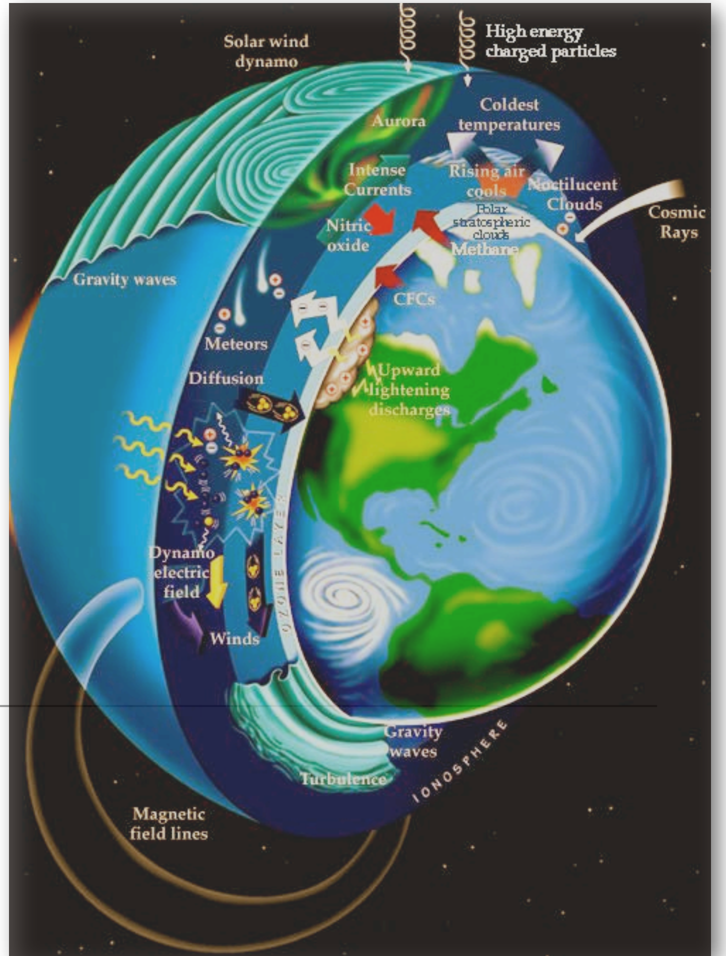
Observations of Energetic Particle Precipitation Effects upon the Middle Atmosphere



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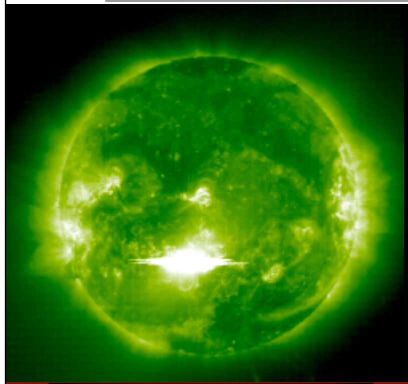
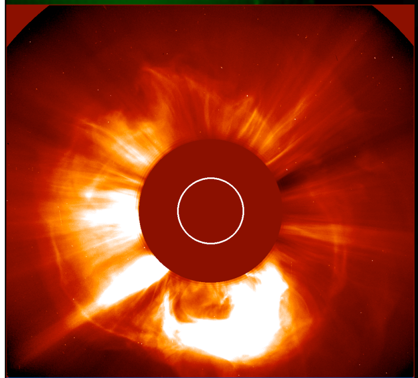
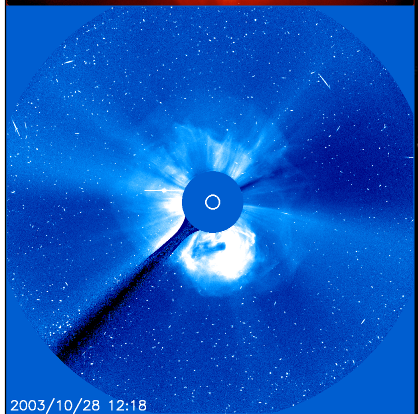
POLAR SCIENCE FOR PLANET EARTH

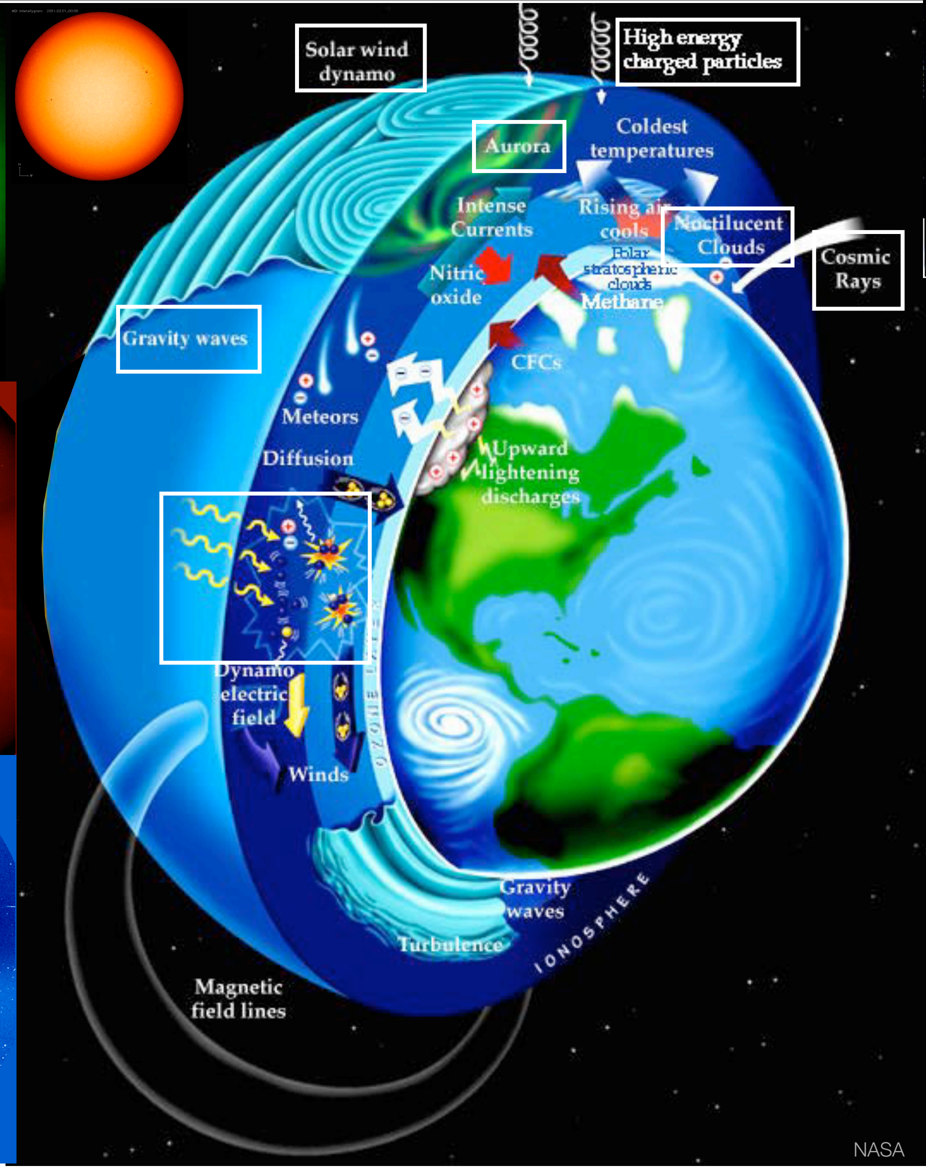
View to the coupled system -

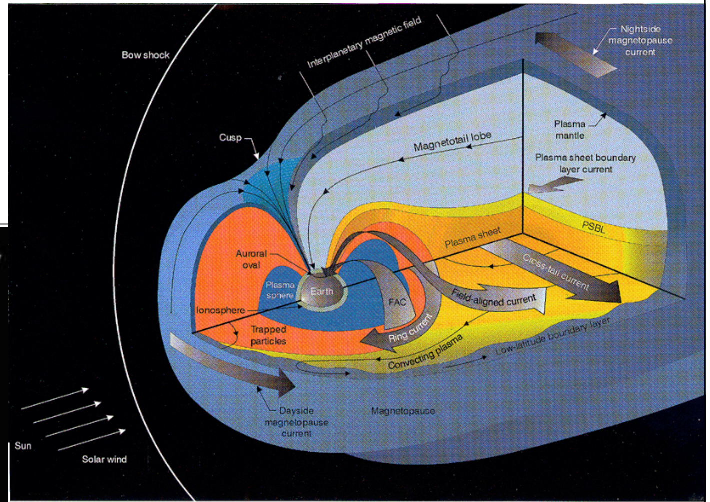
Sun-magnetosphere-ionosphere-upper & middle atmosphere

