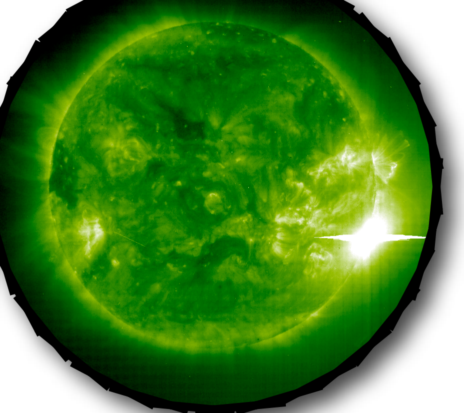
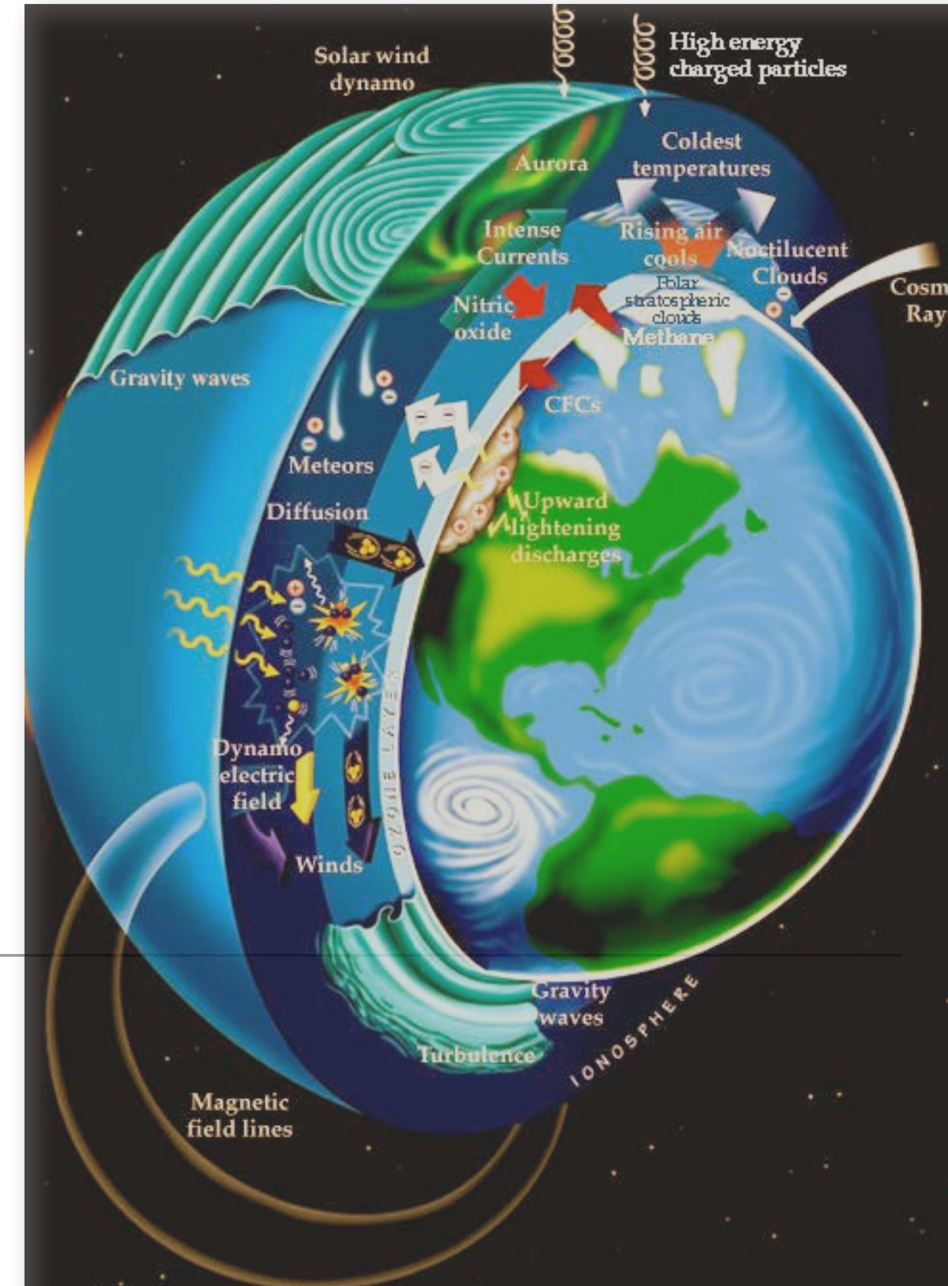


Solar Energetic Particles and their effects on the chemistry of the middle and upper atmosphere *(and beyond?)*



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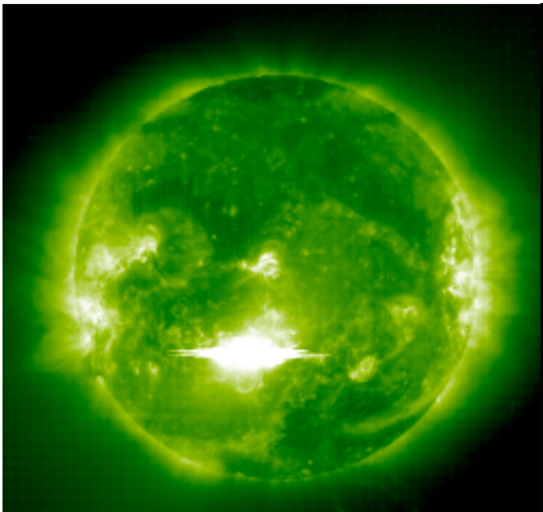
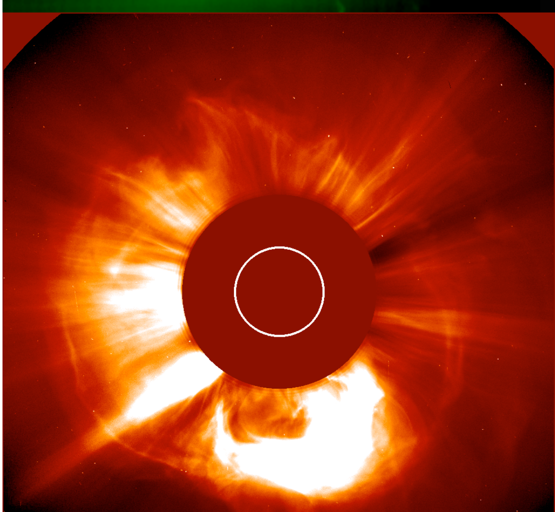
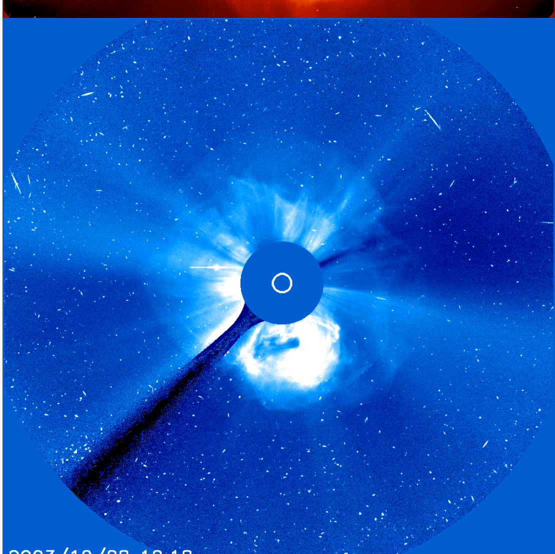
British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

