Atmospheric measurements and The Long term effects of energetic particle events

Research Seminar on Sun-Earth connections

University of Helsinki, spring 2006

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Finnish Meteorological Institute

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- Atmospheric measurements from Sun-Earth connection point of view
- Why? Where? What?

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- Results from the Oct/Nov 2003 solar storm

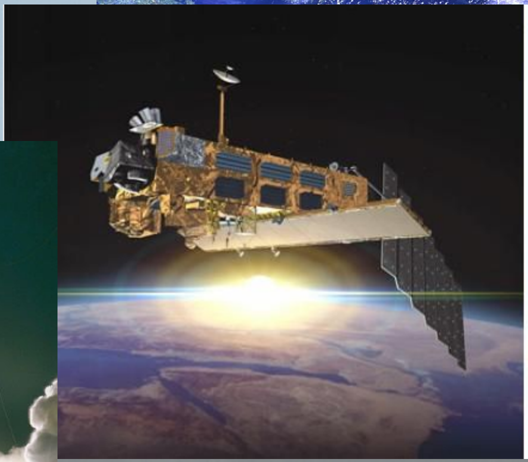
Atmospheric measurements

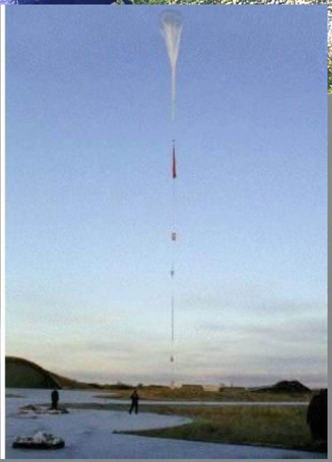
Why?

Where?

- Space: Satellite platforms
- Ground

What?





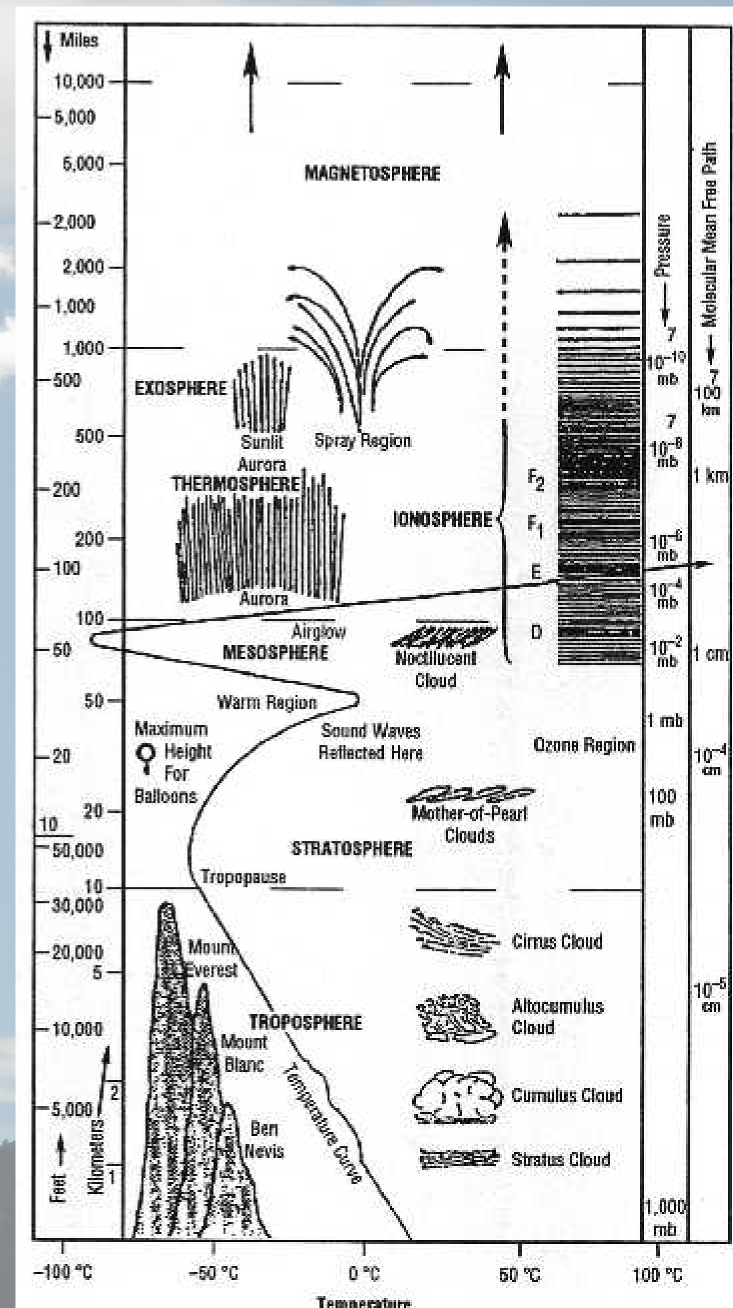
Atmosphere

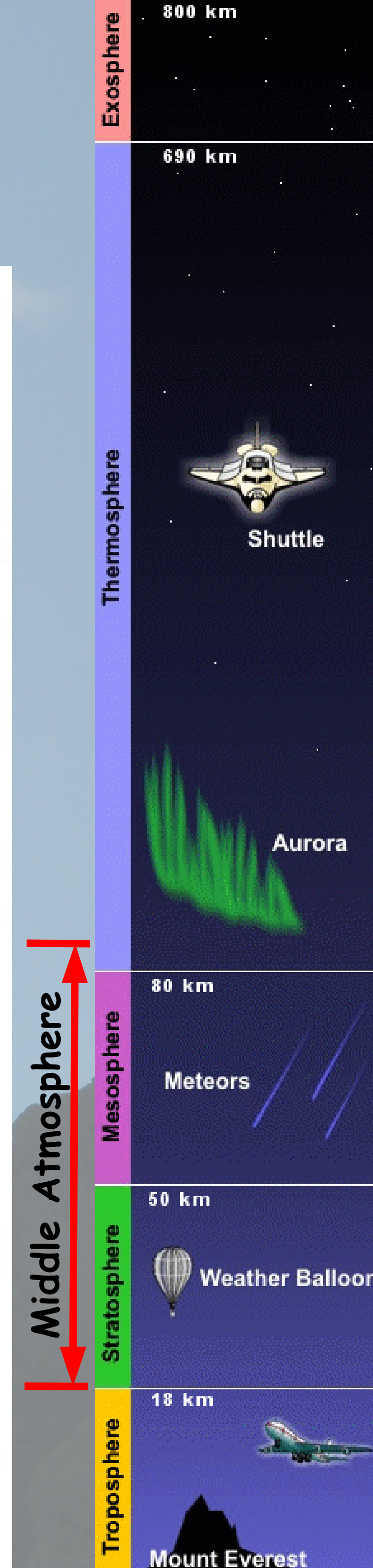
Neutral Atmosphere

- Main constituents: N_2, O_2
- Minor Species: O_3, NO_2, CO_2, CH_4,…

Ionosphere

- See previous lectures





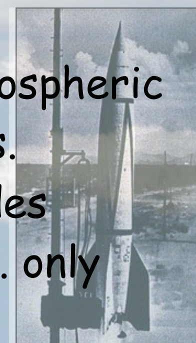
Time line of atmospheric measurements

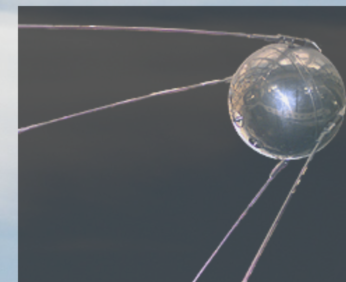
1783 First scientific balloon flight

1890's Start of balloon soundings of T and p

1929 First rocket sounding, T and p

After WWII V1 and V2 rockets used (also) for atmospheric measurements. Higher altitudes reached (prev. only 50km)