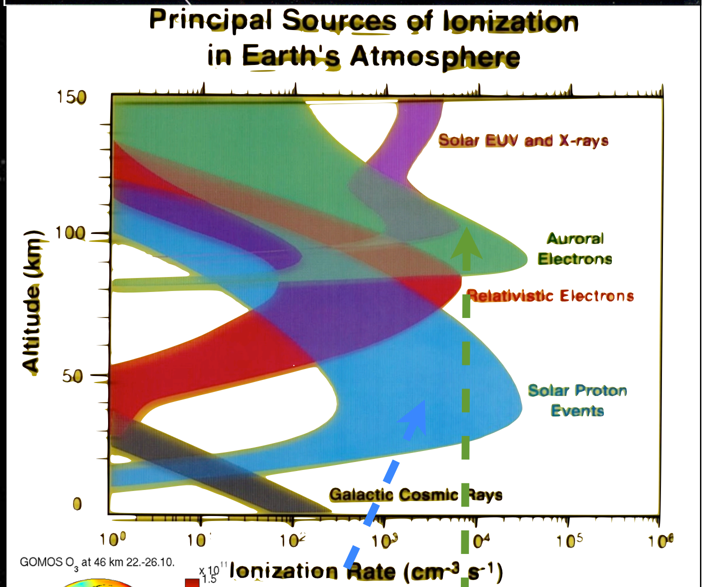


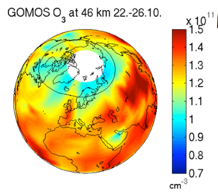


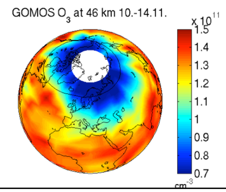


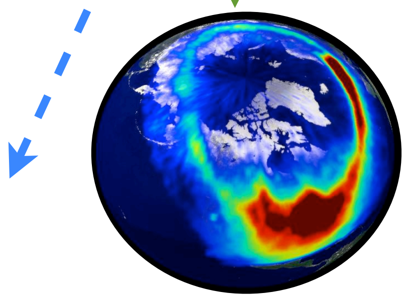




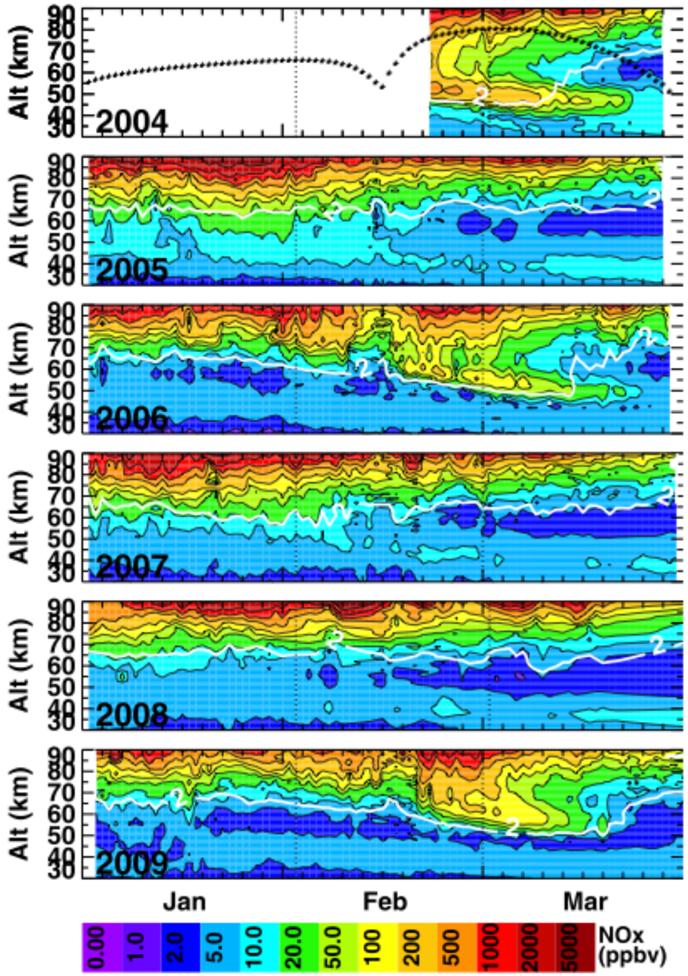


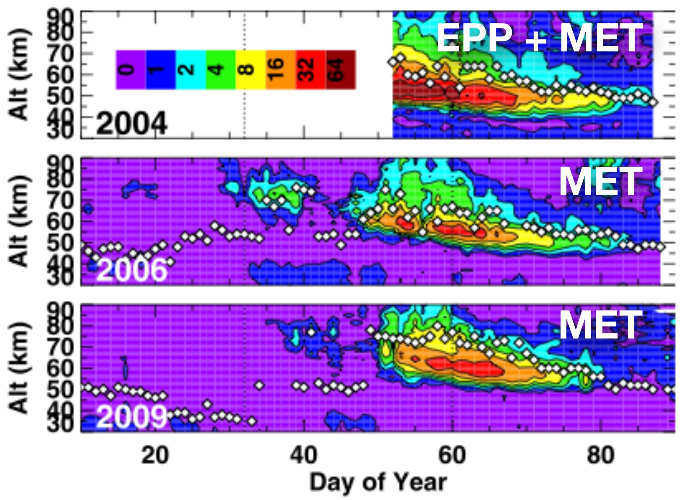






Limb measurements have given us important insights to the polar winter middle atmosphere…

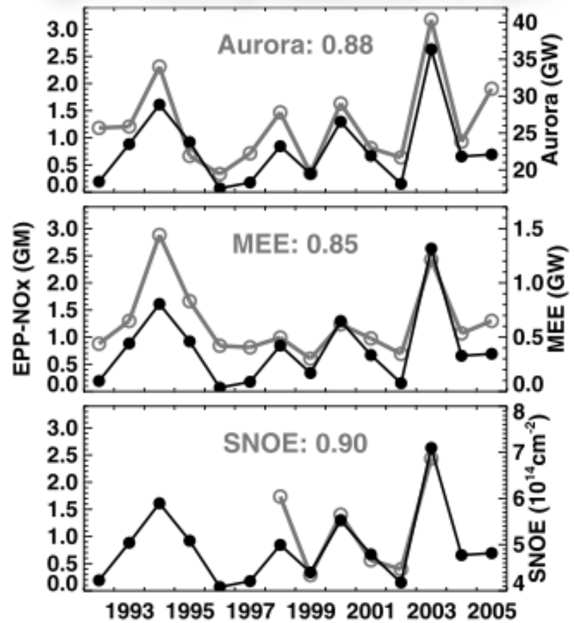




ACE NH polar observations seen in Chris Boone's invited talk.

Energetic Particle Precipitation vs. meteorology in NO_x production.

EPP-NO_x production in SH



Randall et al., 2007, 2009

Energetic particle precipitation (EPP) and the atmosphere

Particle precipitation into the middle atmosphere (30 - 100 km) increases ionisation

Proton and electron precipitation, SPEs, REP, etc.

Ionisation leads to production of NO_x and short-lived HO_x through ion chemistry

NO_x ($NO + NO_2$) chemical lifetime months during polar winter → descent to stratosphere