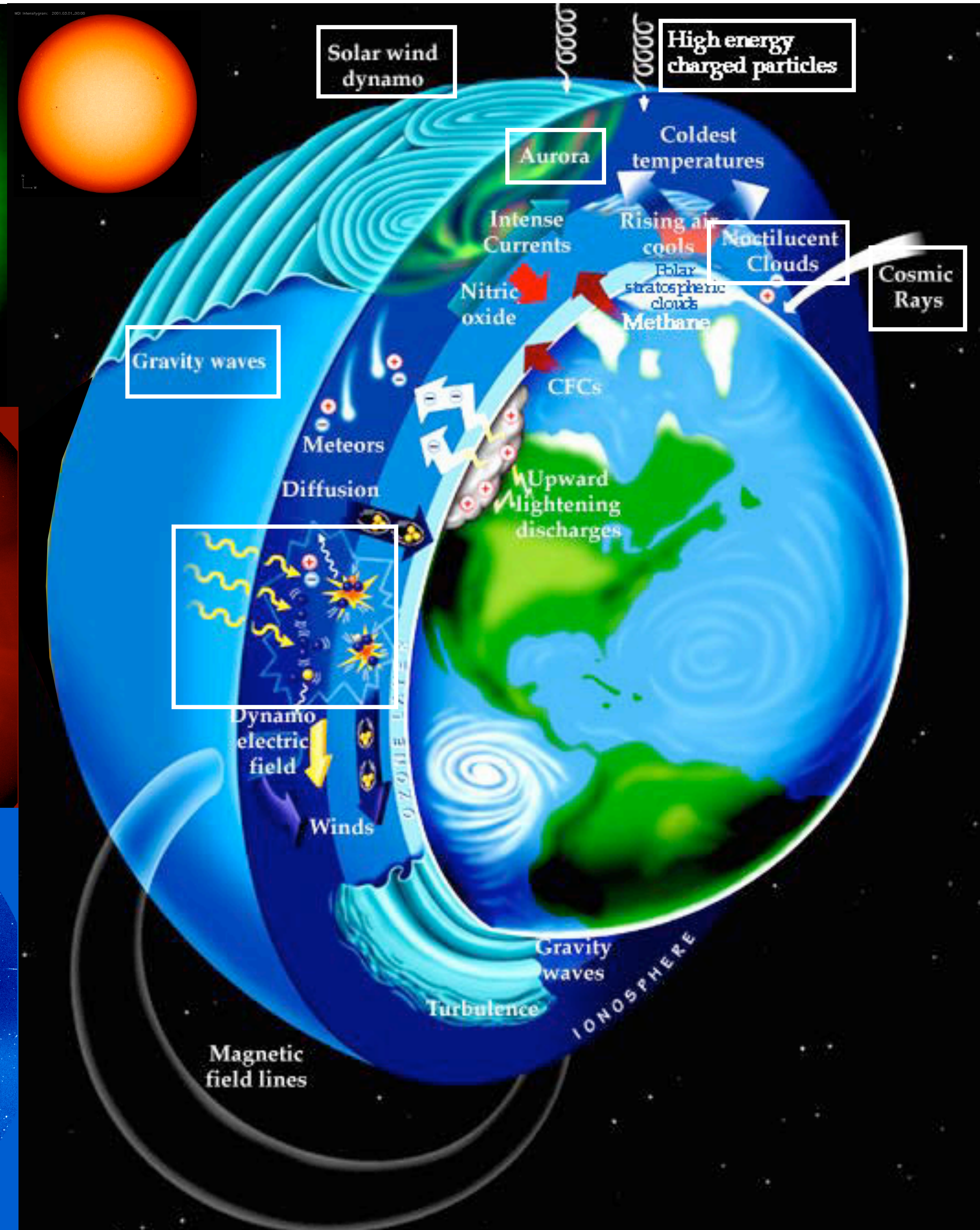
View to the coupled system -

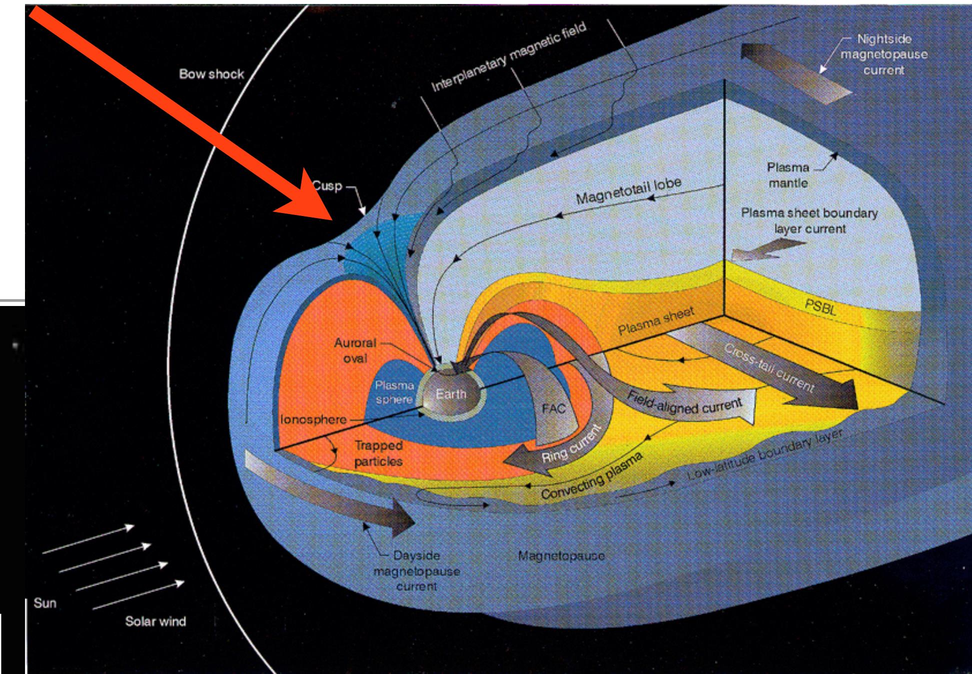
Sun-magnetosphere-ionosphere-upper & middle atmosphere

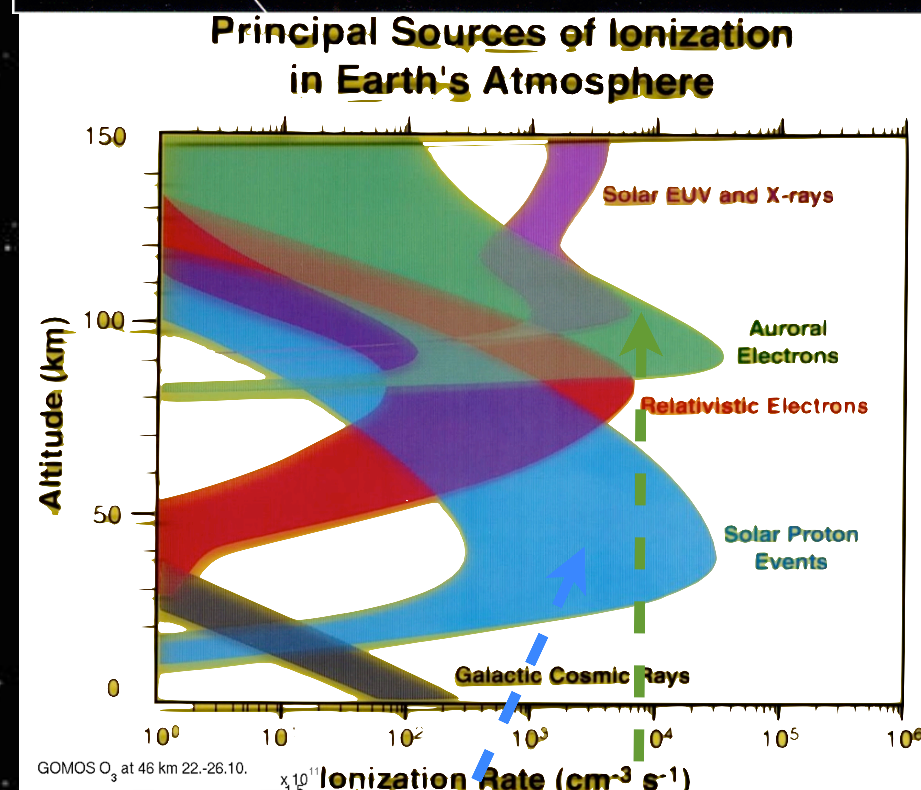


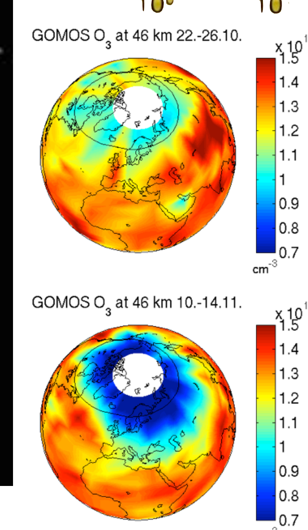


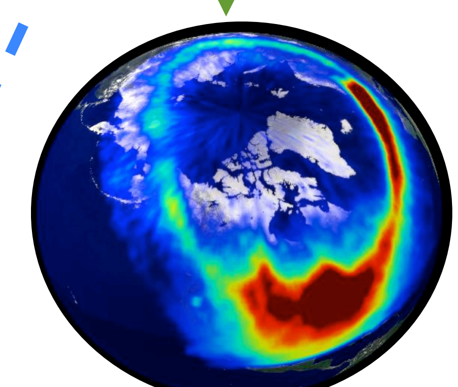




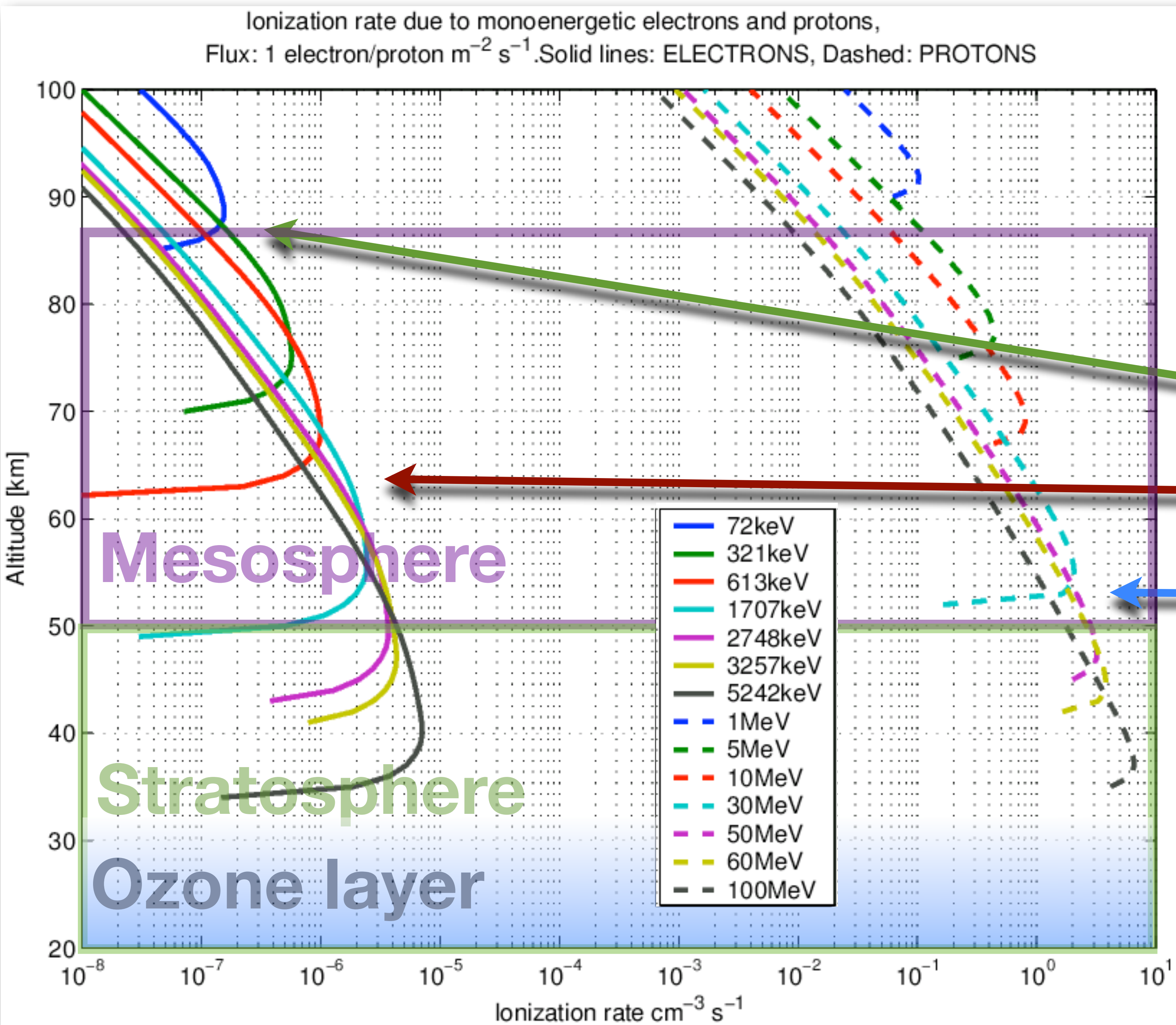


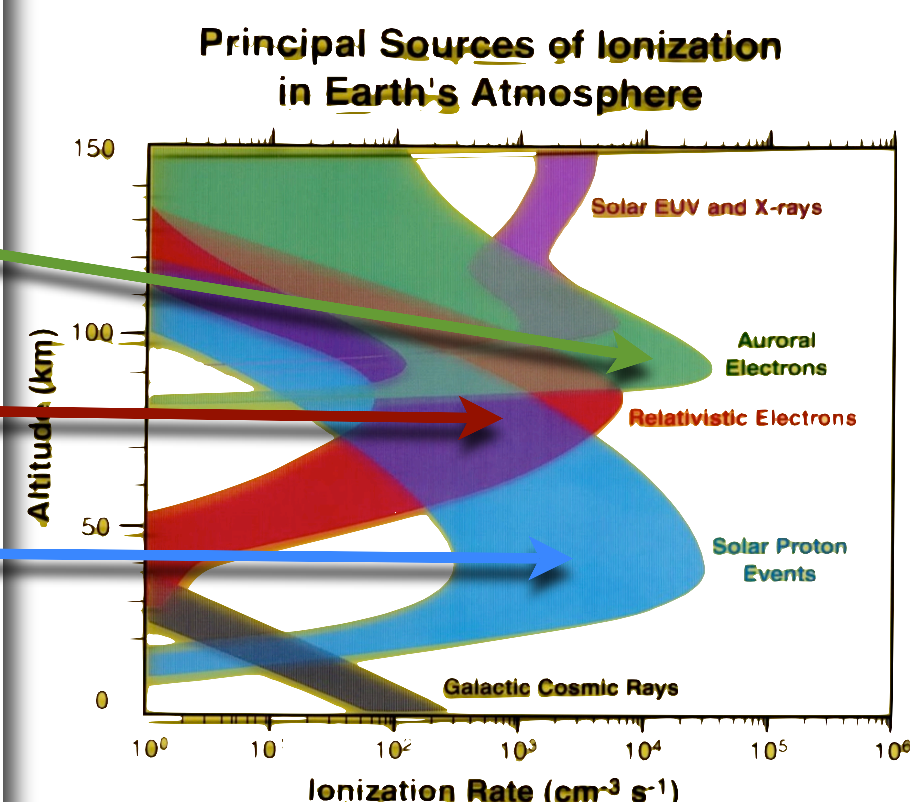






Particles effecting the middle and upper atmosphere





We refer to these as *high energy particles* or *energetic particles*.