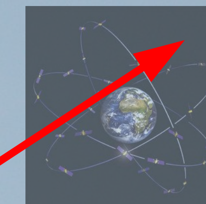
1950's Riometer

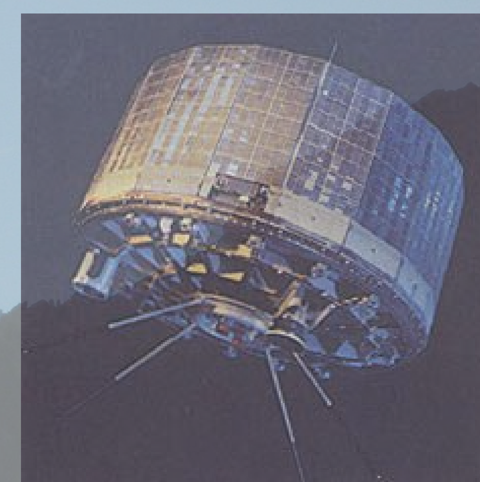
1957 Satellite era starts with Sputnik

1958 Incoherent scatter

1960's Operational weather satellites

1960-1970's NASA starts to develop satellites targeted for atmospheric studies

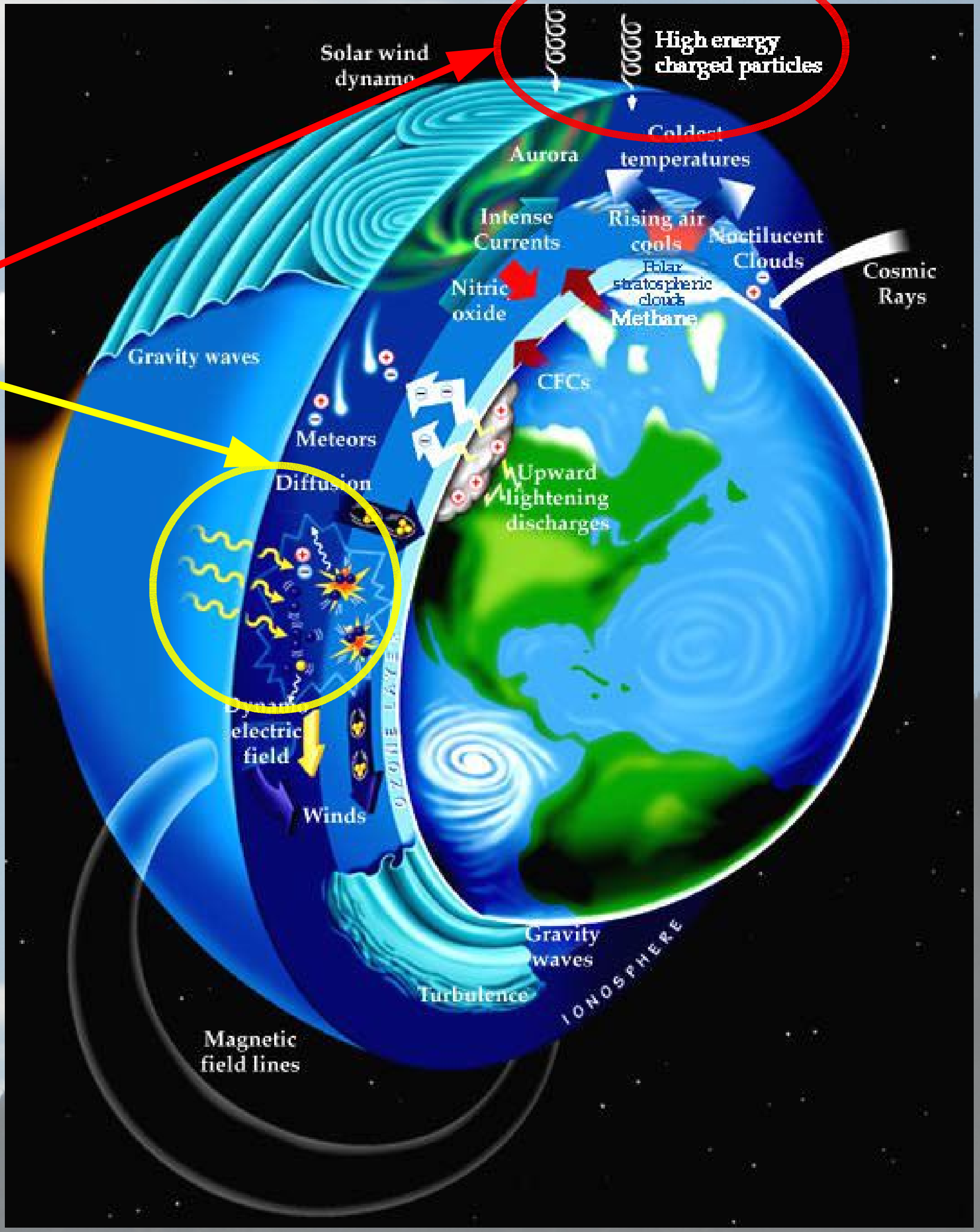




The Sun-Atmosphere connection

How does the Sun affect the atmosphere?

- Radiation
- Charged particles
  - Photoionization, -dissociation, and excitations of atoms and molecules
  - Charged particles precipitate in the polar areas, main effect in the middle-and upper atmosphere: strato-, meso-,and thermosphere

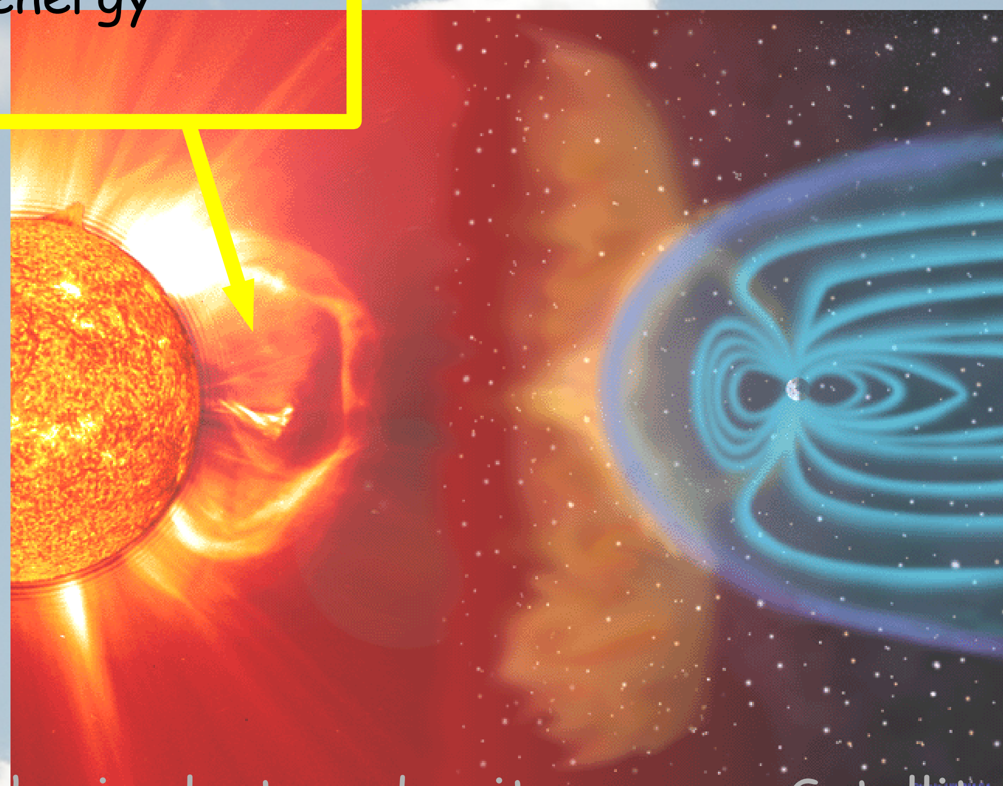


The Sun-Atmosphere connection – What can be measured?

Lets consider a Solar storm

Satellite observing the Sun sees the beginning of the storm(Flare, CME, emitted high energy particles)

Satellite on geostationary orbit measures high energy particle flux

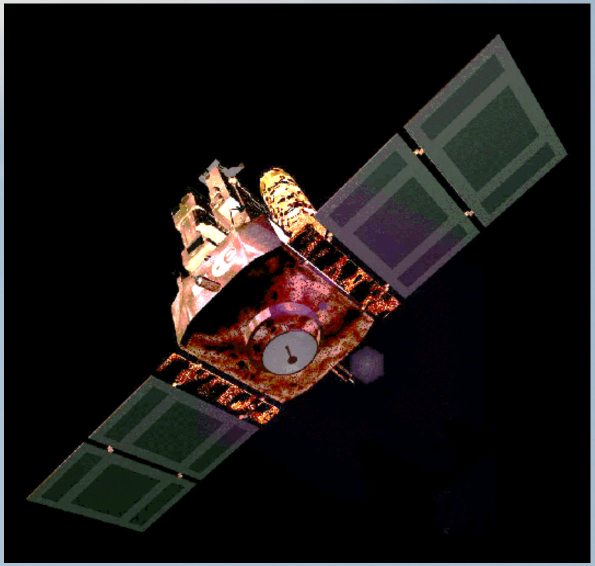


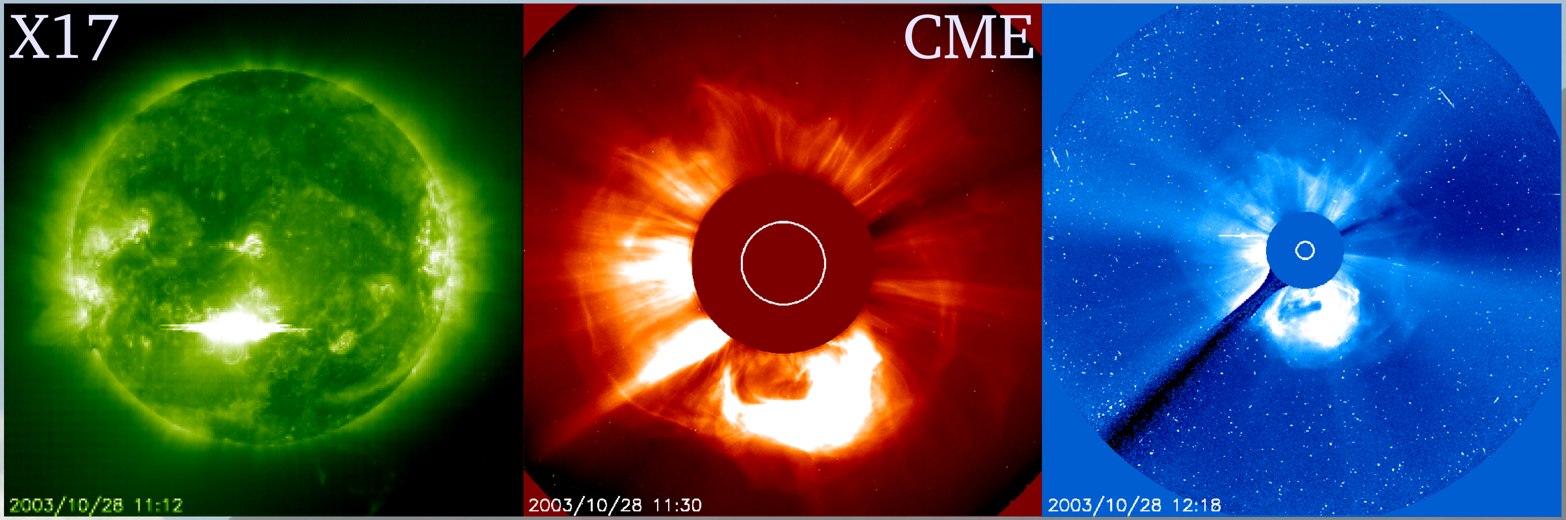
Changes in the ionospheric electron density can be observed from ground based instruments (Incoherent scatter, riometer, VLF)

Satellites on Low Earth Orbits measure changes in the atmospheric composition

Satellite observing the Sun

- The SOHO (Solar & Heliospheric Observatory) satellite has been observing the Sun for over 10 years
- Oct/Nov 2003 Solar Storm:
  - X17 Flare on Oct 28 (X45 4 Nov!)
  - CME on Oct 28





Courtesy of SOHO/EIT and SOHO/LASCO consortiums.