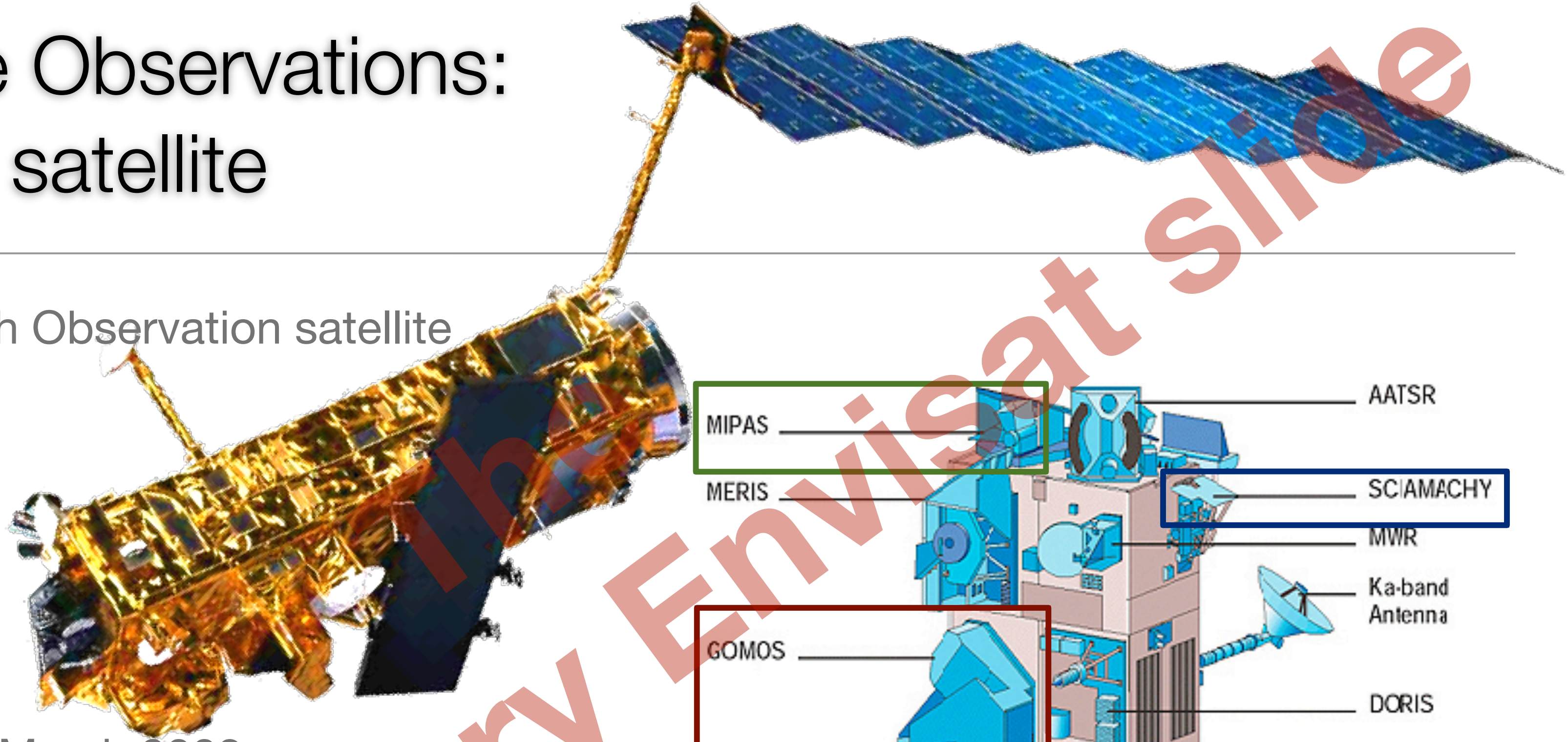
NO_x and HO_x gases cause catalytic ozone destruction

$2(NO + O_3) \rightarrow 2(NO_2 + O_2)$
$NO_2 + h\nu \rightarrow NO + O$
$NO_2 + O \rightarrow NO + O_2$
Total: $2O_3 \rightarrow 3O_2$

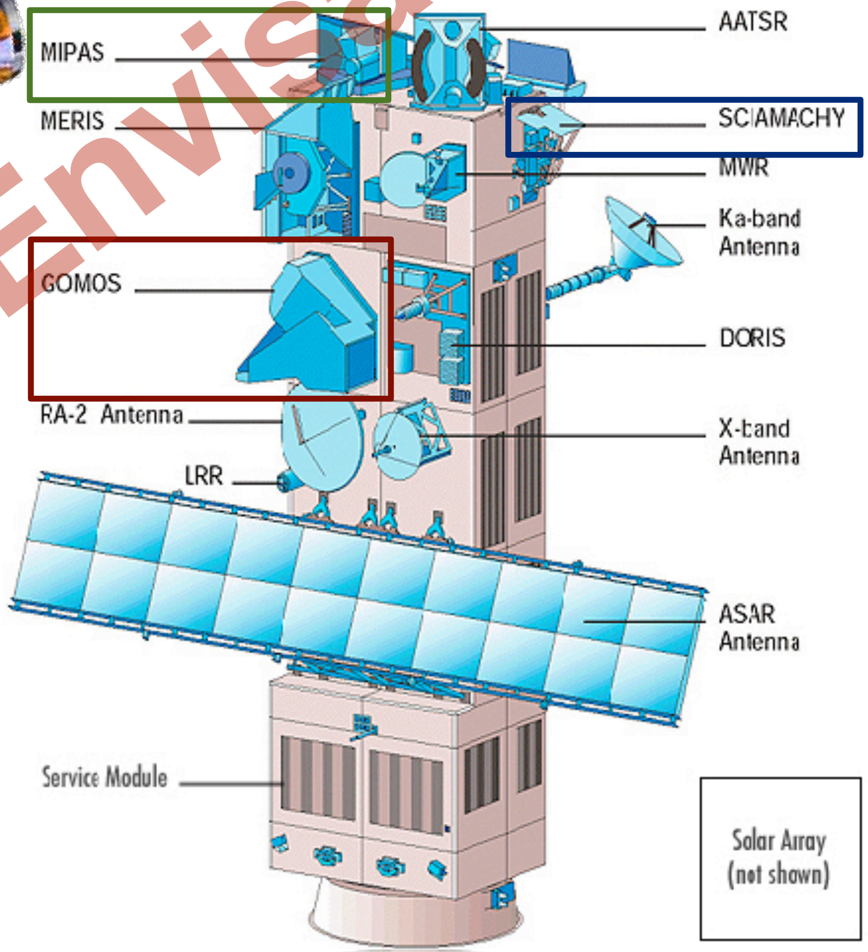
Ozone important to temperature and dynamics

Link to climate variability?

Satellite Observations: Envisat satellite

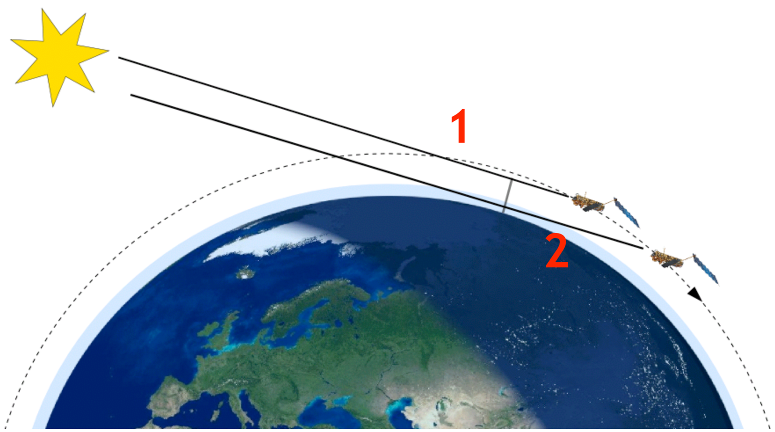


- ESA's Earth Observation satellite
- Launched March 2002
- 10 instruments studying the atmosphere, seas, land and ice
- Instruments measuring atmospheric composition: **GOMOS**, **MIPAS** and **SCIAMACHY**
- This talk contains observations from GOMOS!



GOMOS/Envisat
Global Ozone Monitoring by Occultation of Stars

- Stellar occultation instrument: measures attenuation of light from a star as it is absorbed in the atmosphere. Not using the Sun as light source enables measuring atmospheric composition during the night.
- Nighttime vertical profiles of O_3 and NO_2 used.

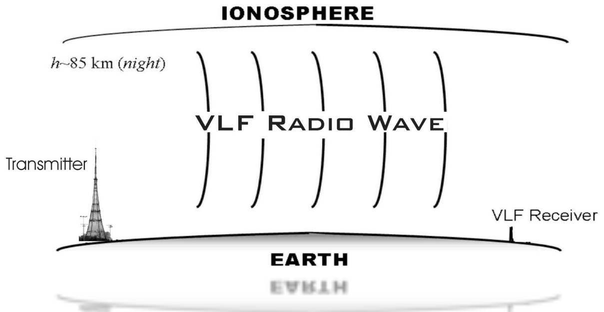


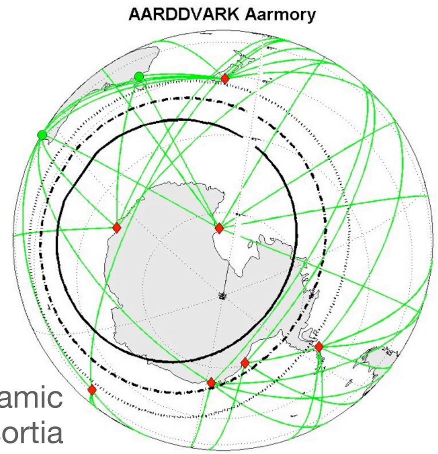
POAM III: Polar Ozone and Aerosol Measurement

- Solar occultation → daytime measurements. These complement the GOMOS nighttime observations!
- Vertical profiles of O_3 and NO_2 between about 10 and 60 km used.

