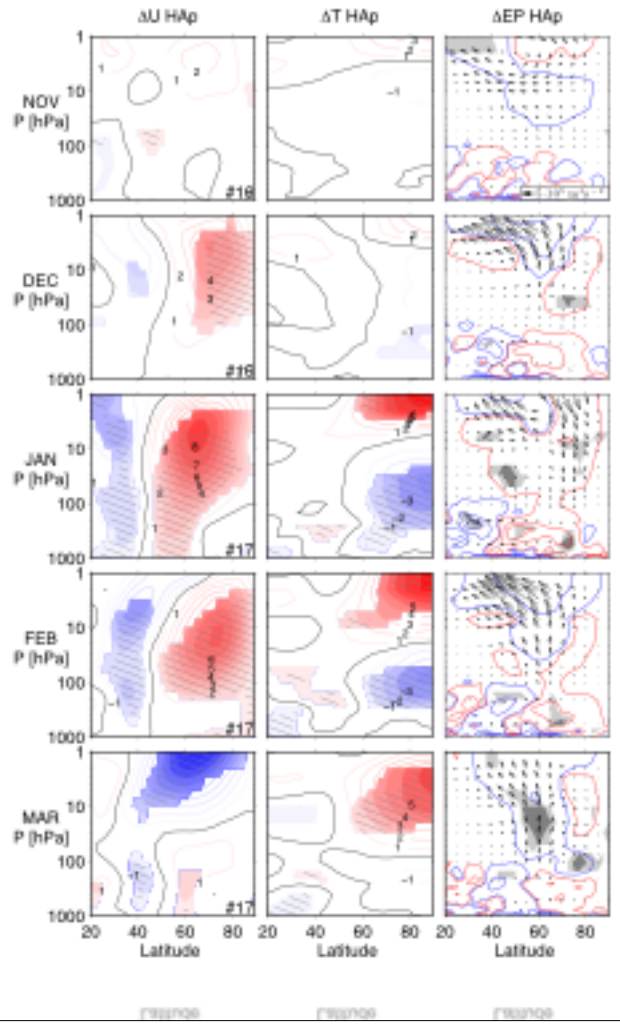


To Here?



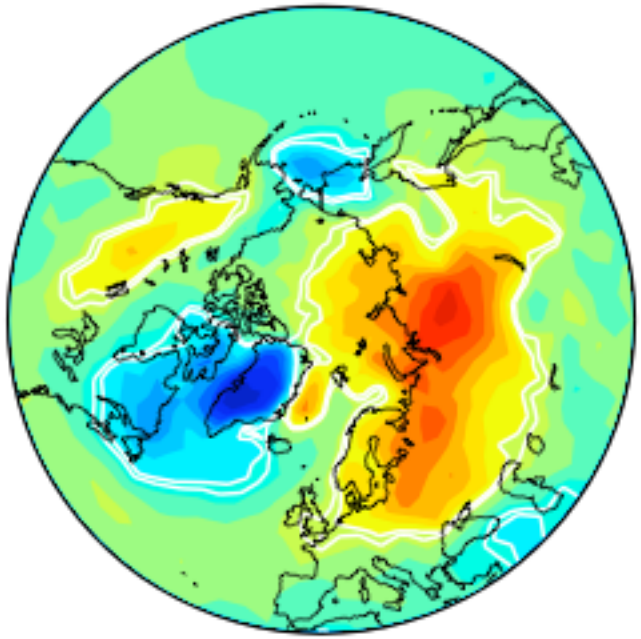
How are these linked to the surface level signals?

Stronger Polar Vortex



Northern Annular Mode

(NAM/NAO/AO)

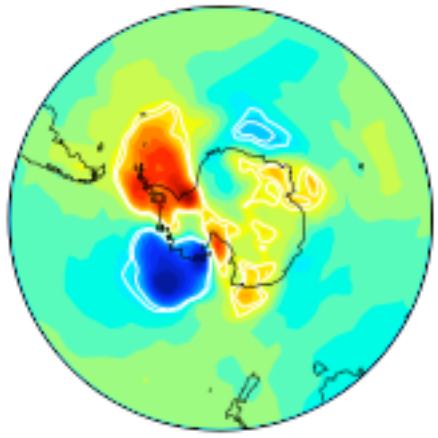


The Northern Annular Mode (NAM) reflects the strength of the polar vortex. *Stronger polar vortex drives positive NAM anomalies. The high EPP temperature pattern is typical to positive NAM.*

Supported also by model simulations by Baumgaertner et al., 2011

Interhemispheric differences. NH vs. SH

- Focus on the NH. What about the SH?
  - More stable polar vortex in SH.
    - Better conditions for descent from mesosphere.
    - Dynamics more difficult to influence?
    - Shorter timeseries of observations, only since 1979.
  - Nevertheless, SH tropospheric temperatures show variations, both in model simulations and re-analysis
    - Effects show up earlier than in NH (both in reanalysis data and model simulations).
  - Mechanism?



Summary

- EPP effects middle atmosphere chemistry during winter (both HO_x and NO_x).
- Transition from chemical control to dynamical control. Stratosphere? Mesosphere?
- From December to March anomalously strong polar vortex and more planetary wave reflection towards the equator.
  - Anomalies propagate downwards as winter progresses.
  - EPP effect on wave propagation more likely during high solar irradiance periods or westerly QBO (less disturbed background flow, stronger vortex).
- Strong polar vortex leads to positive NAM anomalies, reflecting on surface temperatures.
- Some puzzles solved, but still working towards understanding the EPP coupling to tropospheric dynamics from start to finish. It's complicated and internal variability & solar irradiance effects need to be considered simultaneously.