Energetic particle precipitation (EPP) and the atmosphere

Particle precipitation into the polar 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

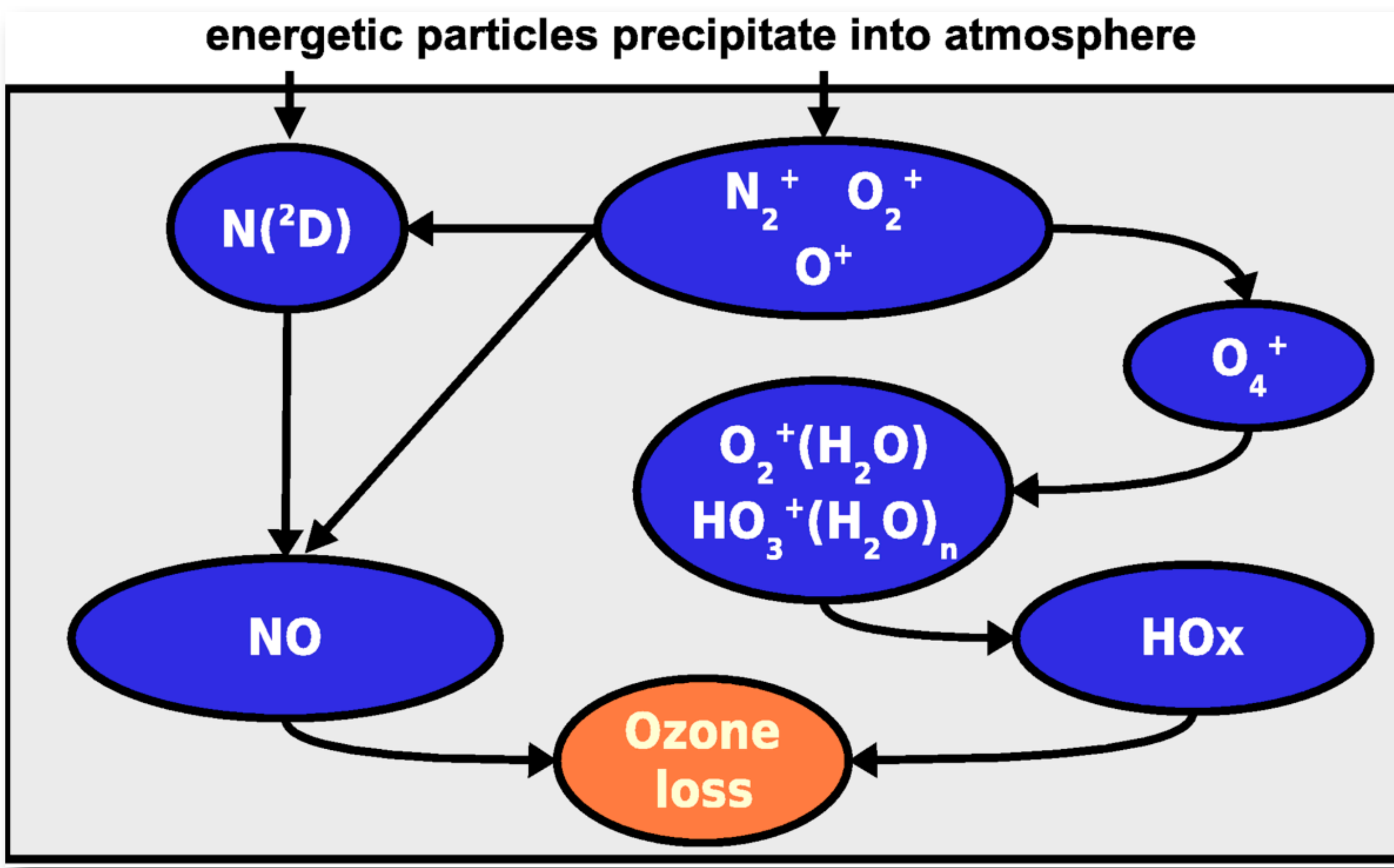
$$2(NO + O_3) \rightarrow 2(NO_2 + O_2)$$
$$NO_2 + h\nu \rightarrow NO + O$$
$$NO_2 + O \rightarrow NO + O_2$$
$$\text{Total: } 2O_3 \rightarrow 3O_2$$

Ozone important to temperature and dynamics

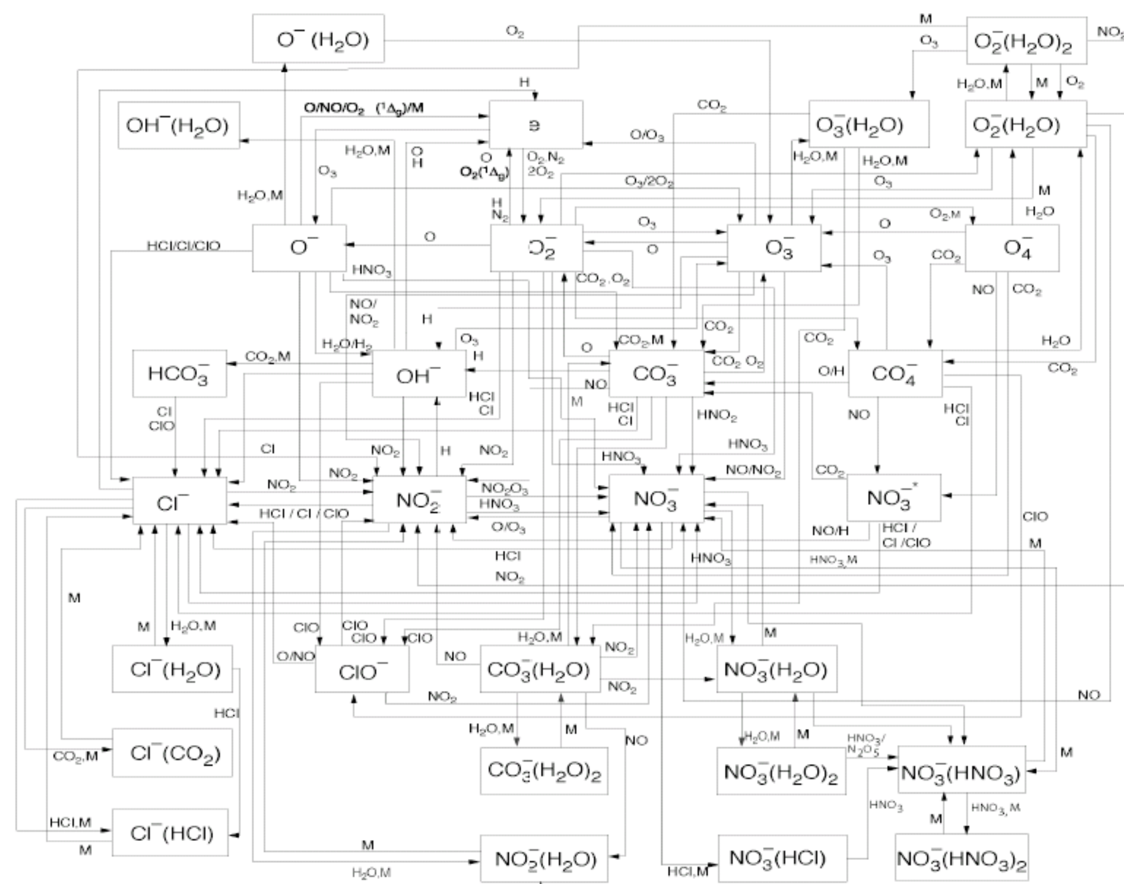
Link to climate variability?