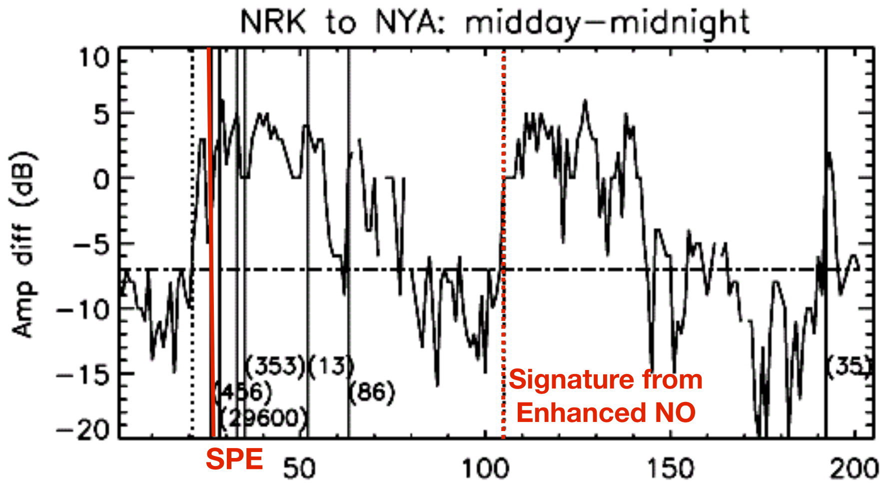
Sometimes satellites don't reach high enough (or are not in the right place at the right time)!
Observing the high altitudes from the ground - VLF

- Very Low Frequency (VLF) radio signals transmitted from the ground are reflected from the lower ionosphere.
- Changes in the ionisation levels of the mesosphere-lower thermosphere region lead to changes in the VLF signals.
- Ionisation of NO in mesosphere by Lyman-α also affects VLF propagation.
- An index provided by the difference between the average daytime amplitude of the received signal and the average night-time amplitude identifies the presence of ionisation caused by either precipitating protons/ electrons or enhanced levels of NO. → Can be used to detect enhanced levels of NO in the upper mesosphere-lower thermosphere.





Antarctic-Arctic Radiation-belt Dynamic Deposition VLF Atmospheric Research Konsortia (AARDDVARK) has a network of VLF receivers around the world monitoring the polar areas.

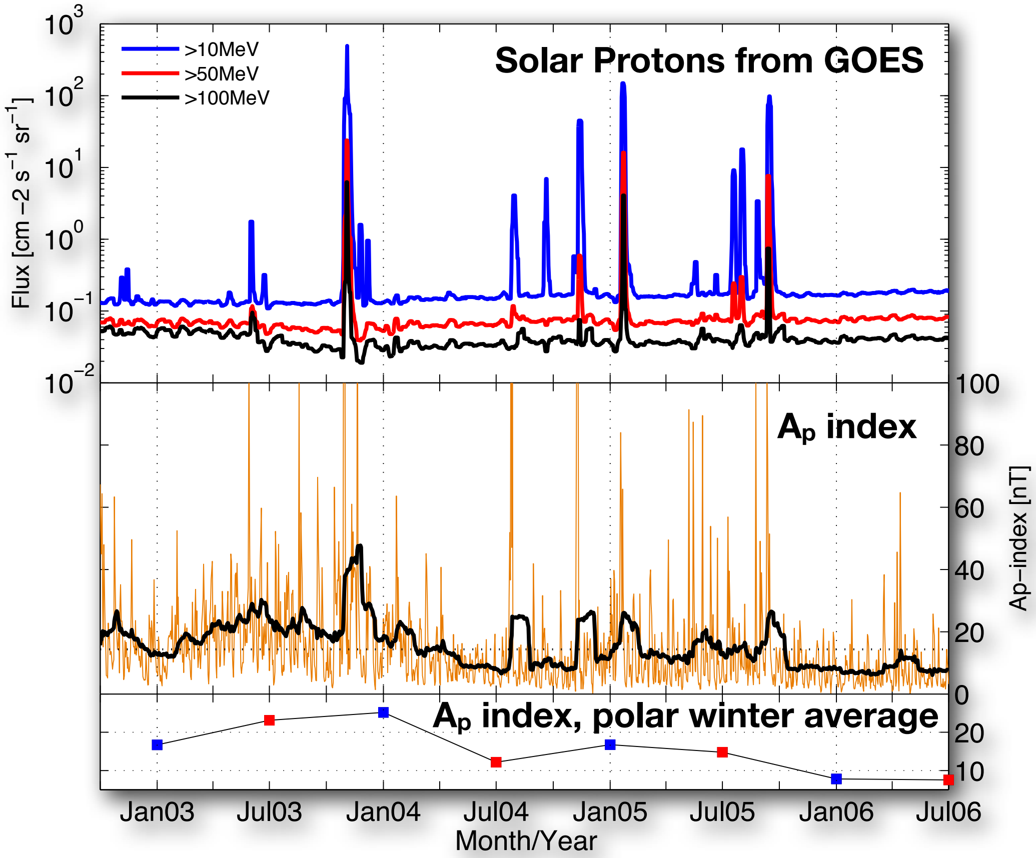


Ionisation signatures across the Northern polar cap area. Polar winter 2003-2004.

Clilverd, et al. (2007), Temporal variability of the descent of high-altitude NO_x. J. Geophys. Res.

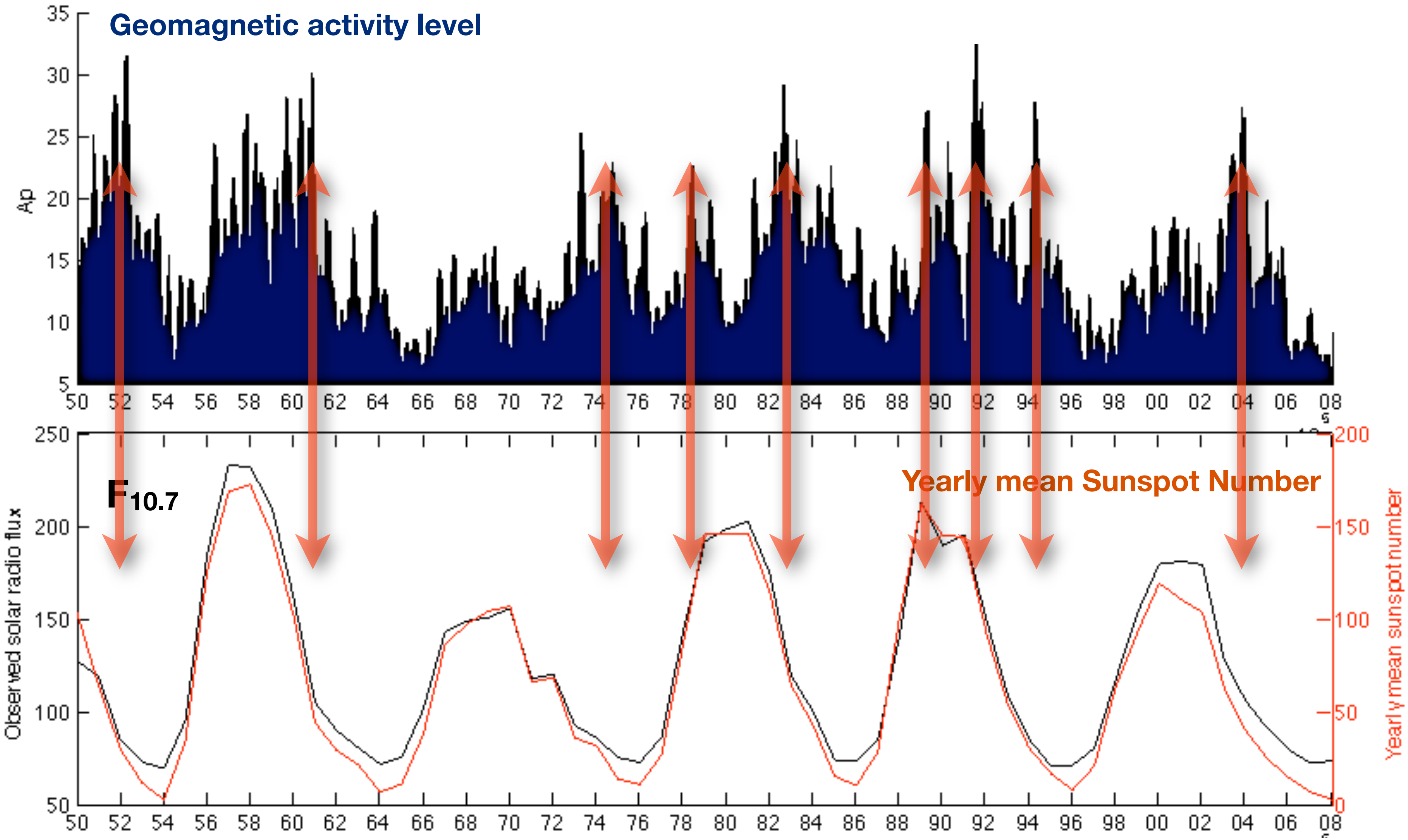
How we estimate particle input to the Atmosphere?