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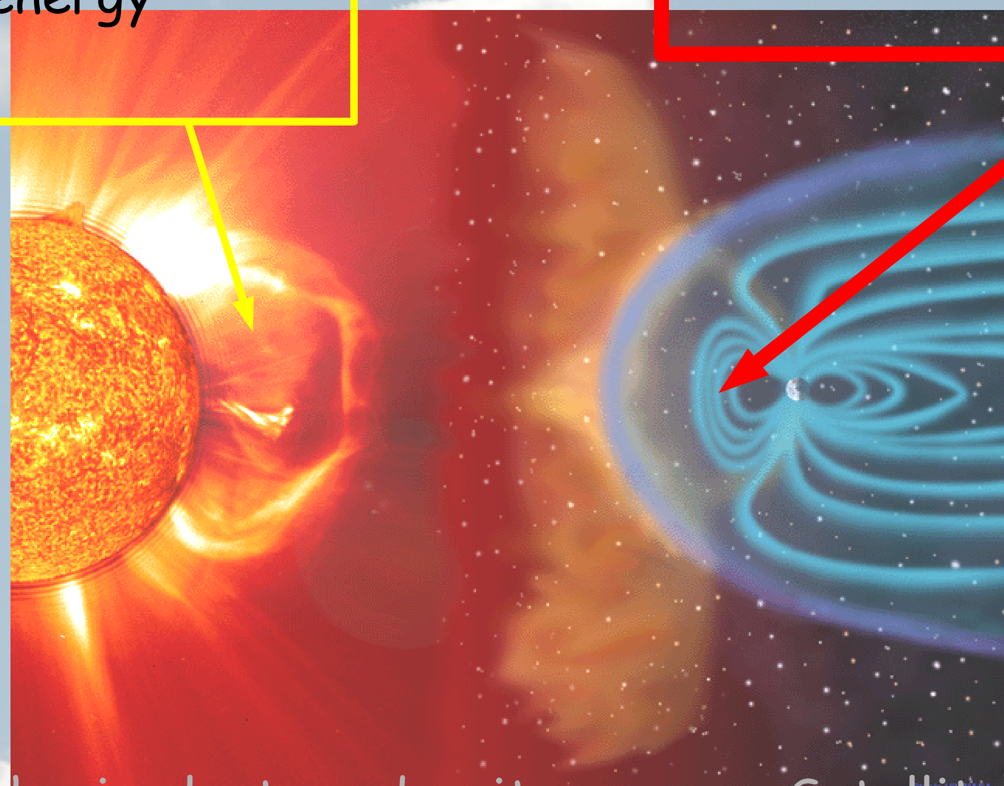

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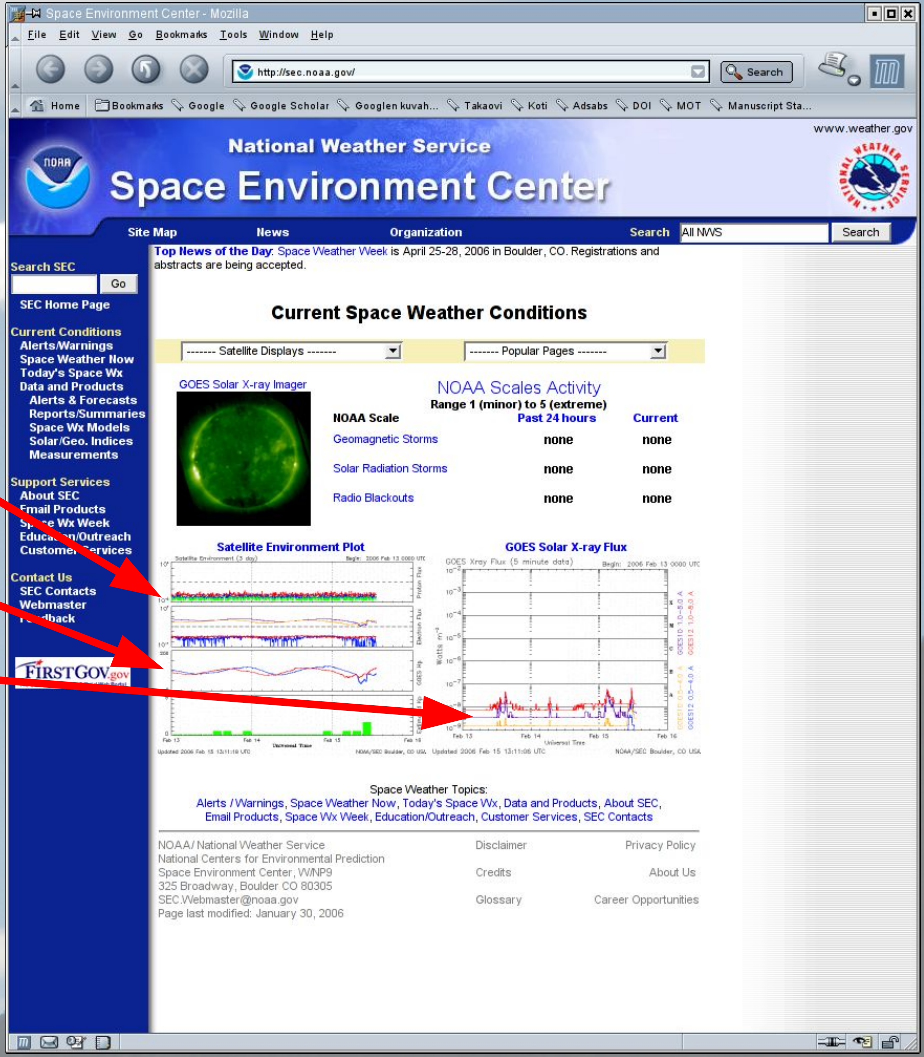
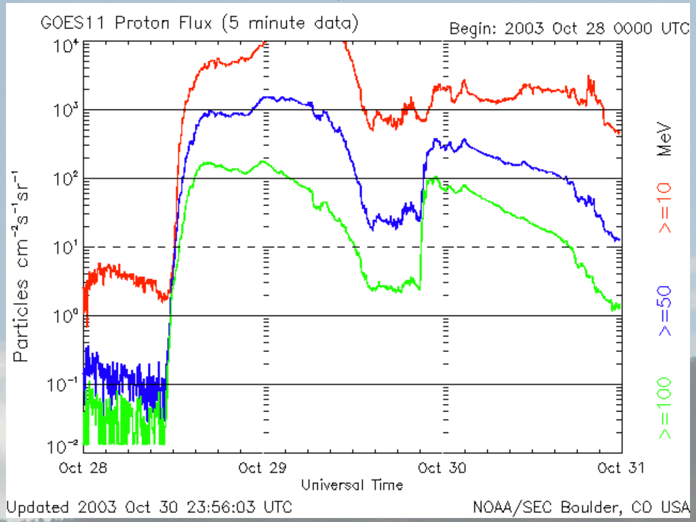
Satellites on Low Earth Orbits measure changes in the atmospheric composition

Measurements of high energy particles

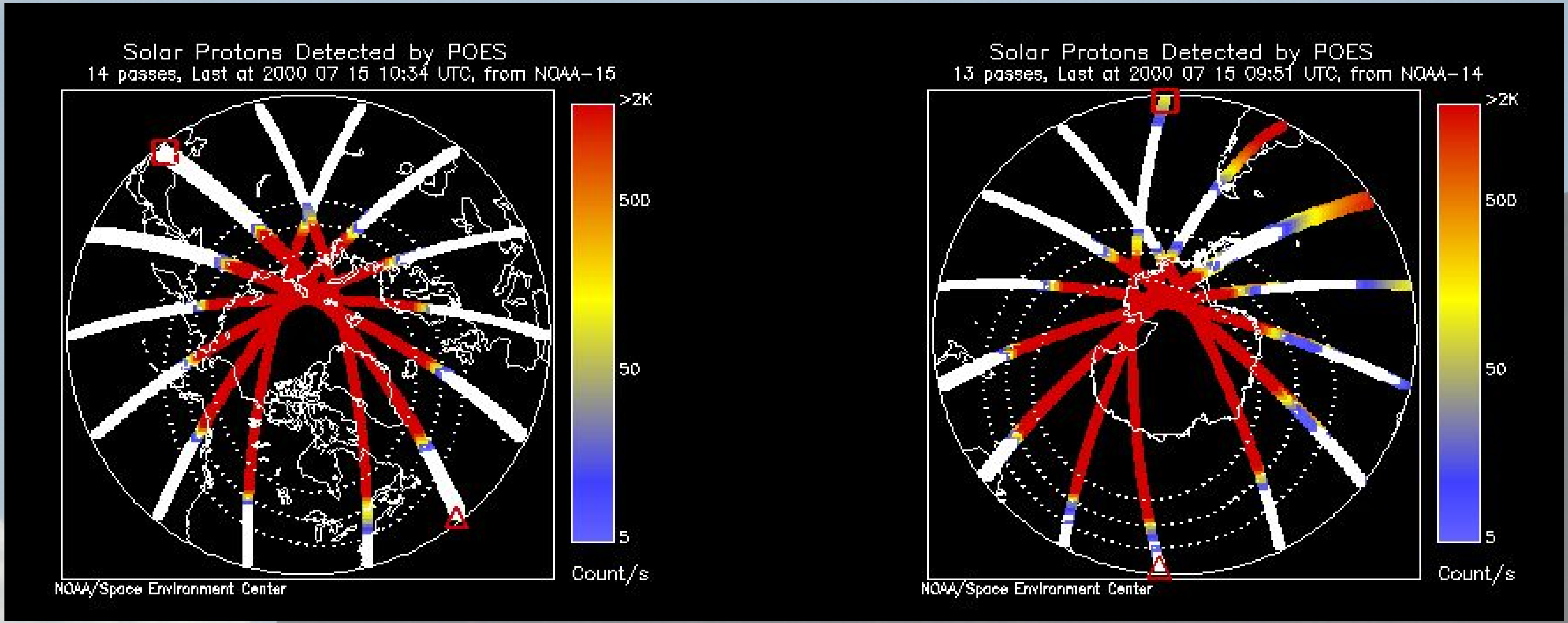
- GOES (Geostationary Operational Environmental Satellite) satellites carry a SEM instrument (Satellite Environment Monitor)
  - Energetic particle sensor
  - Magnetometer sensors
  - Solar x-ray sensor