*See next slide

Effects on Chemistry: Production of HO_x and NO_x

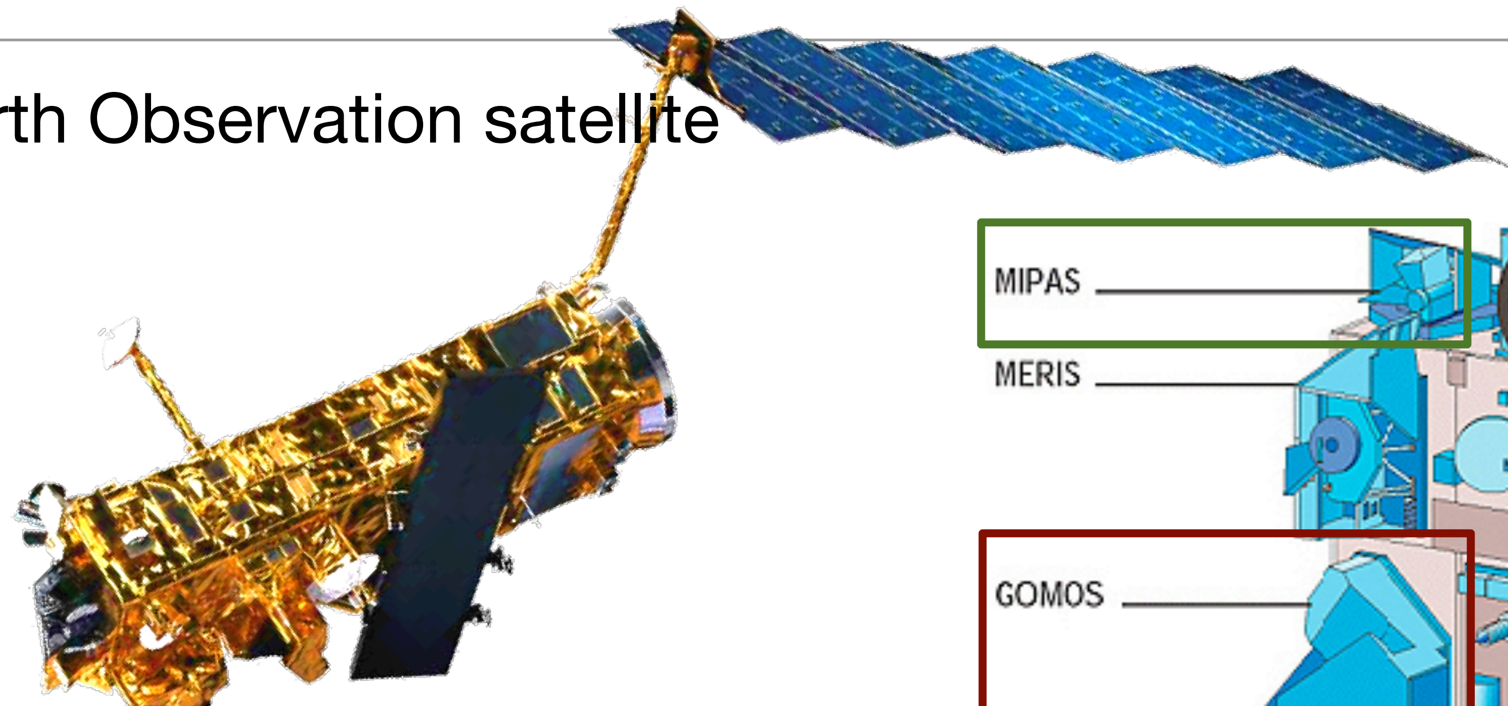


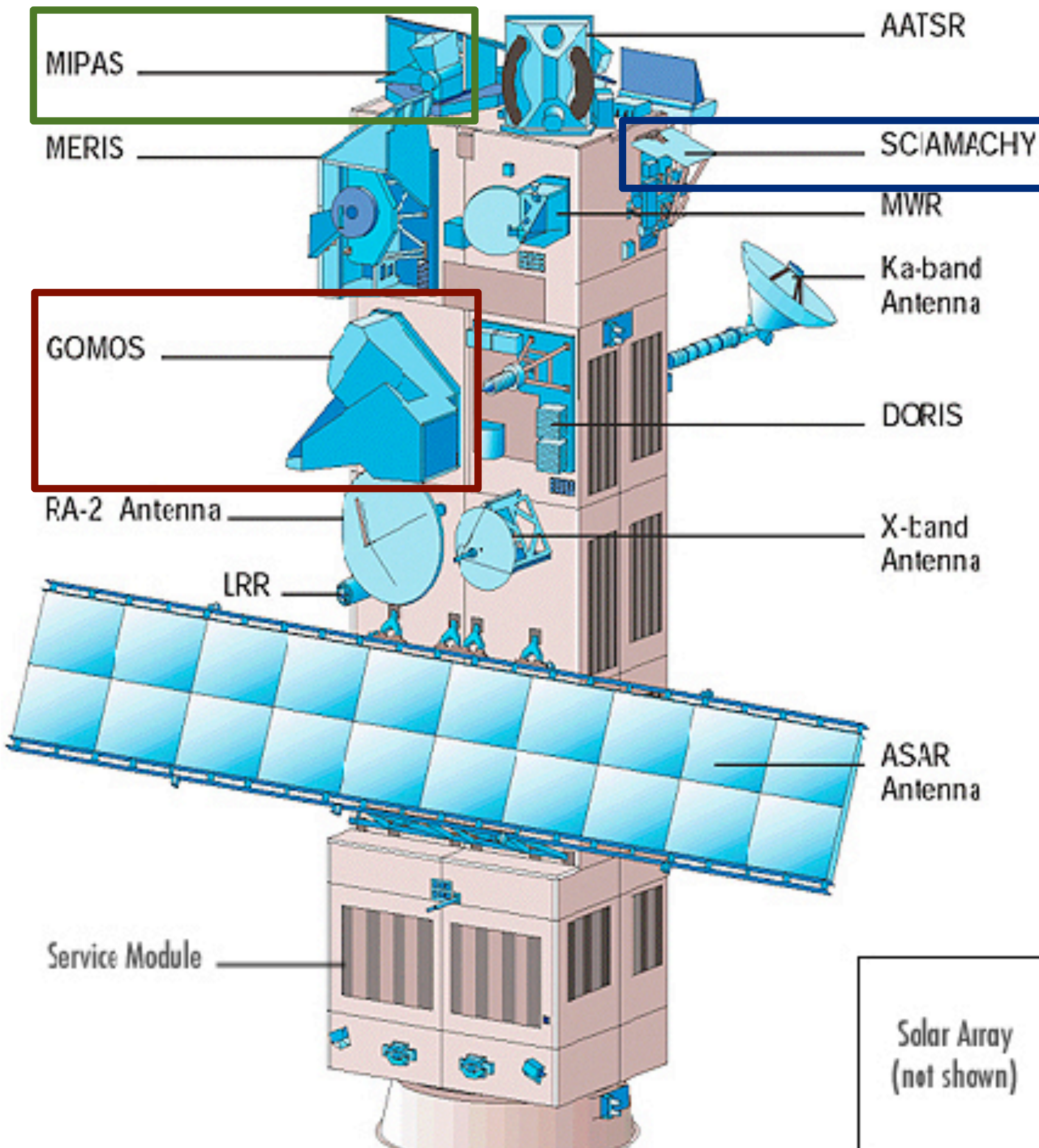
Some of the ion reactions involved...



Detecting the impact of EPP on the atmosphere: Satellite Observations - Envisat satellite

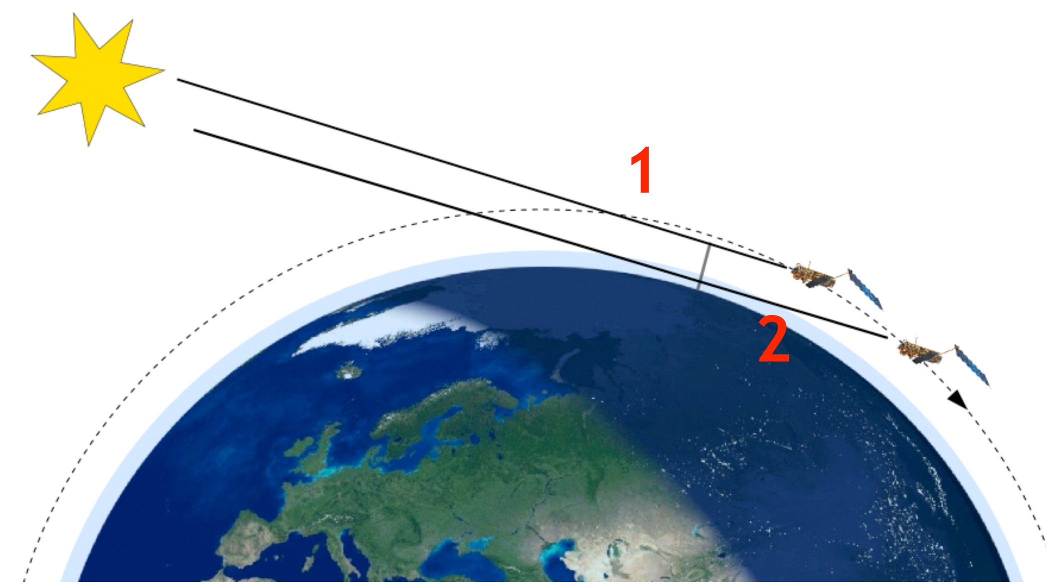
- ESA's Earth Observation satellite





- Launched March 2002, planned lifetime 10 years, now extended to 2015
- 10 instruments studying the atmosphere, seas, land and ice
- Instruments measuring atmospheric composition: **GOMOS**, **MIPAS** and **SCIAMACHY**

GOMOS/Envisat
Global Ozone Monitoring by Occultation of Stars



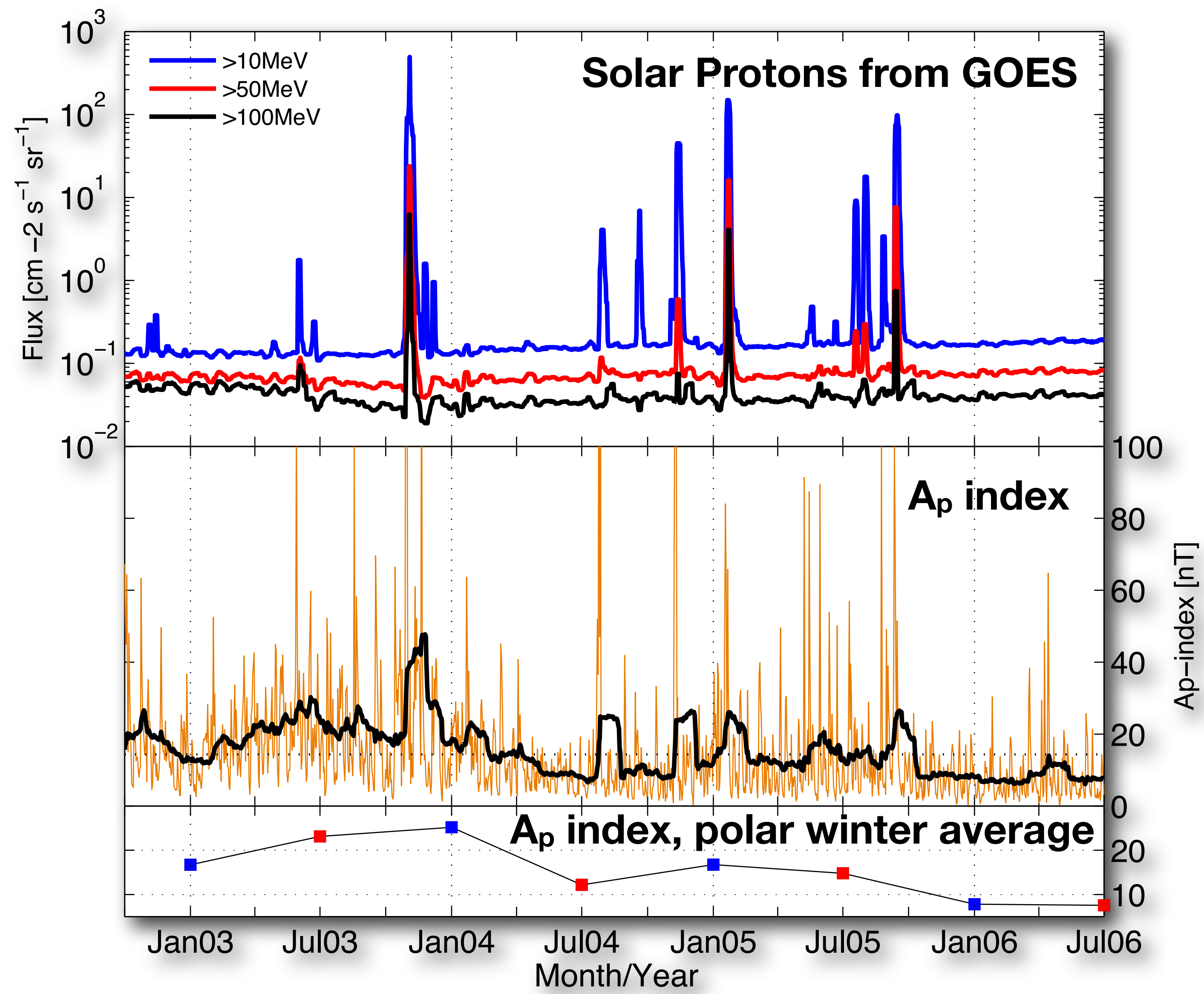
- Stellar occultation instrument: measures attenuation of light from a star as it is absorbed in the atmosphere.
- "Finnish-French" instrument first proposed to ESA in 1988
- Measures vertical profiles of O_3, NO_2, NO_3, H_2O, O_2,... from about 10 to 100 km
- Stars are everywhere → global coverage with up to 600 profiles per day
- Most other instruments measuring atmospheric trace gases use solar light (solar occultation, limb scattering) - stellar occultation not dependent of solar light - **measurements may be done under dark conditions**.

Another example of satellite platform observations
POAM III: Polar Ozone and Aerosol Measurement

- Solar occultation instrument - limited to outside polar night
- Measures vertical profiles of O_3, NO_2,... between about 10 and 60 km

How to estimate particle input to the Atmosphere?