- High energy Solar Protons (Solar Proton Events) observed from geostationary orbit (GOES-satellites). SPEs are sporadic.
- How to estimate fluxes of medium and high energy electrons (electrons from radiation belts, auroral particles,...)?
    - This precipitation can be considered *almost ever present*.
    - Variety of geomagnetic indices available.
    - Which one would best represent the level of particle precipitation?
- The A_p index often used for atmospheric chemistry purposes. *(This does not mean that it's ideal!)*
- We will use the average wintertime A_p (NH: Nov-Jan, SH: May-Jul) as *a proxy* for particle precipitation levels.



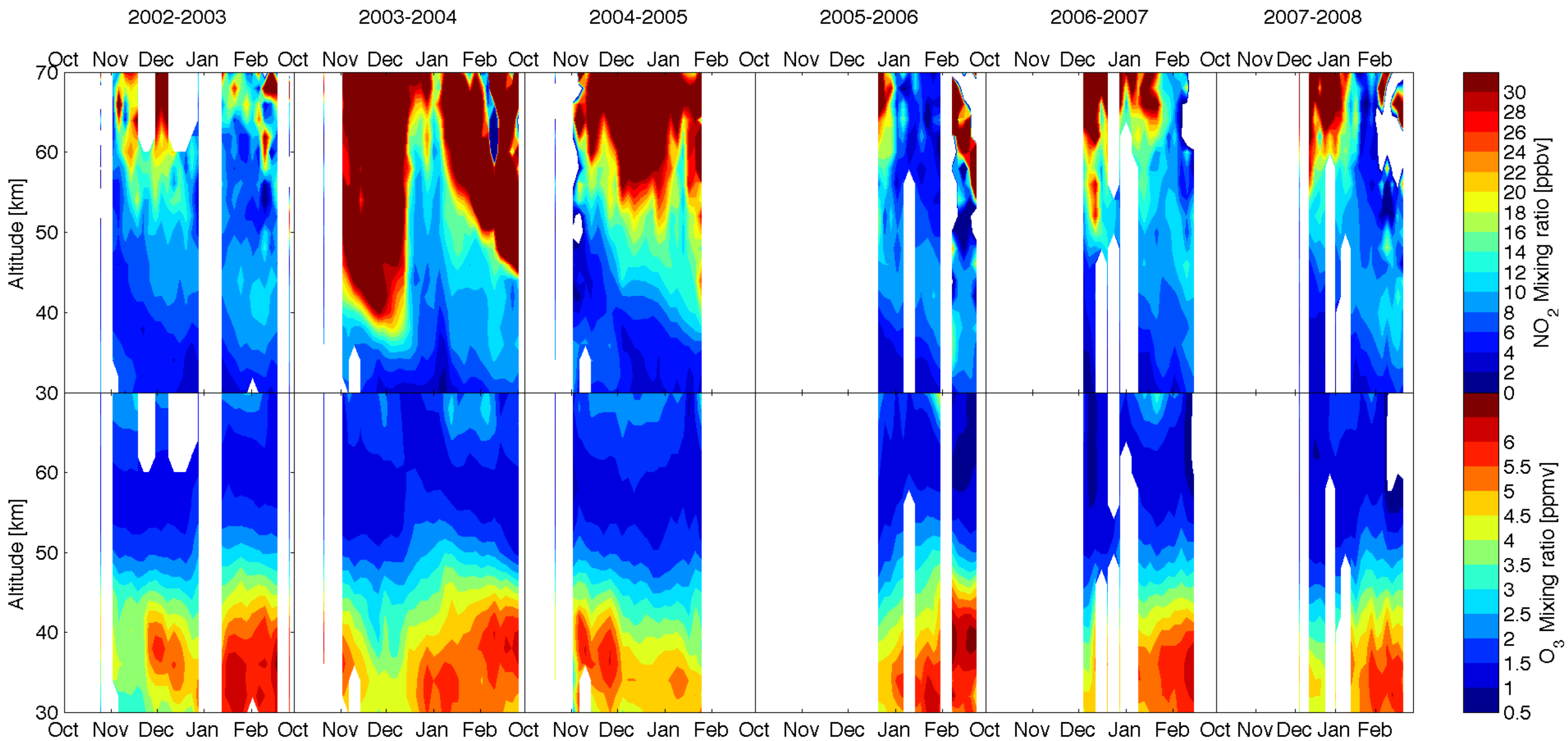
Seppälä, et al. (2007), Arctic and Antarctic polar winter NO_x and energetic particle precipitation in 2002-2006. Geophys. Res. Lett.,.

Geomagnetic activity variation vs. solar cycle variation



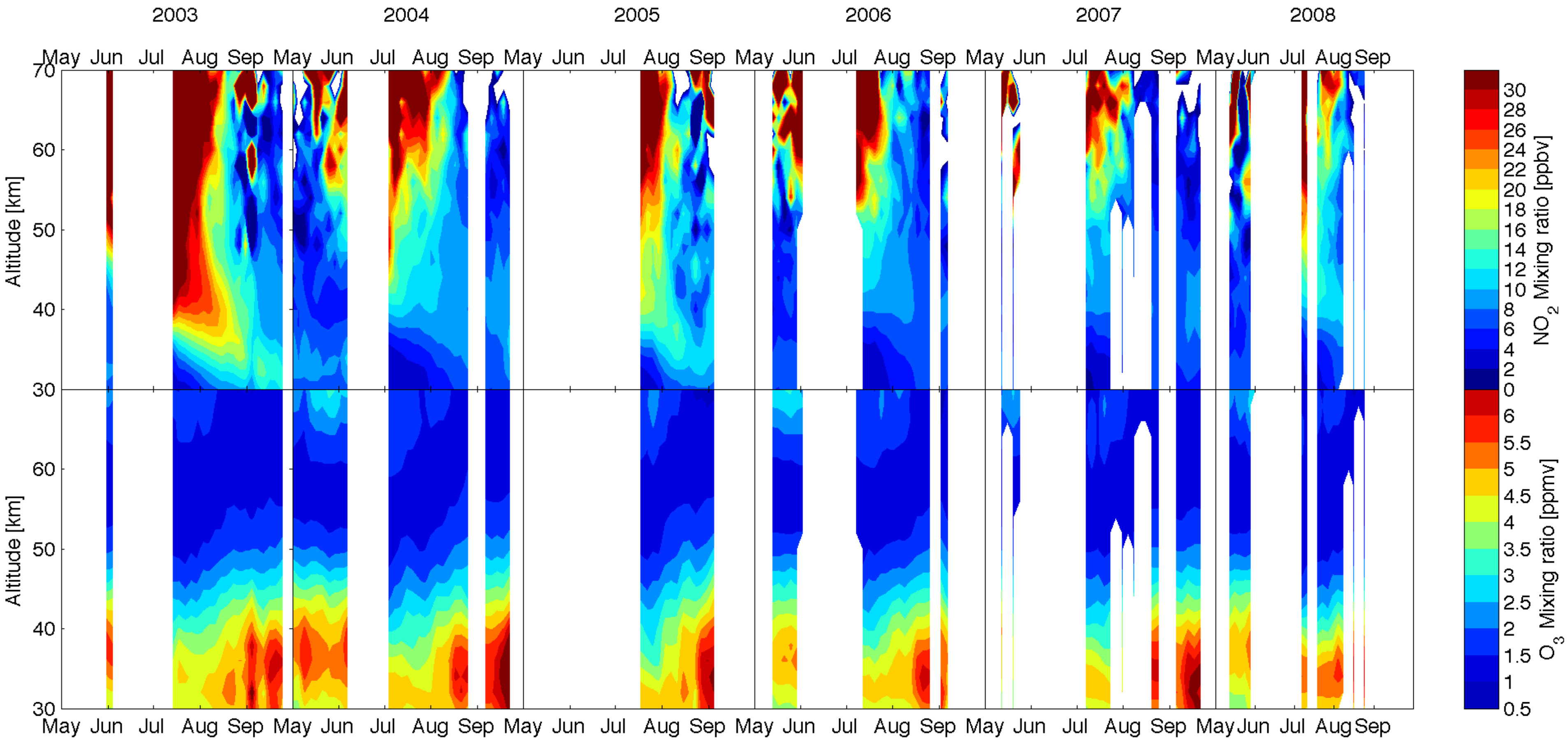
Polar winter NO_x and Ozone - NH

- GOMOS polar night NO_x and O_3 observations from Envisat satellite.
- 30 - 70 km, high polar latitudes > 60°N/S