Measurements of high energy particles

- POES (Polar Operational Environmental Satellite) satellites carry a SEM-2 instrument
  - In addition to SEM/GOES, monitors also electrons and protons in the atmospheric loss cone



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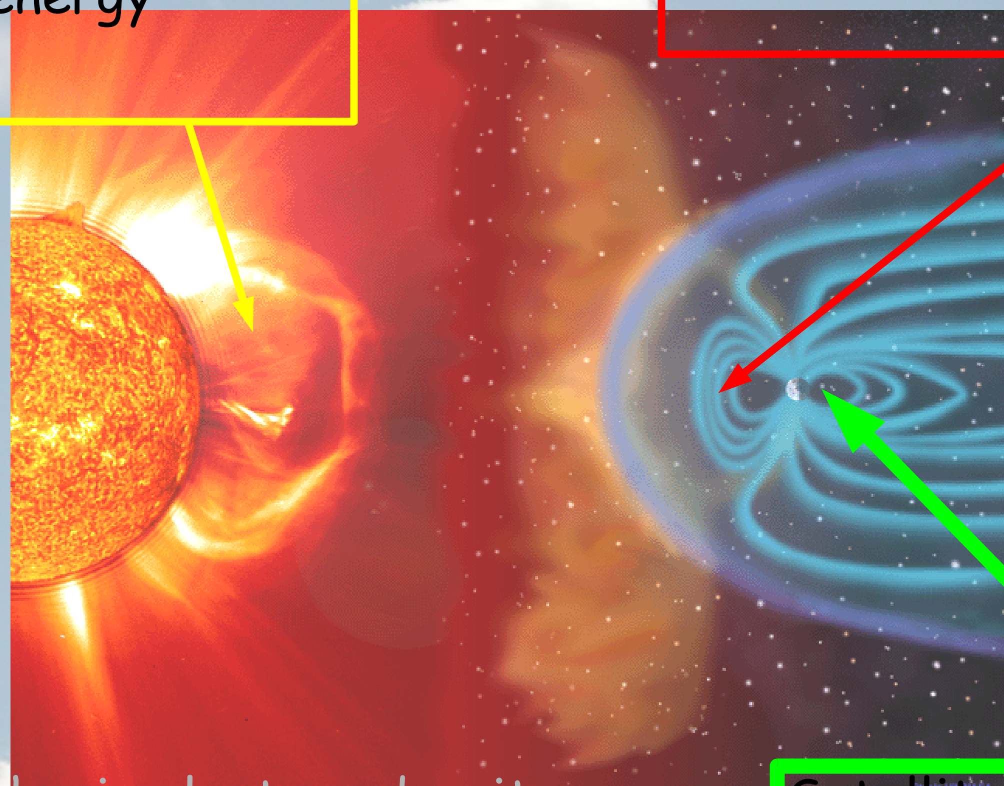


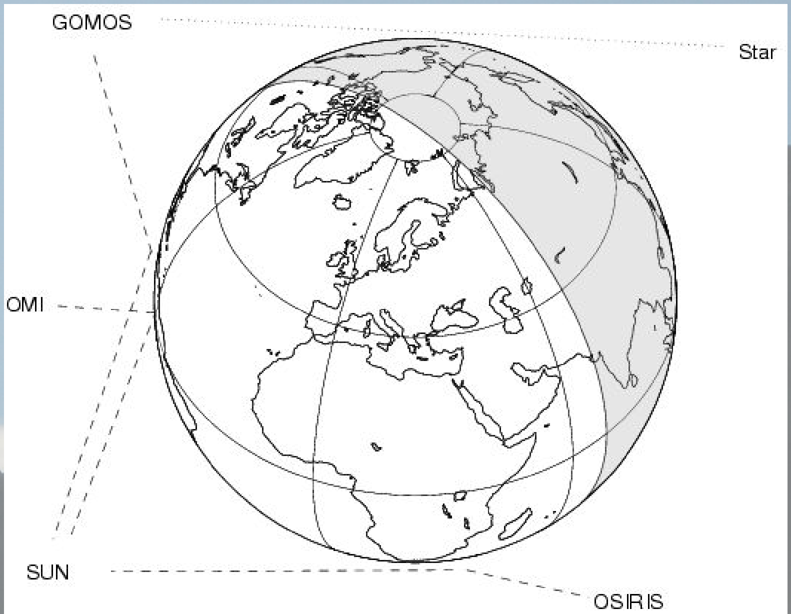
Changes in the ionospheric electron density can be observed from ground based instruments (Incoherent scatter, riometer, VLF)

Satellites on Low Earth Orbits measure changes in the atmospheric composition

Measuring the atmospheric composition from space

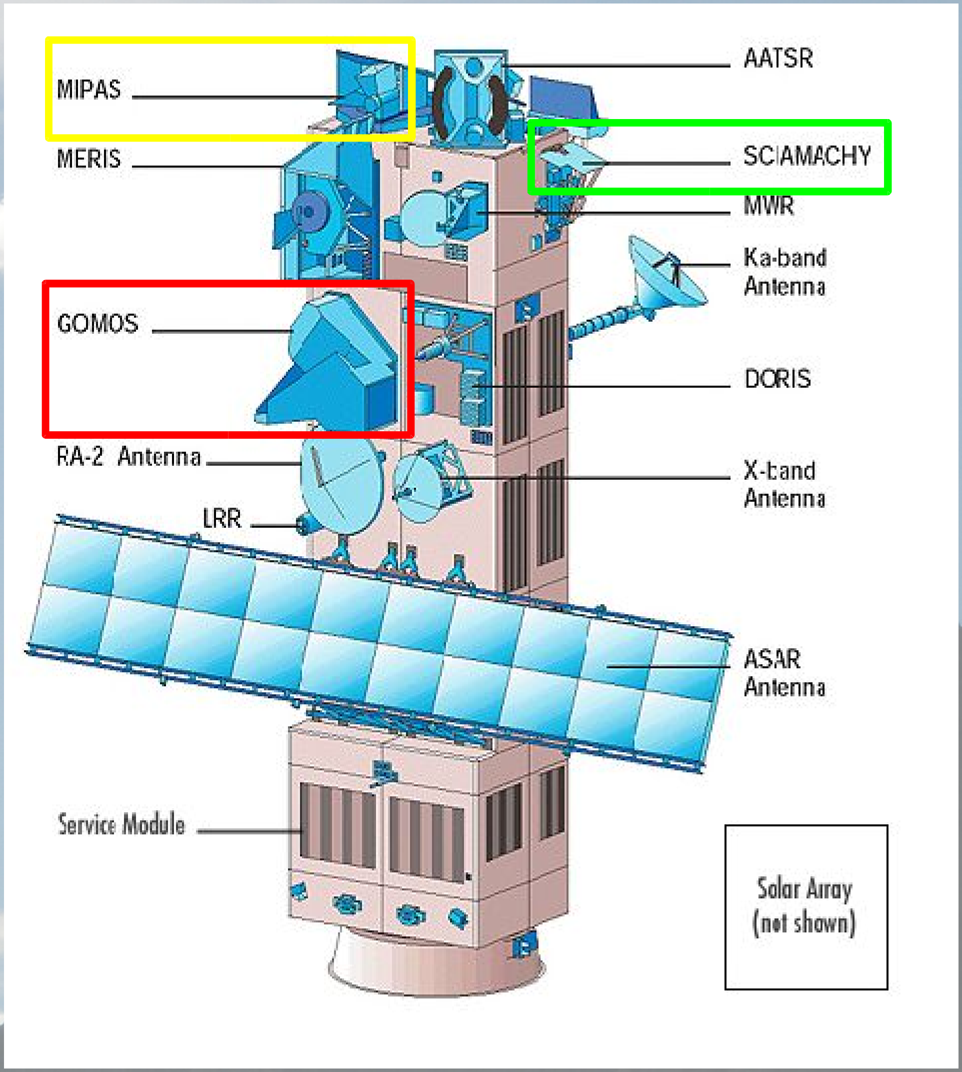
- Different observation techniques:
  - Solar/Moon occultation
  - Stellar occultation
  - Limb scatter (scattered solar light)
  - Atmospheric emissions
- Good: Continuous measurements (if you are lucky)
- Bad: Satellites are Expensive!