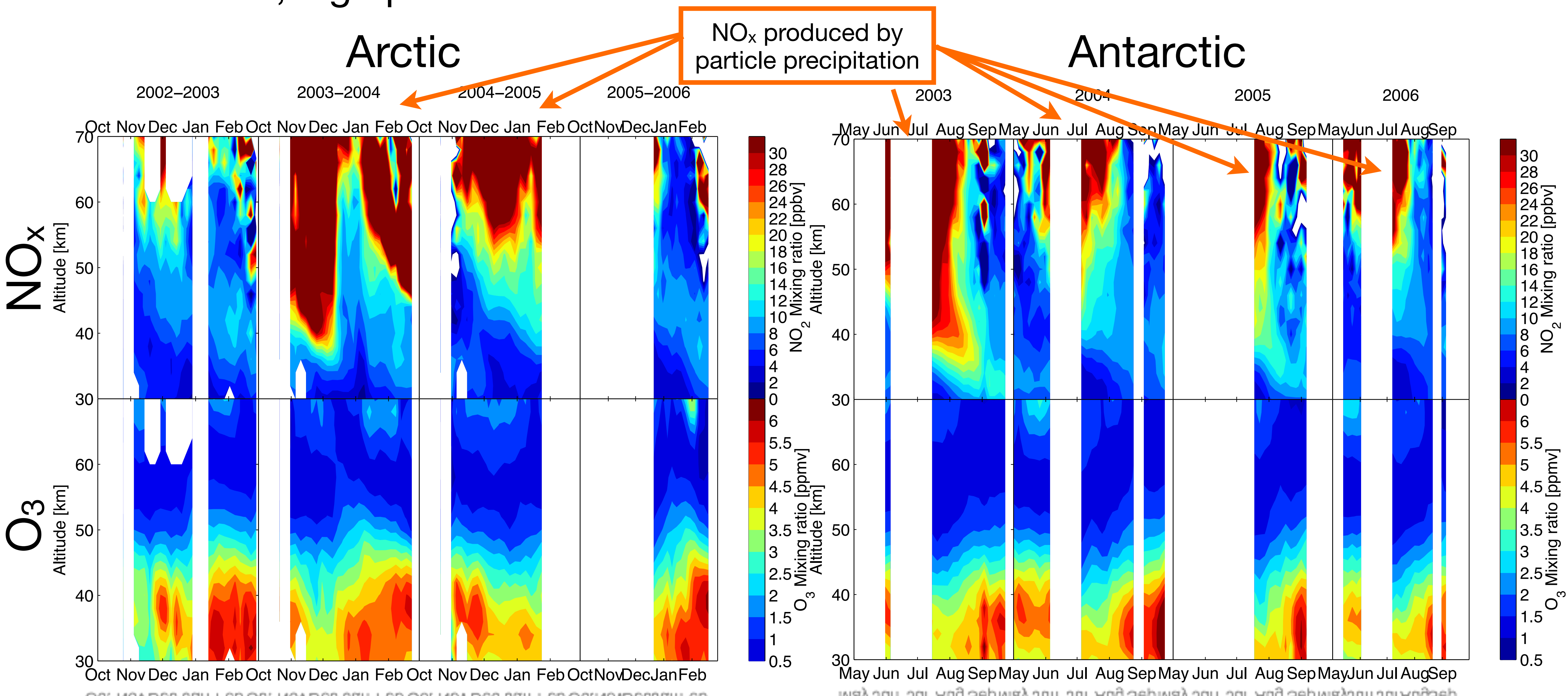
- Energetic Solar Protons (Solar Proton Events) observed from geostationary orbit (GOES-satellites). SPEs are sporadic.
- How to estimate fluxes of *medium* and *high* (few MeV) energy electrons (electrons from radiation belts, auroral particles,...)?
  - This precipitation can be considered almost ever present, but measurement are sparse.
  - Variety of geomagnetic indices available.
  - Which one would best represent the level of particle precipitation?
- The geomagnetic activity index A_p often used for atmospheric chemistry purposes.
- 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.,.

Polar winter NO_x and Ozone

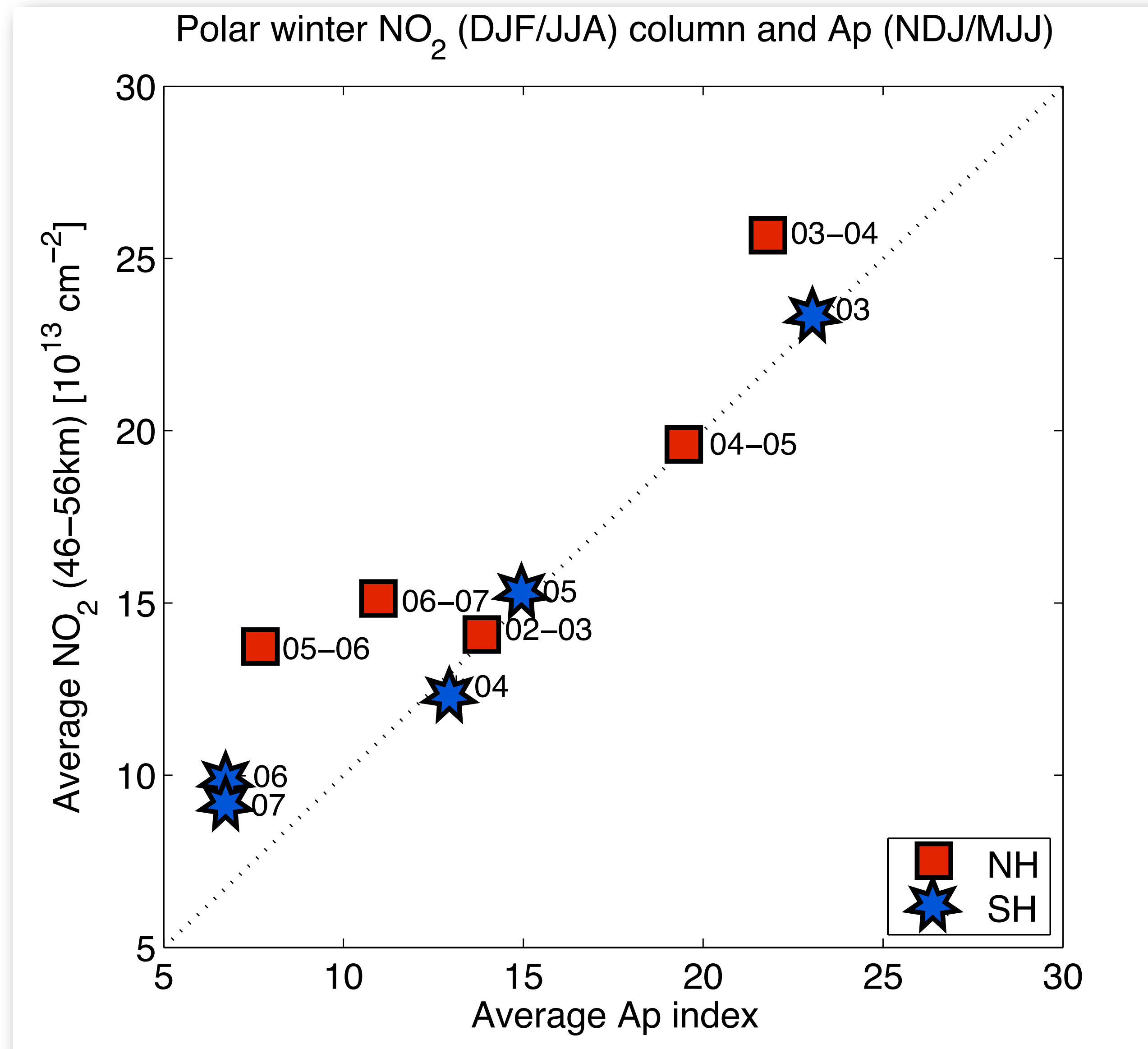
- GOMOS polar night NO_x and O_3 observations from Envisat satellite.
- 30 - 70 km, high polar latitudes > 60°N/S