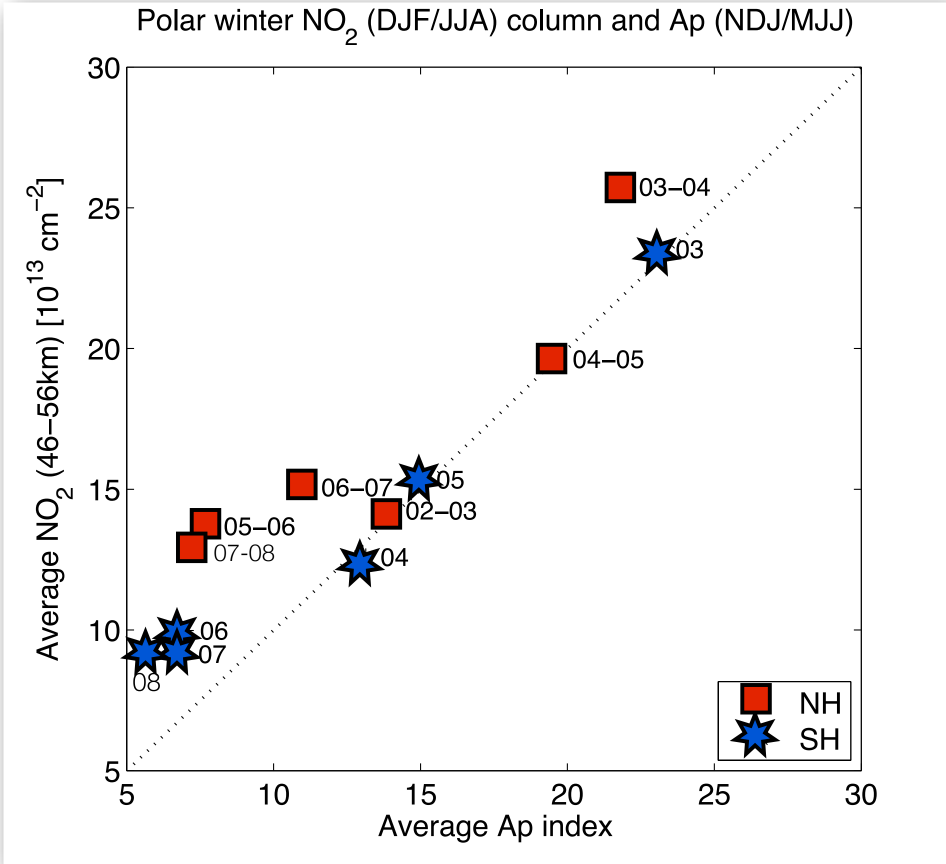
Polar winter NO_x and Ozone - SH

- GOMOS polar night NO_x and O_3 observations from Envisat satellite.
- 30 - 70 km, high polar latitudes > 60°N/S



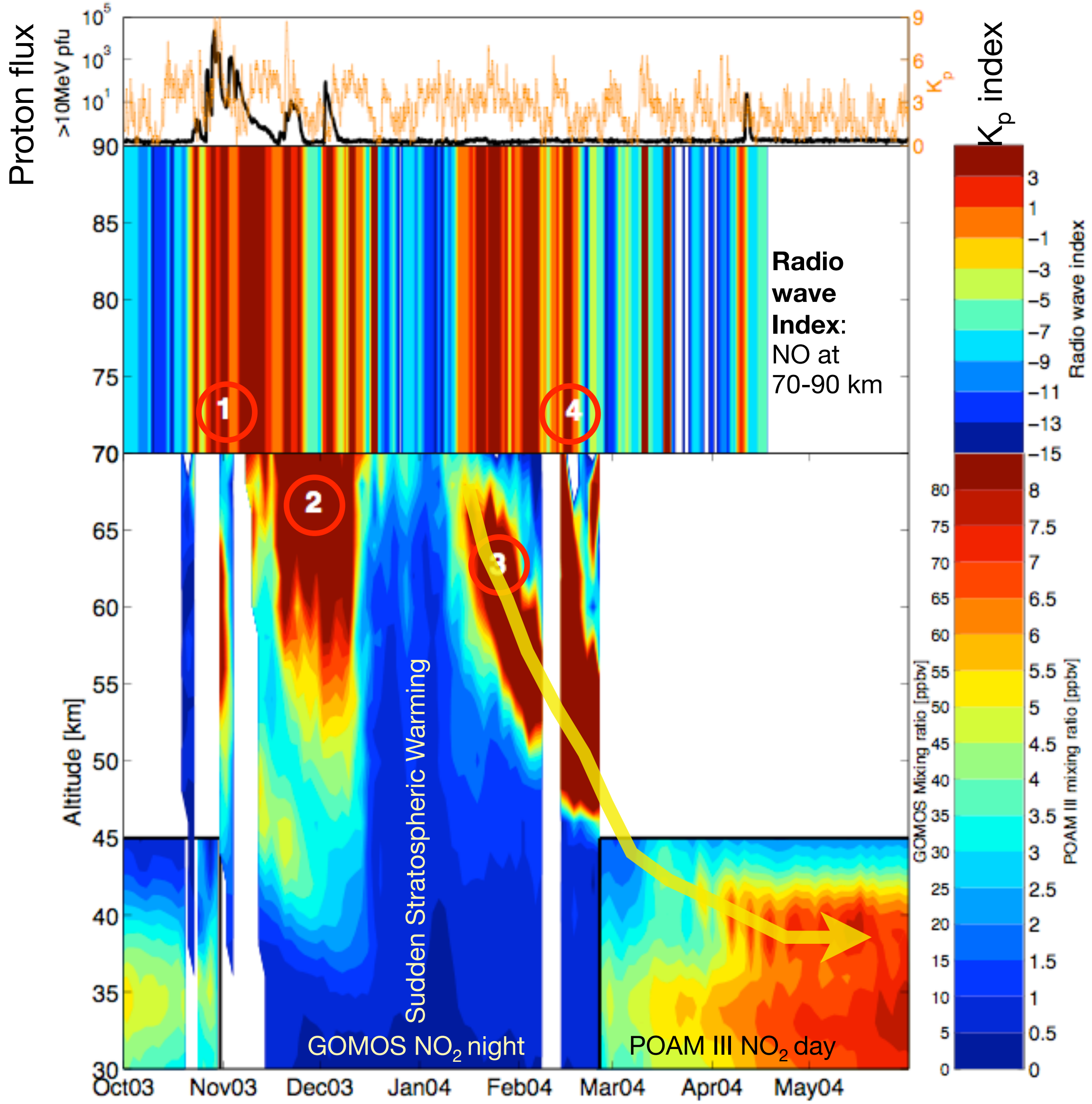
Upper Stratospheric NO_x - A_p

- Calculate the total amount of NO_x in the upper stratosphere (46-56 km).
- Average winter time geomagnetic activity level.
- Allow 1 month lag between A_p and NO_x for possible descent effects.
- A nearly linear relationship between geomagnetic activity and NO_x levels on both hemispheres.



Seppälä, et al. (2007), Arctic and Antarctic polar winter NO_x and energetic particle precipitation in 2002-2006. Geophys. Res. Lett.,.