- Constituent retrieval depends on used wavelength range + altitude



The Envisat satellite

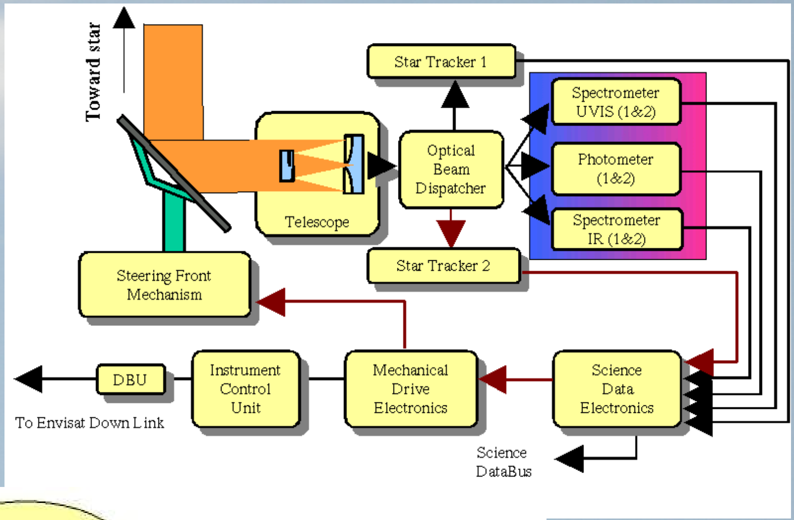
- European Space Agency's polar-orbiting Earth observation satellite
- Launched in March 2002
- 10 instruments observing the atmosphere, ocean, land, and ice
- Atmospheric chemistry: GOMOS, MIPAS, and SCIAMACHY

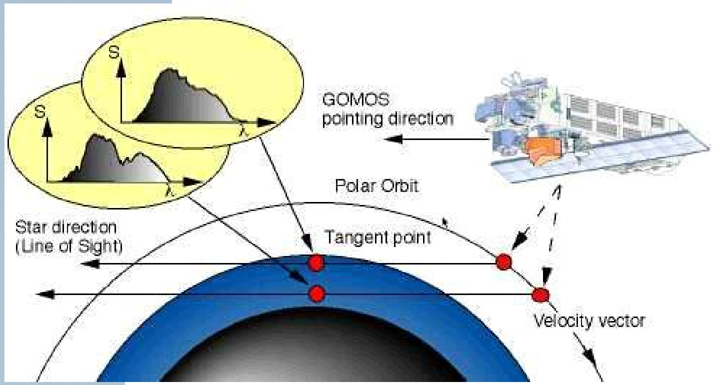


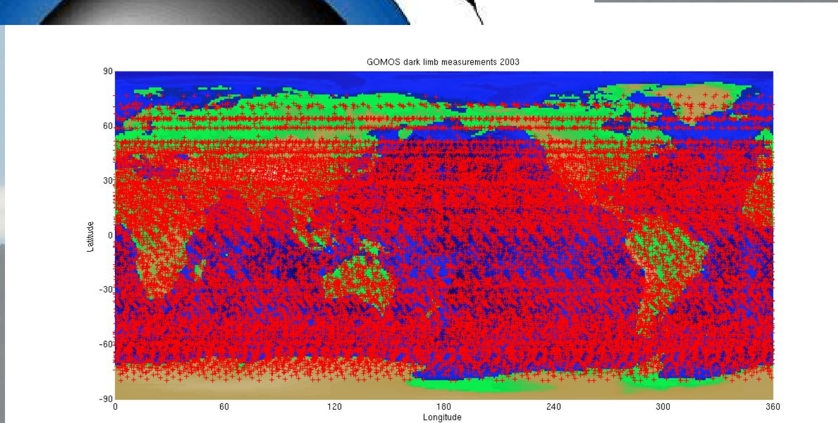
GOMOS

Global Ozone Monitoring by Occultation of Stars

- Stellar Occultation instrument, first proposed by FMI and Service d'Aeronomie 1988
- First measurement on March 20, 2002
- 3 spectrometers (250-950nm), 2 fast photometers (1kHz, 470-520nm, and 650-700nm)
- 600 measurements/day with good global coverage
- Altitude range 10-100km, with sampling resolution <1.7km
- O_3, NO_2, NO_3, H_2O, O_2, aerosols, and temperature







GOMOS night-time measurements 2003

MIPAS - SCIAMACHY

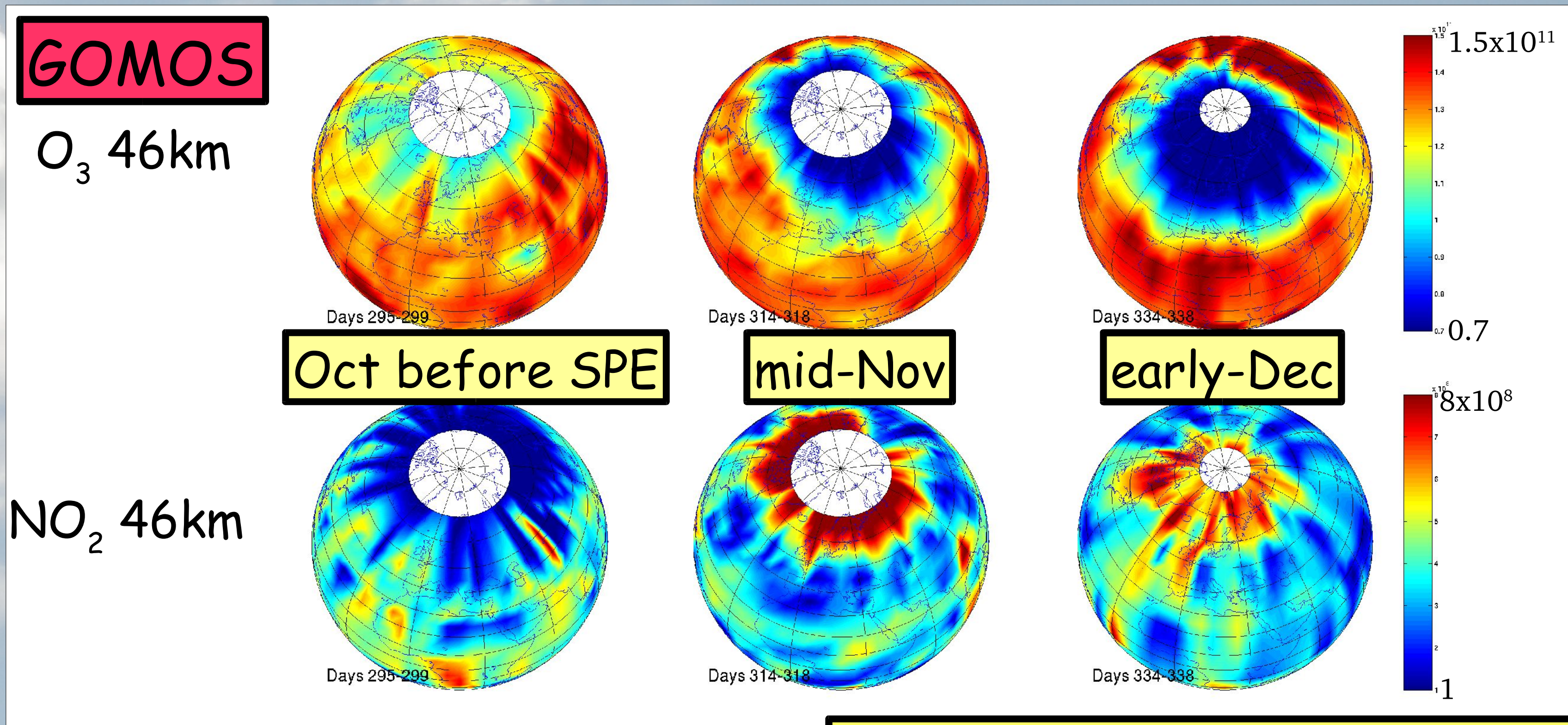
Michelson Interferometer for Passive Atmospheric Sounding

- Near – mid-IR (4.15 – 14.6µm)
- Limb emissions
- O_3, NO, NO_2, H_2O, CH_4, N_2O, HNO_3, HNO_4, T, ClO, $ClONO_2$, N_2O_5, CFC's
- Due to instrumental problems MIPAS has been switched off for significant periods

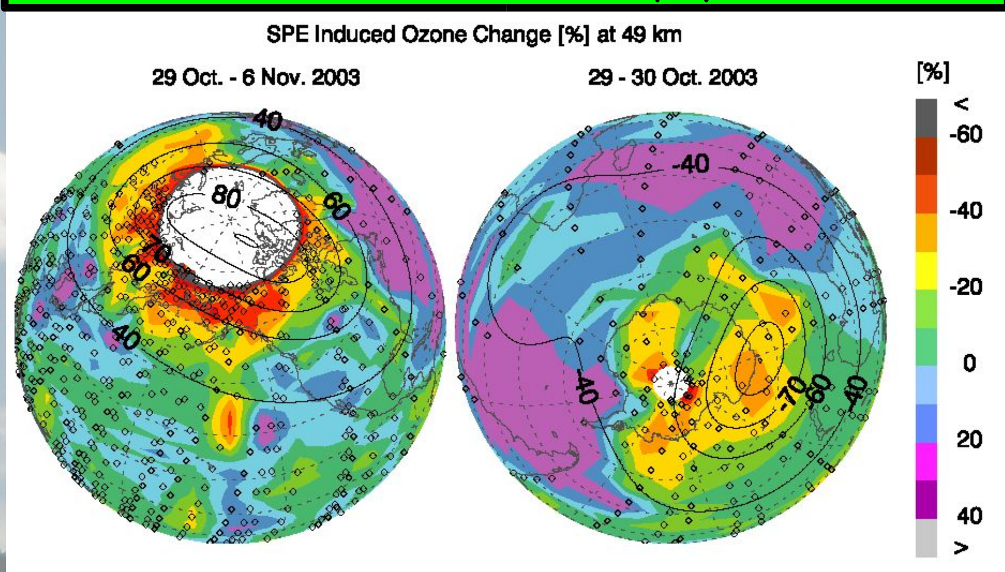
SCanning Imaging Absorption SpectroMeter for Atmospheric ChartographY

- UV - Vis – near-IR (240-1700nm, 8 chanels)
- Measurements in Limb, Nadir and Occultation (Sun & Moon) mode
- O_3, BrO, OClO, ClO, SO_2, H_2CO, NO_2, CO, CO_2, CH_4, H_2O, N_2O, p, T, aerosol, radiation, cloud cover and cloud top height
- Problems with the growing ice layer on the near-IR detectors