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

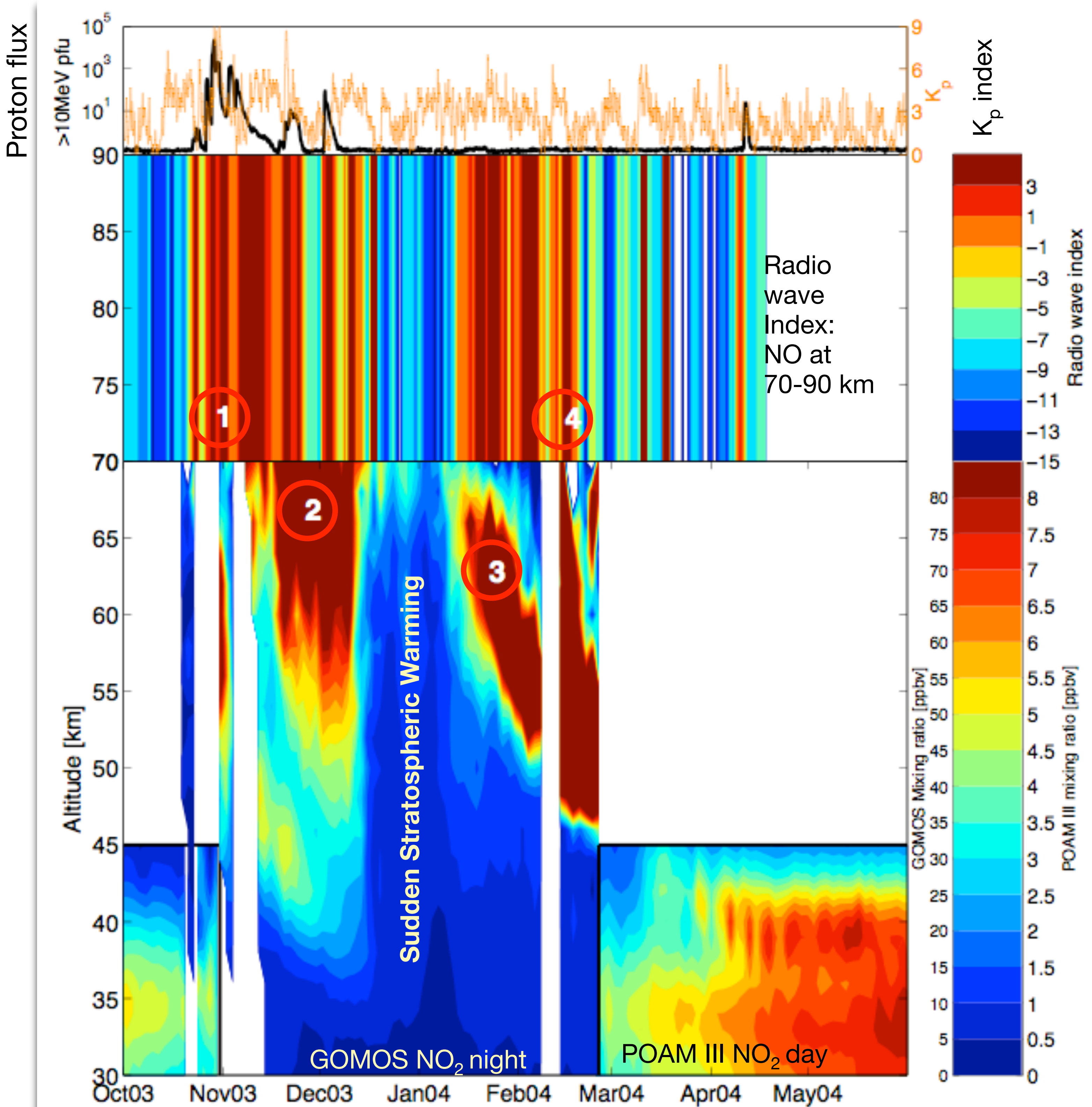
Upper Stratospheric NO_x - A_p

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



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

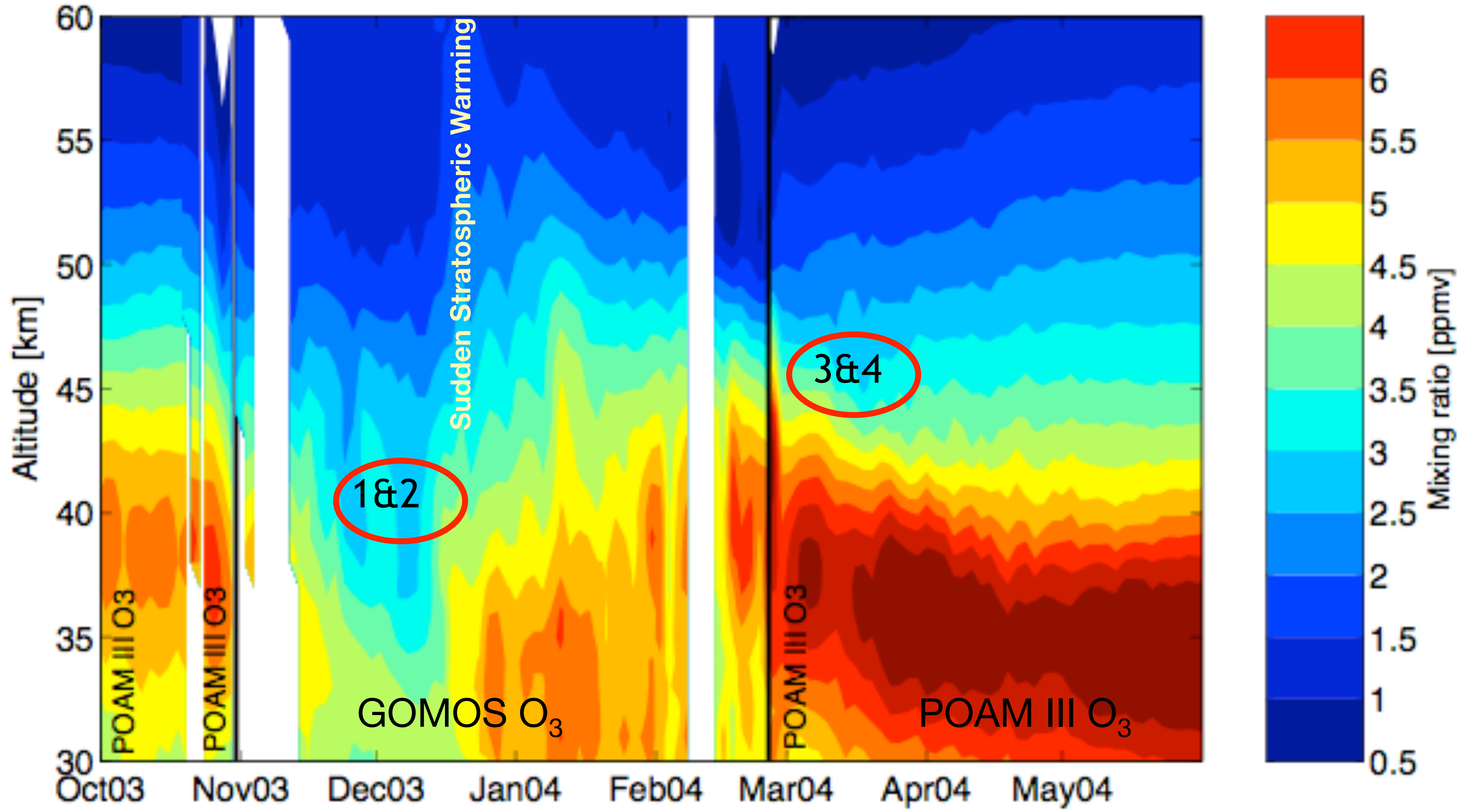
Case study: Different Forms of Solar/Particle NOx Production. Oct 2003 - May 2004

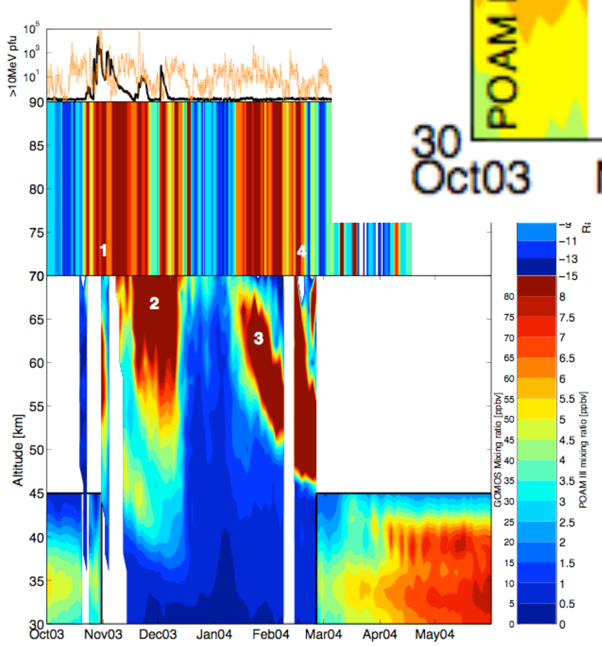


- We can identify 4 events.
- **Event 1**: Halloween Solar Proton Events 2003
- **Event 2**: Energetic electron and auroral precipitation from Halloween storms and small events afterwards
- **Event 3**: Descend of thermospheric (aurorally produced) NO_x
- **Event 4**: Geomagnetic storms & Relativistic 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. 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,

EPP signatures in Surface Air Temperatures?

- Model studies have suggested that NO_x, created by Energetic Particle Precipitation (EPP), and consequent ozone loss through catalytic loss cycles could have an indirect effect on stratospheric and tropospheric (e.g. surface level) temperatures.
- *Rozanov et al. (2005)*: Chemistry-Climate Model, results predicted winter time (DJF) changes in Surface Air Temperature and 50 hPa Geopotential Height due to precipitating energetic particles.

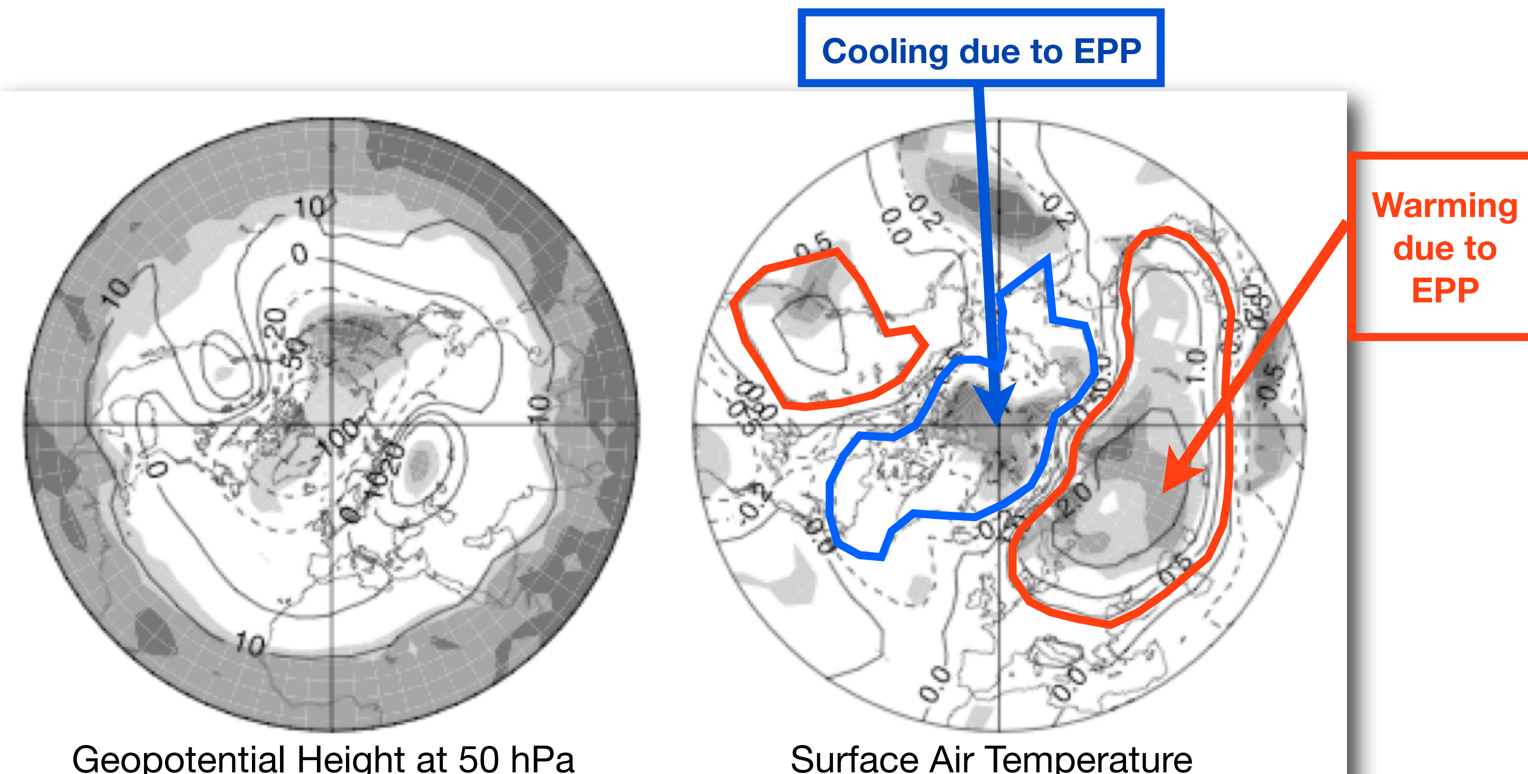
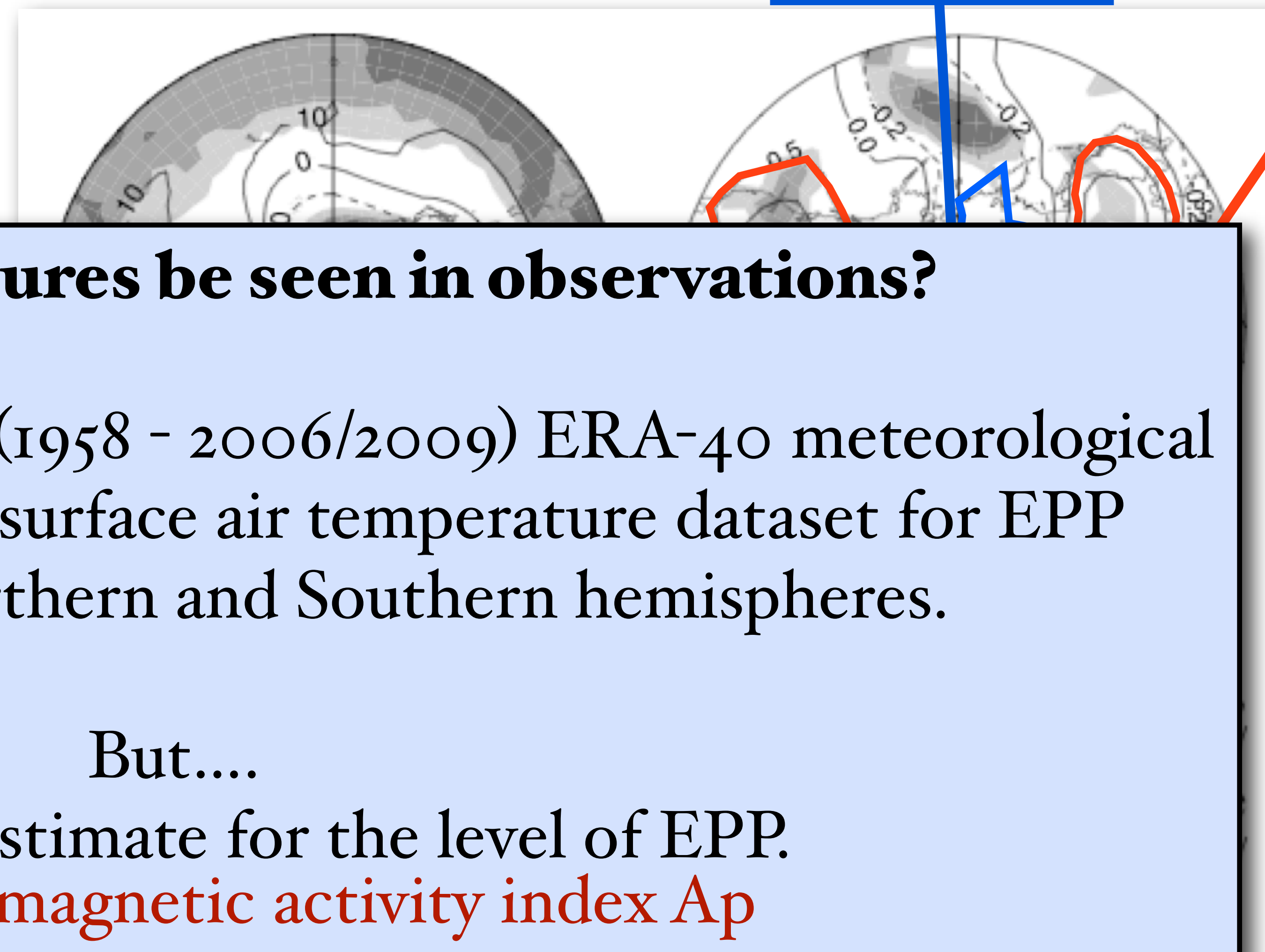


Figure 6. Changes in geopotential height at 50 hPa (m), and SAT (K) for boreal winter due to EEP. The light/dark/heavy shading shows the regions where the changes are judged statistically significant at or better than the 20%/10%/5%) levels.