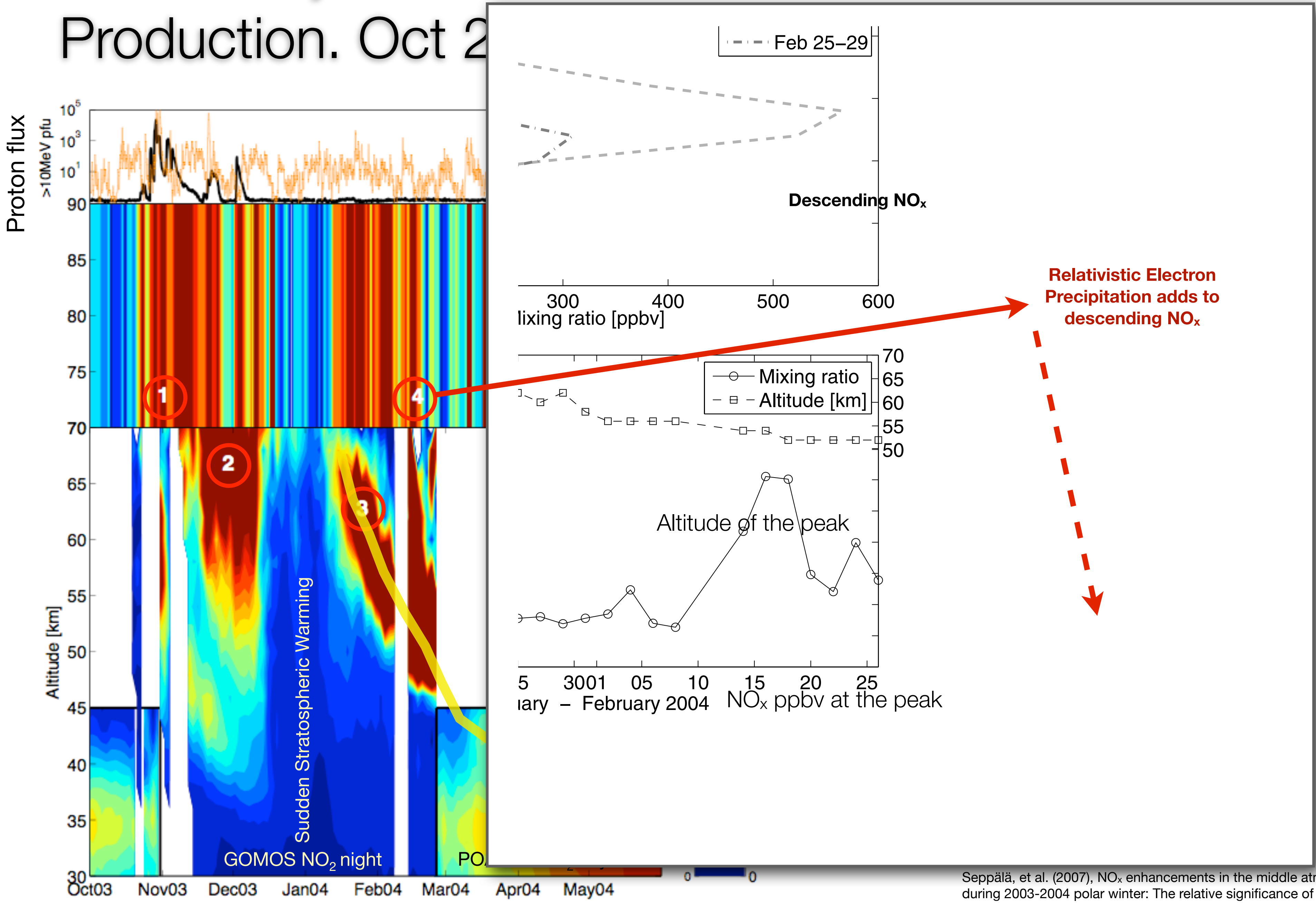
Case study: Different Forms of Solar/Particle NO_x Production. Oct 2003 - May 2004



- We can identify 4 events.
- **Event 1**: Halloween Solar Proton Events 2003
- **Event 2**: Energetic electron and auroral precipitation from Halloween storms and small events afterwards
- **Event 3**: Descend of thermospheric (aurorally produced) NO_x
- **Event 4**: Geomagnetic storms & Relativistic Electron Precipitation
- NO_x descent from Events 3 & 4 seen in the POAM NO_2 until May 2004

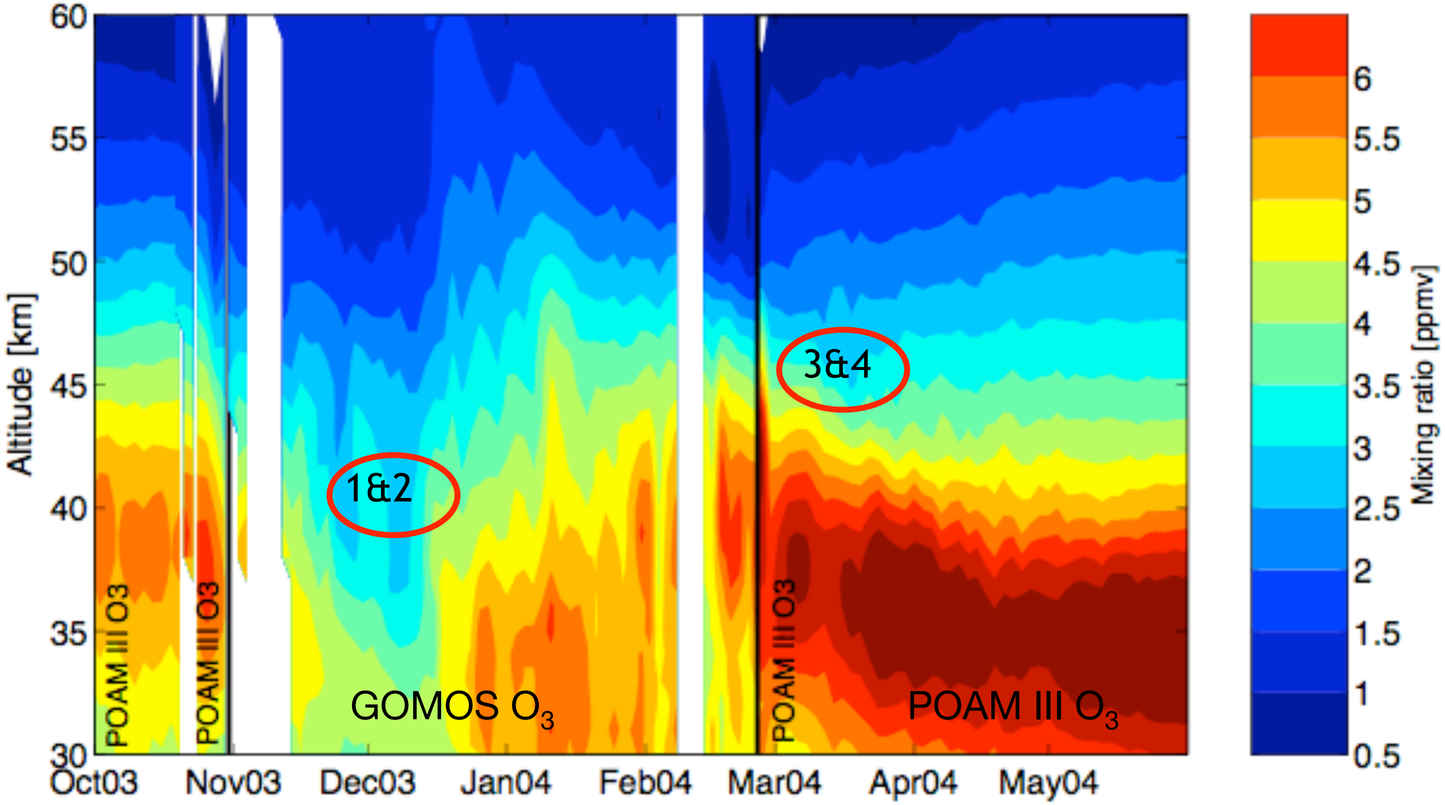
Seppälä, et al. (2007), NO_x enhancements in the middle atmosphere during 2003-2004 polar winter: The relative significance of Solar Proton Events and the Aurora as a source. J. Geophys. Res., 112, D23303,

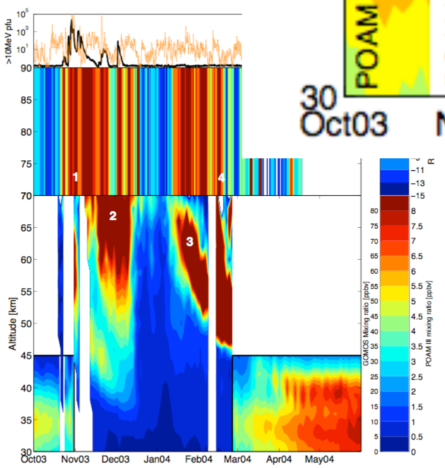
Case study: Different Forms of Solar/Particle NO_x Production. Oct 2



Seppälä, et al. (2007), NO_x enhancements in the middle atmosphere during 2003-2004 polar winter: The relative significance of Solar Proton Events and the Aurora as a source. J. Geophys. Res., 112, D23303,

Case study: Different Forms of Solar/Particle NO_x Production. **Ozone** response