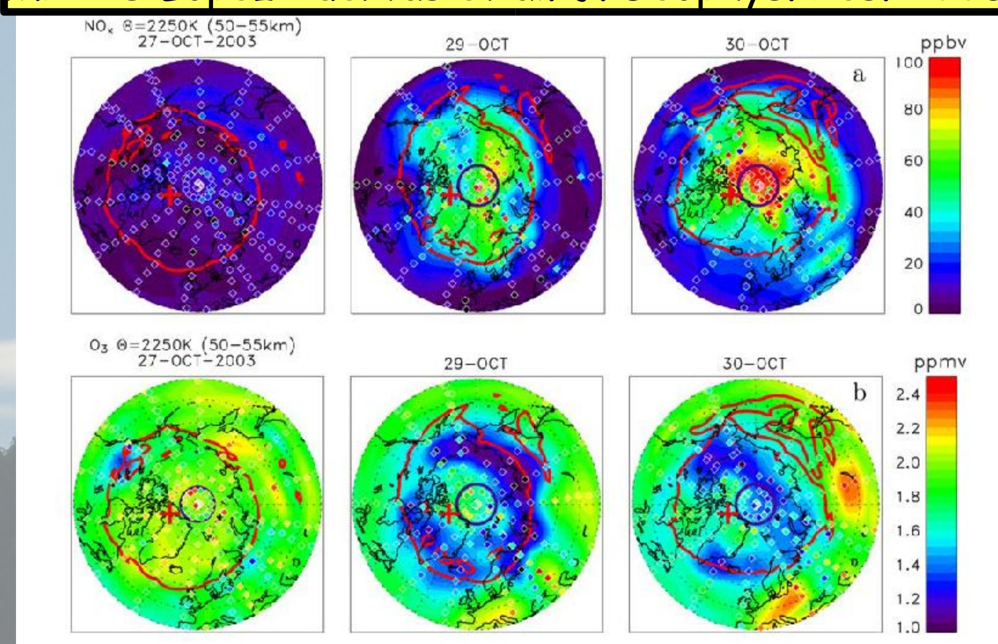
Envisat view of the Oct/Nov SPEs



SCIAMACHY Rohen et al. J. Geophys. Res. 2005



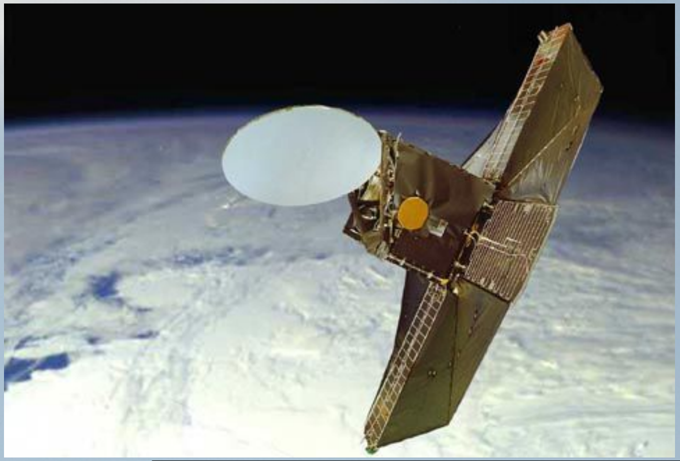
MIPAS López-Puertas et al. J. Geophys. Res. 2005



OSIRIS

Optical Spectrograph & Infra Red Imaging System

- On board swedish Odin satellite (2 instruments: OSIRIS & SMR)
  - 280-800 nm, ~1270 nm
- Measurements in Limb geometry
- O_3, NO_2, BrO, OClO, aerosols
- SMR/Odin: Radiometer, also used for astronomy measurements



Degenstein et al. Geophys. Res. Lett., 2004

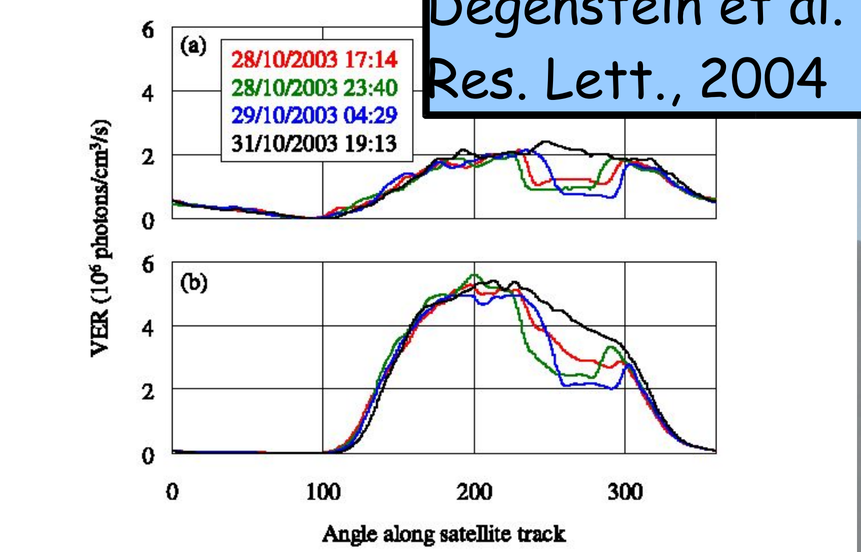
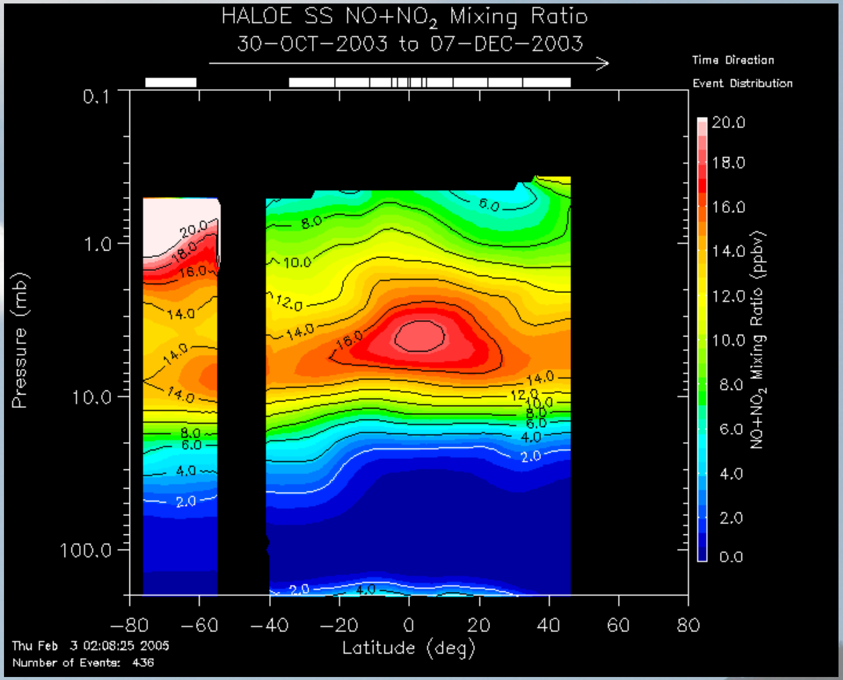
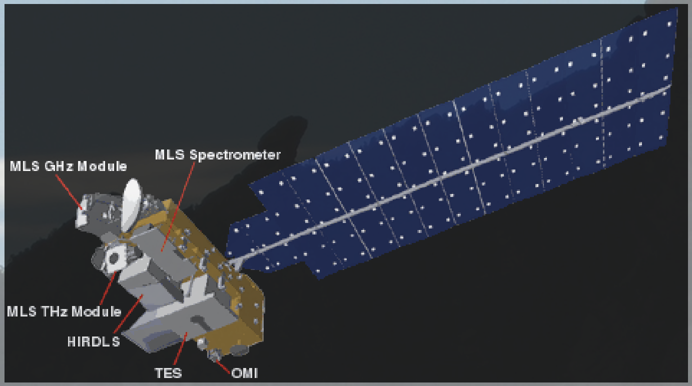


Figure 2. Single altitude VER cross sections that compare the results from three in-SPE orbits with the baseline orbit, 31/10/2003. The cross sectional slices are from 65 km and 55 km for panels a) and b) respectively.

More satellite instruments

- HALOE/UARS (Halogen Occultation Experiment)
  - Solar Occultation 1991-2005
  - O_3, HCl, HF, CH_4, H_2O, NO, NO_2
- SABER/TIMED (Sounding of the Atmosphere using Broadband Emission Radiometry)
- MLS/EOS-Aura (Microwave Limb Sounder) (MLS/UARS)
  - O_3, OH, HO_2, H_2O...
- OMI/EOS-Aura (Ozone Monitoring Instrument)
  - Focus on troposphere