Indirect mechanism: Energetic Particle Precipitation (electron/proton precipitation) → NO_x production → Descent to stratosphere → O_3 loss → Effect on dynamics?→ Temperature effect?

EPP signatures in Surface Air Temperatures?

- Model studies have suggested that NO_x, created by Energetic Particle Precipitation (EPP), and consequent o... c... o... (e...
- R... C... w... A... G... p...



Can similar signatures be seen in observations?

We looked into the ECMWF (1958 - 2006/2009) ERA-40 meteorological re-analysis and operational surface air temperature dataset for EPP signatures in the Northern and Southern hemispheres.

But....

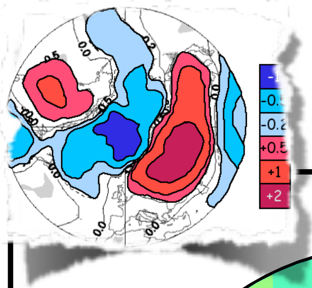
1) We need an estimate for the level of EPP.

✓ Use the geomagnetic activity index Ap

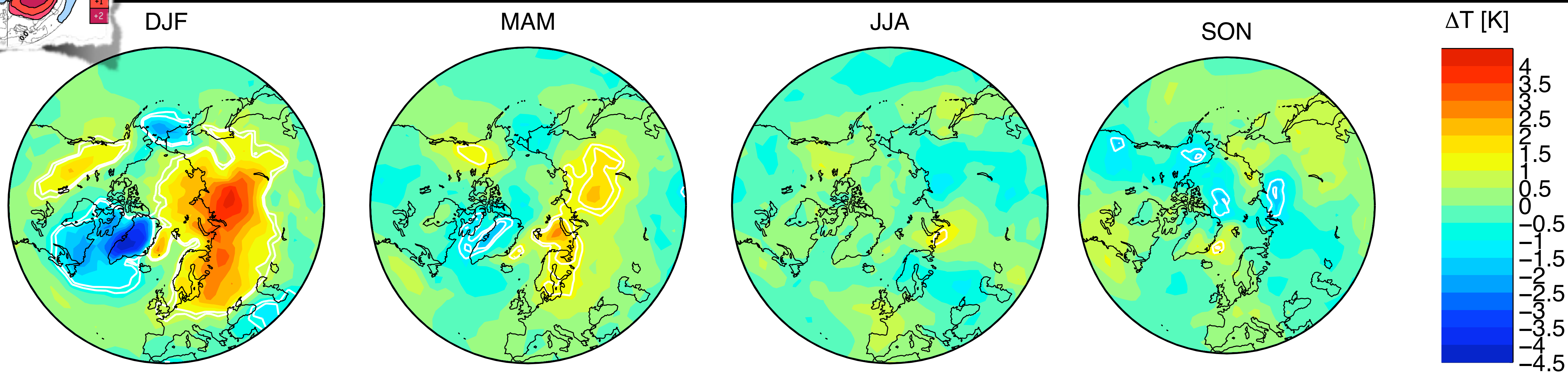
2) Solar irradiance variation affects atmospheric temperatures, we need to take that into account.

✓ Compare years with similar F10.7 flux

Indirect mechanism: Energetic Particle Precipitation (electron/proton precipitation) → NO_x production → Descent to stratosphere → O_3 loss → Effect on dynamics?→ Temperature effect?

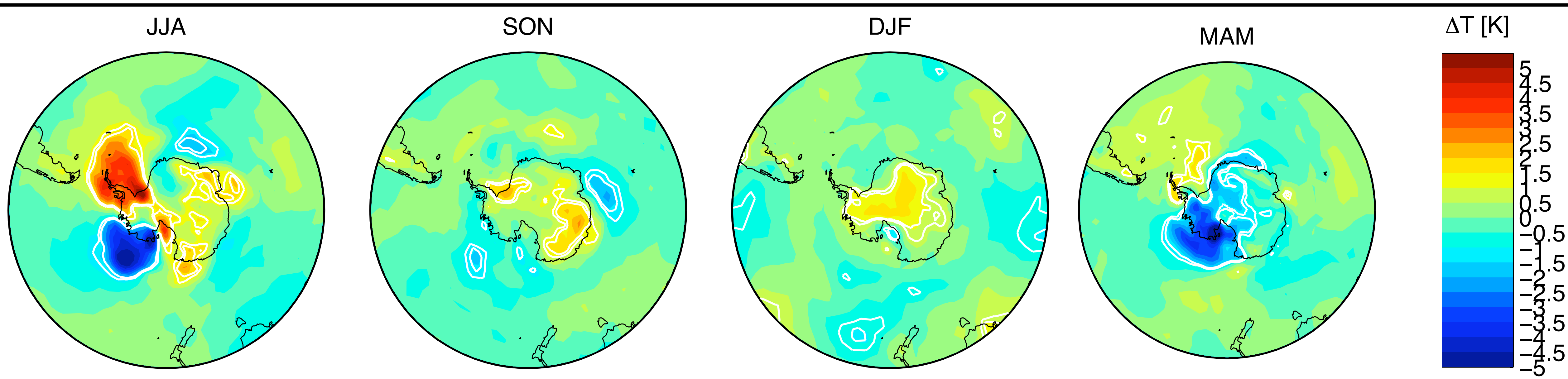


EPP signatures in Surface Air Temperatures



NH: High A_p - Low A_p. Excluding SSW years

"Remove neutral atmosphere extreme dynamical events"



SH: High A_p - Low A_p

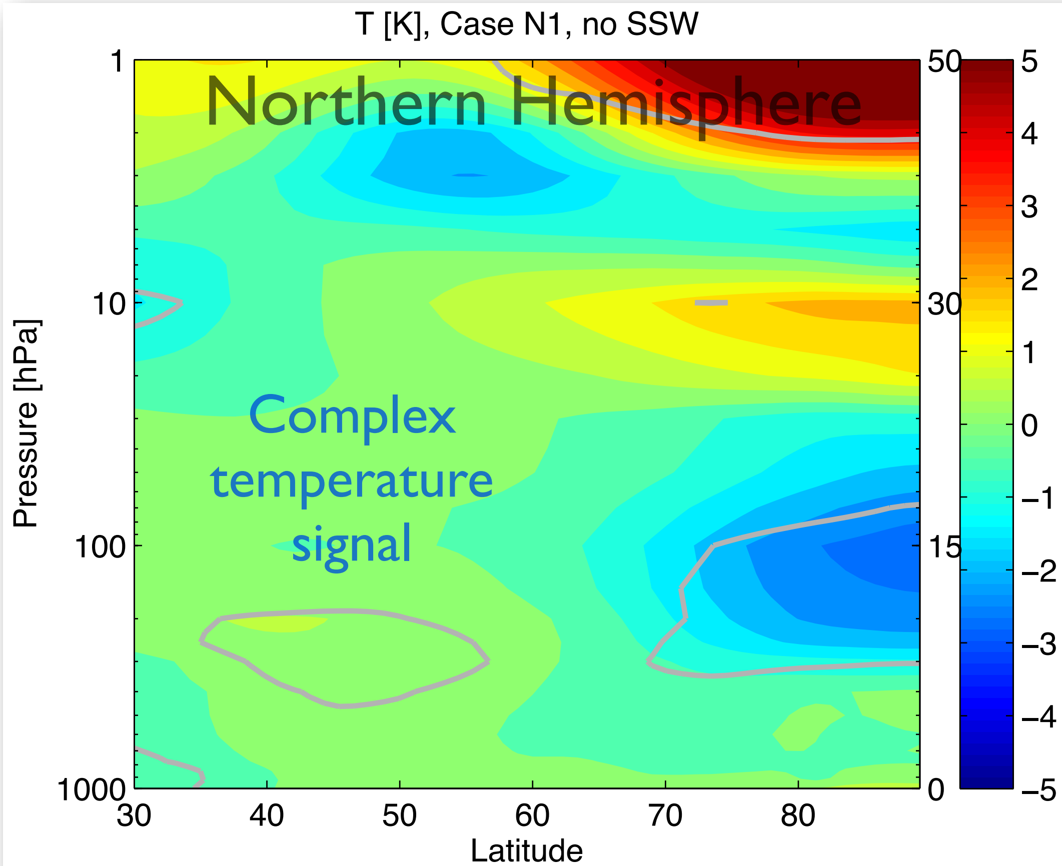
This is not a trend but rather variability!
No global effect, only local polar effect.

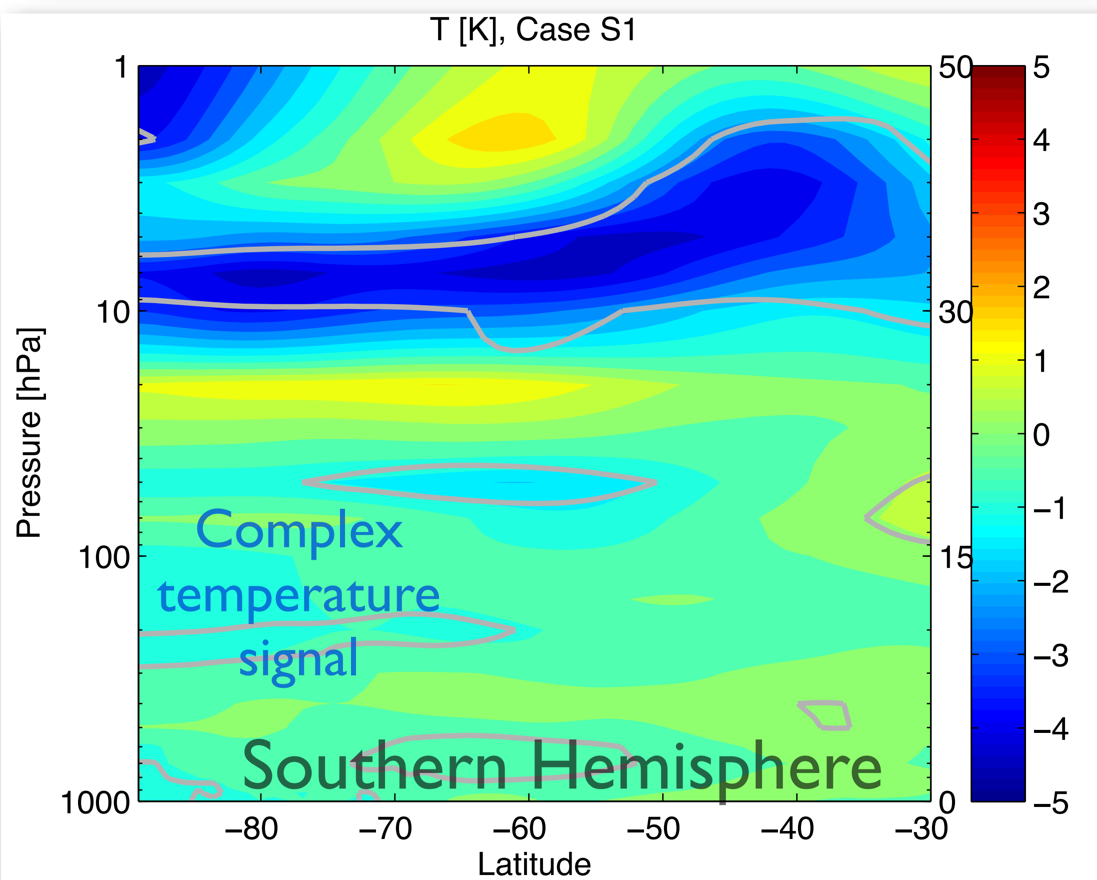
Seppälä, et al. (2009), Geomagnetic activity and polar surface air temperature variability., J. Geophys. Res.