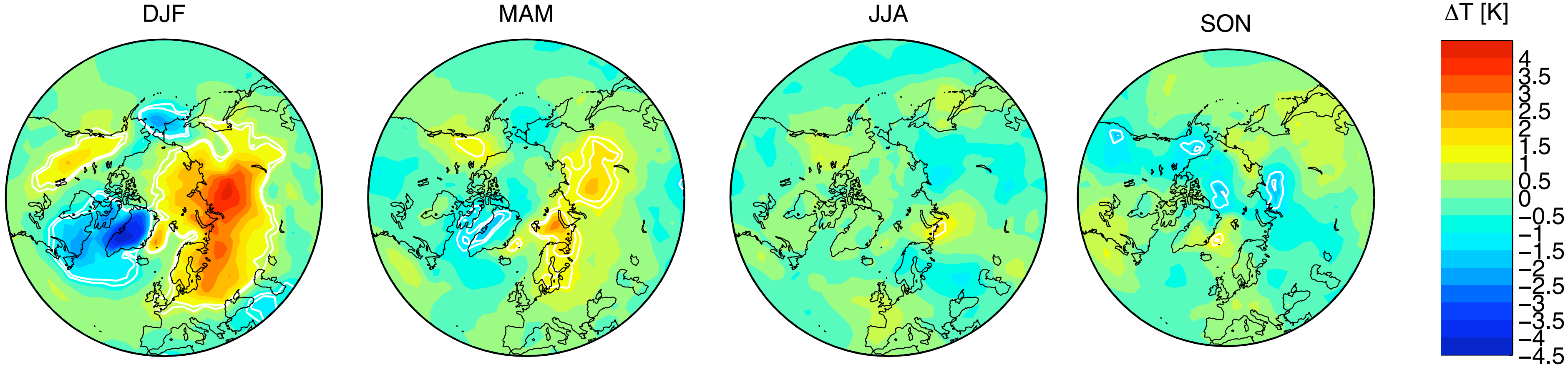




- GOMOS > 65°N nighttime O_3
- POAM III > 55°N daytime O_3 → Diurnal variation in the mesosphere

Seppälä, et al. (2007), NO_x enhancements in the middle atmosphere during 2003-2004 polar winter: The relative significance of Solar Proton Events and the Aurora as a source. J. Geophys. Res., 112, D23303,

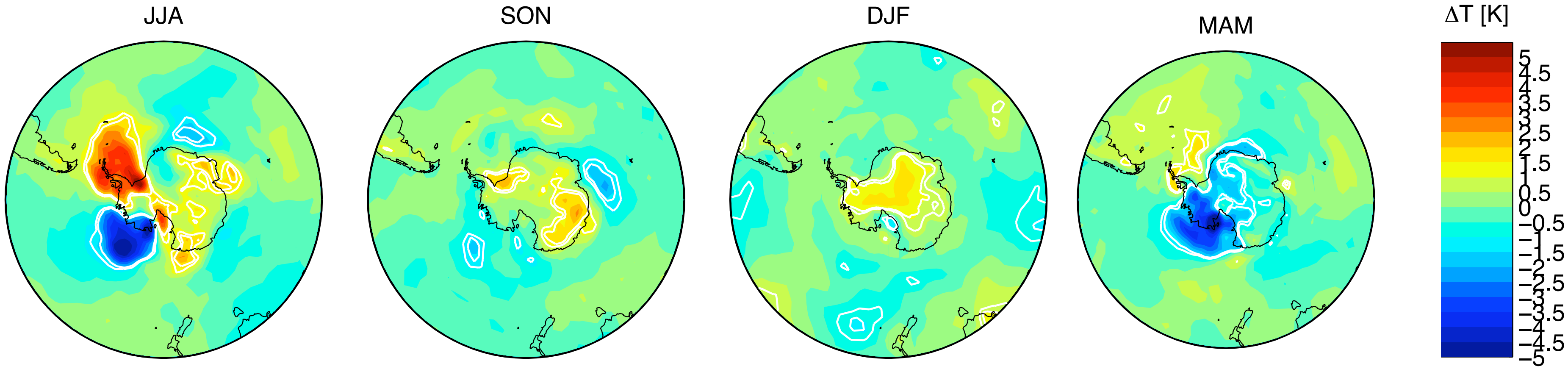
Signatures in Surface Air Temperatures (ERA-40 and NCEP)



NH: High A_p - Low A_p. Excluding SSW years

Seasonal differences for years with high vs. low levels of Particle Precipitation

More stable atmosphere



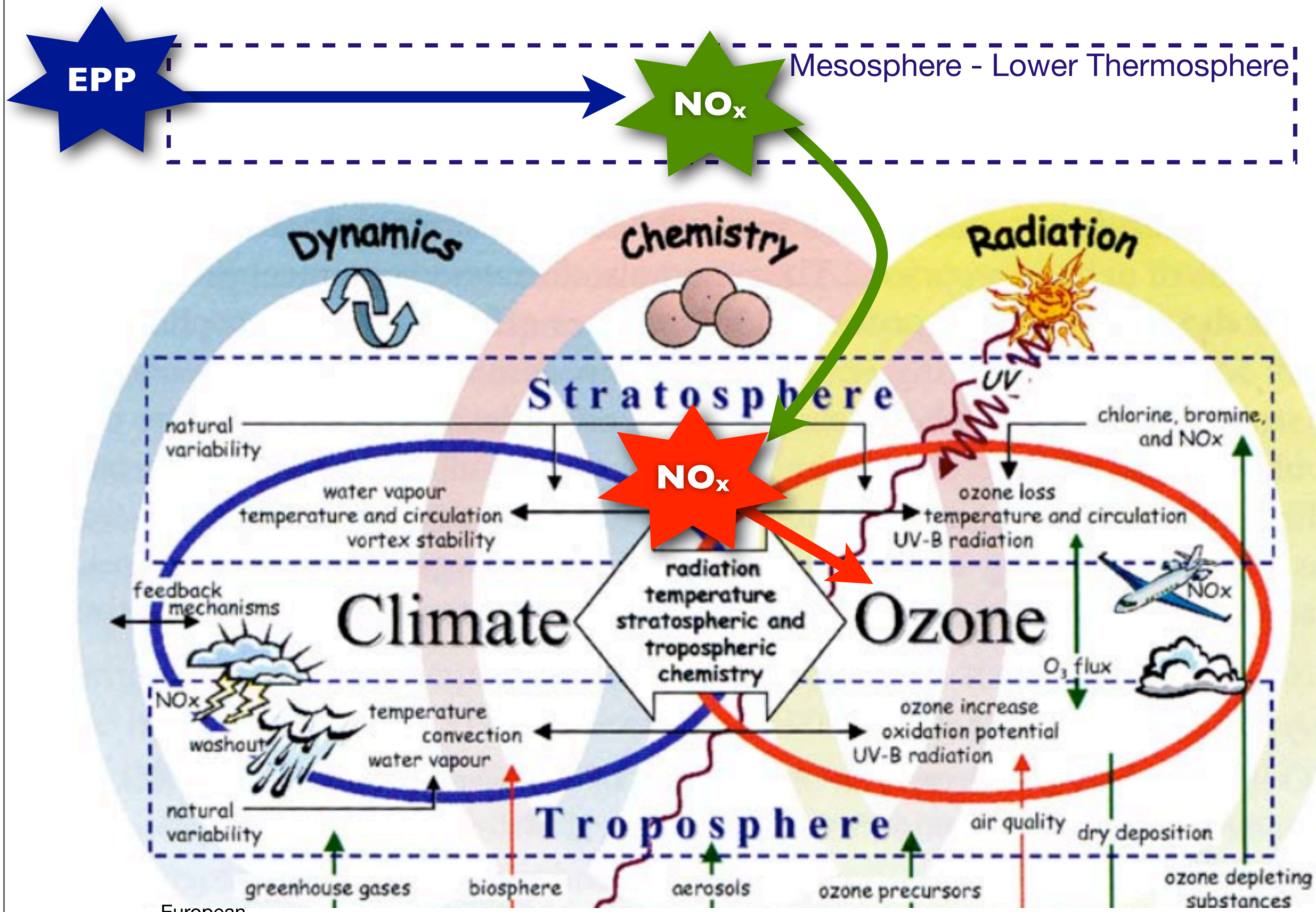
SH: High A_p - Low A_p

Seppälä, et al. (2009), Geomagnetic activity and polar surface air temperature variability, J. Geophys. Res., 2009

Summary

- The impacts of Solar Storms to the polar winter atmosphere were observed from GOMOS nighttime measurements.
  - First observations of stratospheric and mesospheric NO_x and Ozone during the polar winter.
  - Large increases in NO_x and simultaneous significant Ozone loss lasting several weeks.
- Similar effects observed during several polar winters on both Northern and Southern polar regions.
- The chemical changes induced by particle precipitation from Solar Storms are important to the Ozone balance of the atmosphere.
  - Is particle precipitation linked to variability in surface temperatures? More work needed.
- Limb measurements have provided important information about the effects of particle precipitation into the polar winter middle atmosphere. There are still open questions. *What about future?*

Is there a link between Solar forcing of the upper atmosphere and climate?



European Commission