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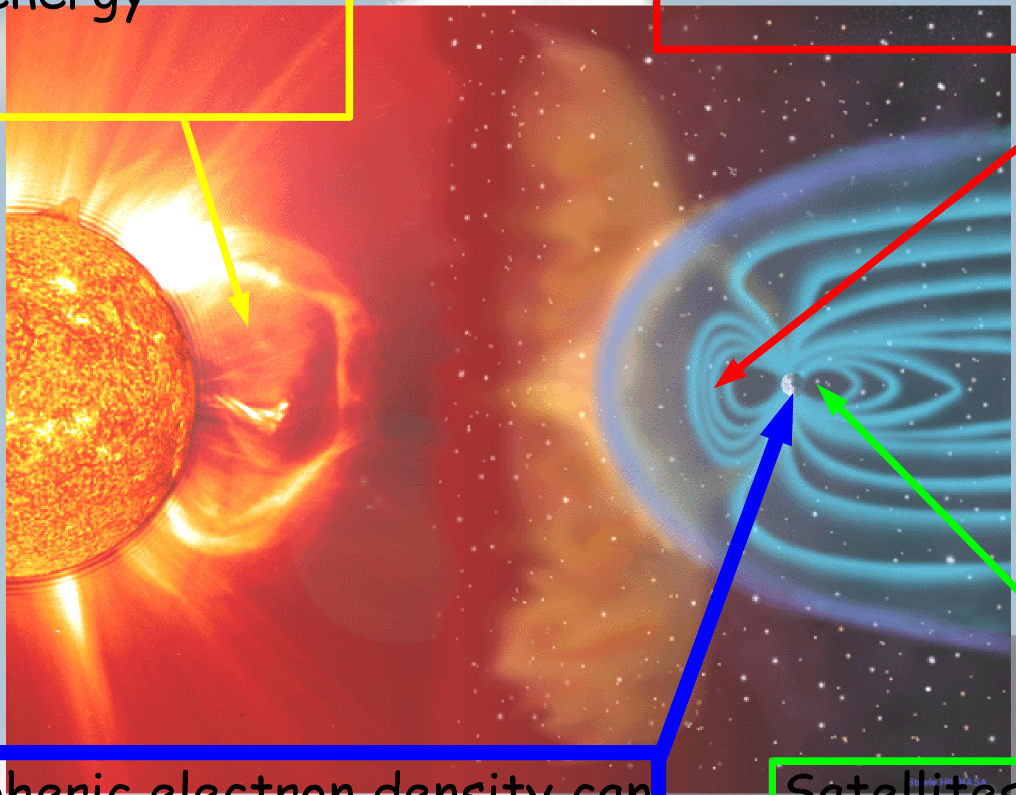
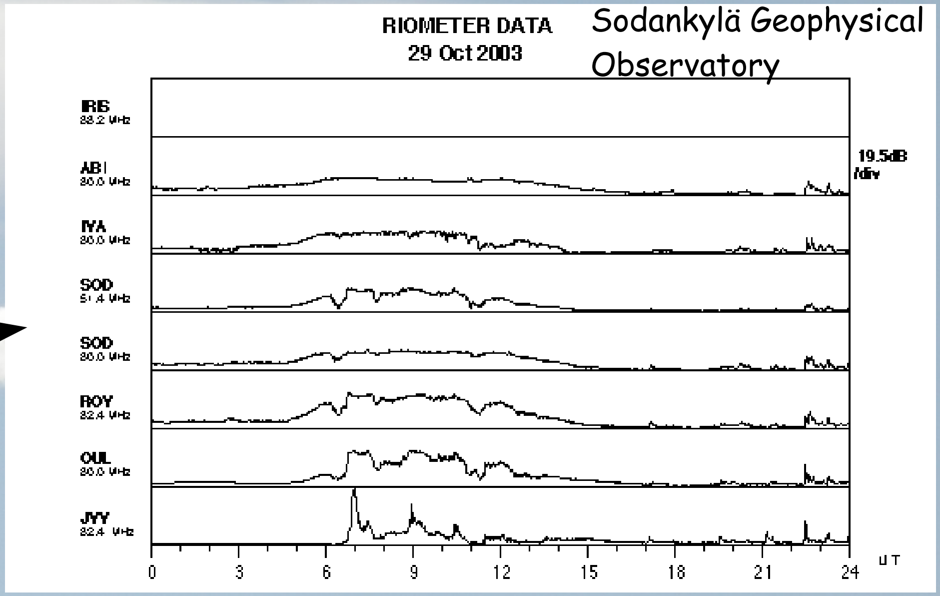


Changes in the ionospheric electron density can be observed from ground based instruments (Incoherent scatter, riometer, VLF)

Satellites on Low Earth Orbits measure changes in the atmospheric composition

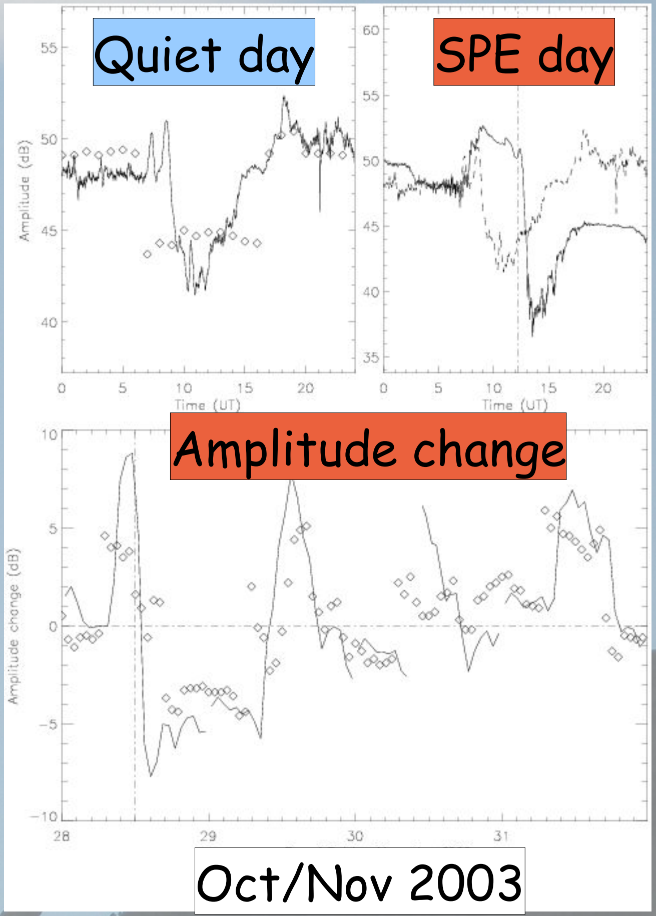
Ground based observations

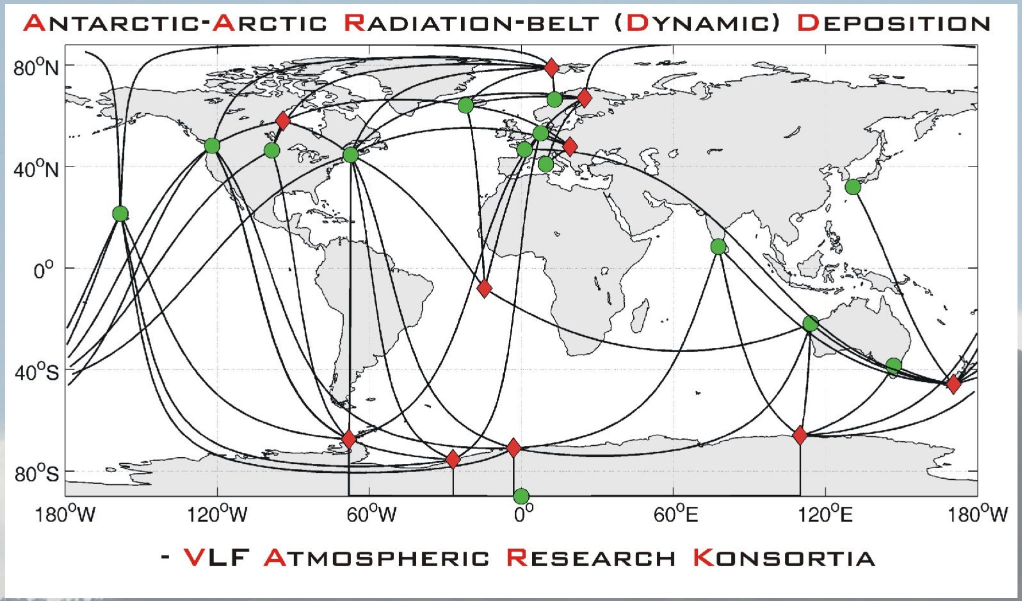
- **Riometer** (Relative Ionospheric Opacity METER)
  - Measures the absorption of cosmic radio noise in <u>D-region</u>
  - Electron density, ionization
- **Incoherent scatter/EISCAT**
  - Electron density, ionization, temperatures



Ground based observations

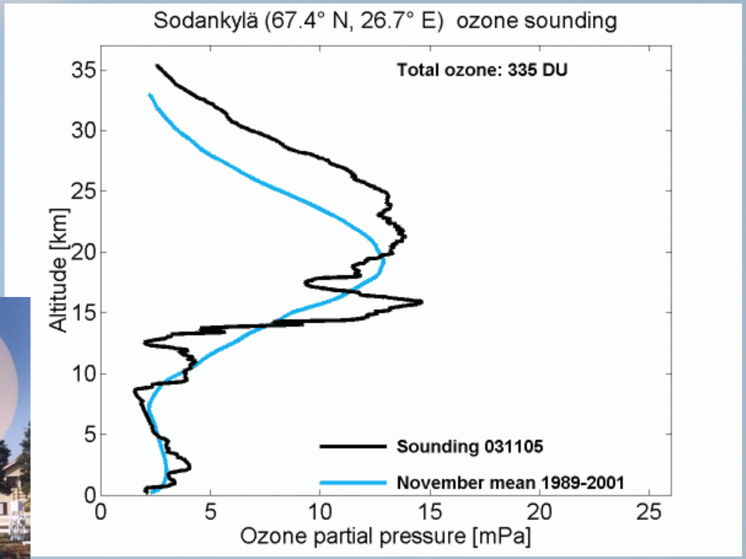
- **VLF radars**
  - <u>Very Low Frequency</u> radio signals
  - Signals travel in a waveguide formed by the Earth surface and the bottom of the ionosphere
  - Changes in ionospheric electron density → change in signal amplitude and phase





Other ground based measurements

- Balloon soundings
  - Basic soundings done regularly (T, p, O_3), balloon campaigns (more parameters)
  - Altitude range < 50km
- Rocket soundings
  - Campaigns
  - Expensive
- Lidar (LIght Detection And Ranging)
- Measurements represent only one point
- Vertical resolution very good for balloons and rockets



References

- Satellite instrument web pages e.g.
  - http://envisat.esa.int http://www.esa.int/esaEO
  - http://sohowww.estec.esa.nl/
  - http://sec.noaa.gov
  - http://odin.ssc.se/ http://osirus.usask.ca/
  - http://www.timed.jhuapl.edu
  - http://aura.gsfc.nasa.gov
  - http://www.eiscat.sgo.fi http://www.eiscat.com
- Brasseur and Solomon: Aeronomy of the Middle Atmosphere, 2005

Long term effects of energetic particle events

Why?