Upmost levels of the ERA-40 data not included!

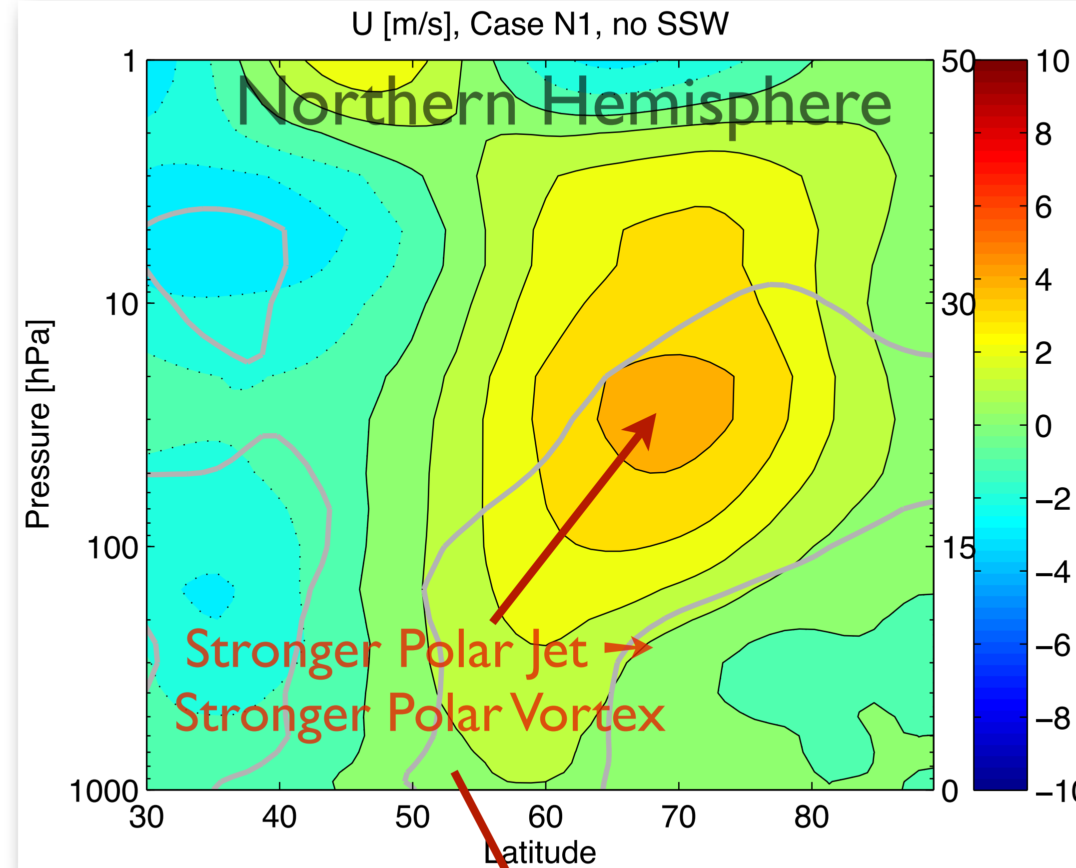
Stratosphere response: High A_p - Low A_p

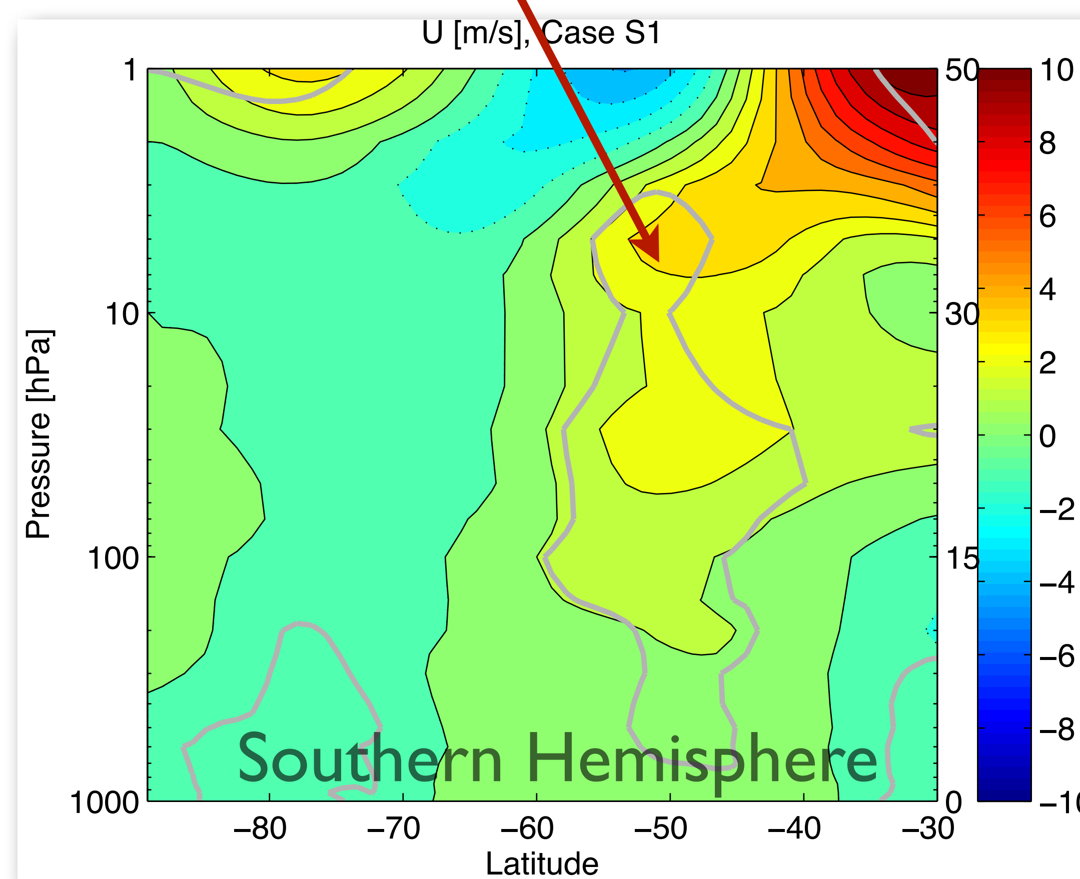
Zonal mean Temperature



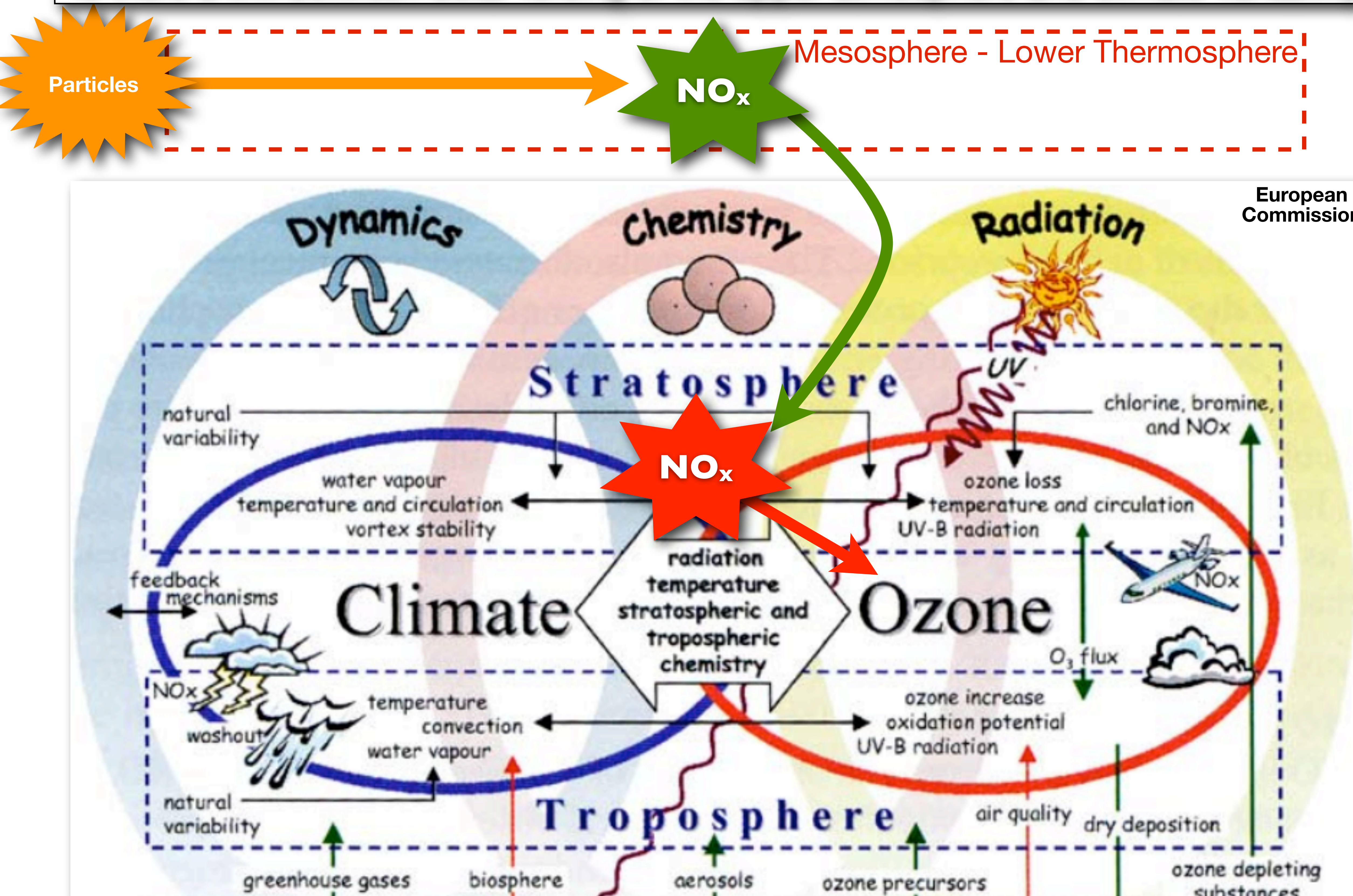


Zonal mean zonal wind





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



...it's a very complex and coupled system.
The role of the upper atmosphere should to be considered more.

Thank you for your attention!

Thank you for the invitation to give this presentation! Questions?

Acknowledgements:
M. A. Clilverd (BAS)
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...and everyone who contributed to these studies.