- Downward transport + lack of sunlight

Where?

- In the winter pole

What?

- More NO_x from precipitation -> only little sunlight to destroy it -> transported to lower altitudes & latitudes

...and Who cares?!?

- Effects on Ozone layer, dynamics, temperature...?

Short Introduction to Energetic Particle Effects on the Atmosphere. Part I

- Energetic particle events are?
  - Solar Proton Event (SPE), Solar Particle Event, Polar Cap Absorption (PCA), other precipitation events
  - (Solar eruptions →) Flux of charged particles (p^+,e^-,...) enhanced → increased ionization in the atmosphere → aurorae, chemistry effects
- **First observation** of **ozone depletion** following a SPE from Rocket measurement Nov **1969**

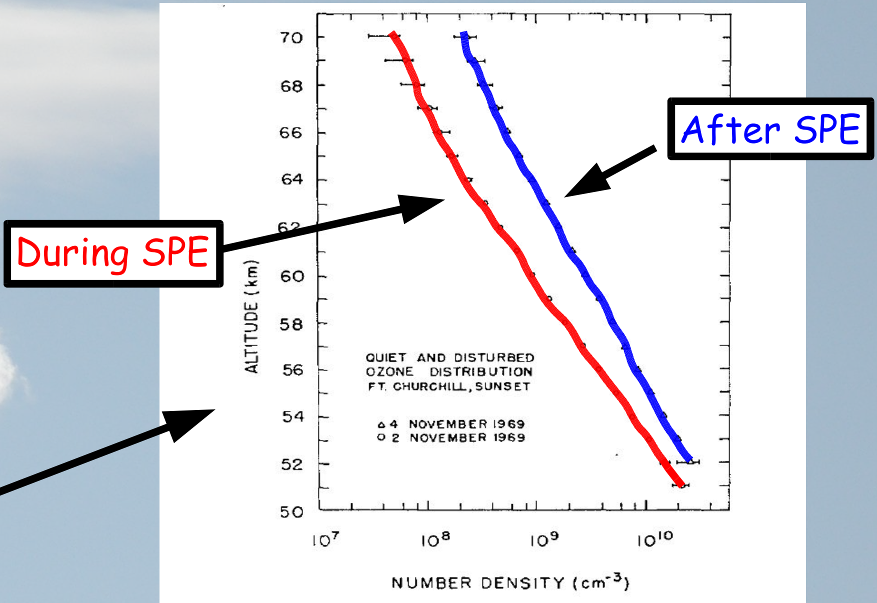
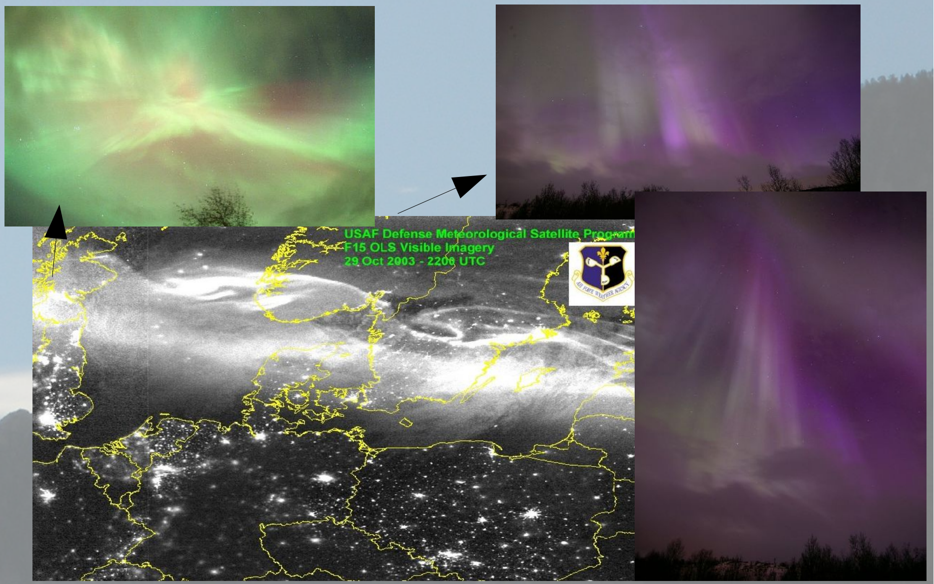


FIG. 4. Comparison of disturbed (2 November 1969) and quieter (4 November 1969) ozone distributions.

- Theory and observations:
  - **1970-1980**: Proton precipitation leads to HO_x and NO_x production → catalytic destruction of ozone
  - First NO_x measurements during SPE in **1980's**
  - NO_x has a great impact during polar night conditions. Conformation from GOMOS measurements
  - Continuous HO_x measurements new



Short Introduction to Energetic Particle Effects on the Atmosphere, Part II

Charged particles precipitate in the polar areas producing HO_x and NO_x in mesosphere and stratosphere

HO_x (H + OH + HO_2)

Short lifetime

HO_x cycle,upper-stratosphere + lower-mesosphere

$$OH + O_3 \rightarrow HO_2 + O_2$$

$$HO_2 + O \rightarrow OH + O_2$$

$$\text{Net: } 2O_x \rightarrow 2O_2$$

Ionpair production → **water cluster** ion production and -reactions → HO_x

NO_x (N + NO + NO_2)

Loss: photodissociatio → longlived during night → transported to <u>stratosphere</u> and <u>lower latitudes</u>

NO_x cycle, upper-stratosphere

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

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

$$NO_2 + O \rightarrow NO + O_2$$

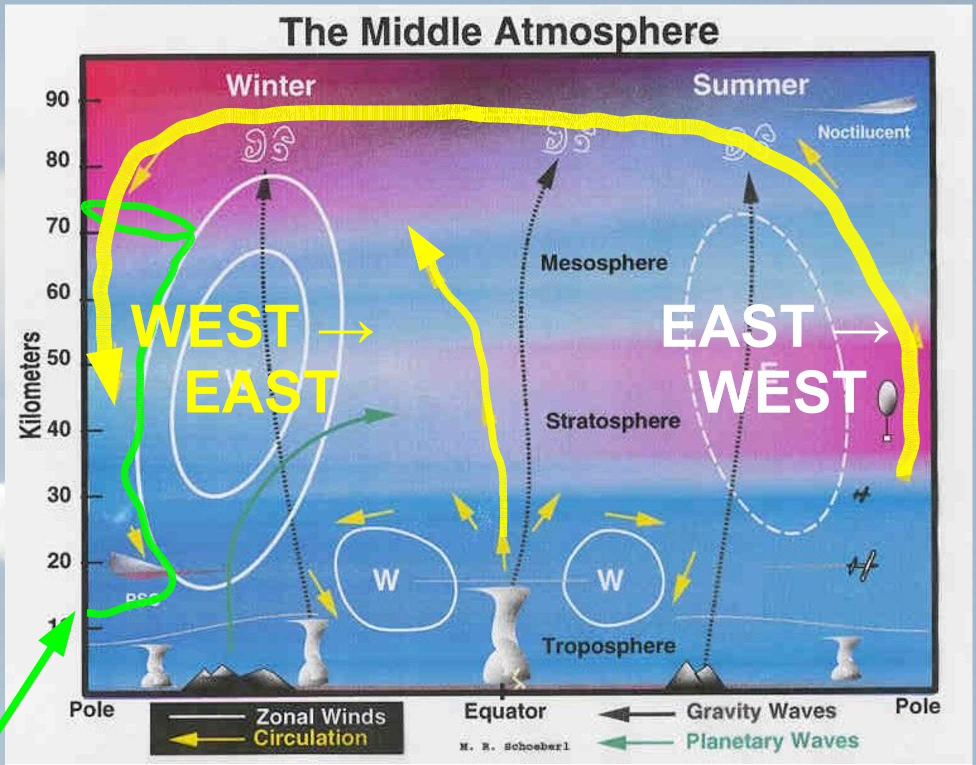
$$\text{Net: } 2O_3 \rightarrow 3O_2$$

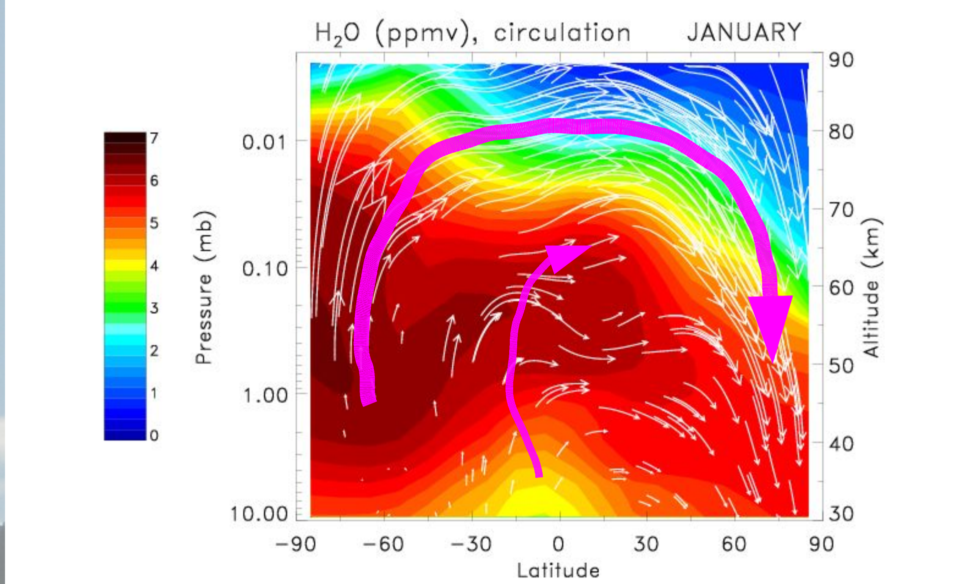
p, e* + N_2 → ionchemistry → NO_x

For detailed information see the presentation by Pekka Verronen

Dynamics

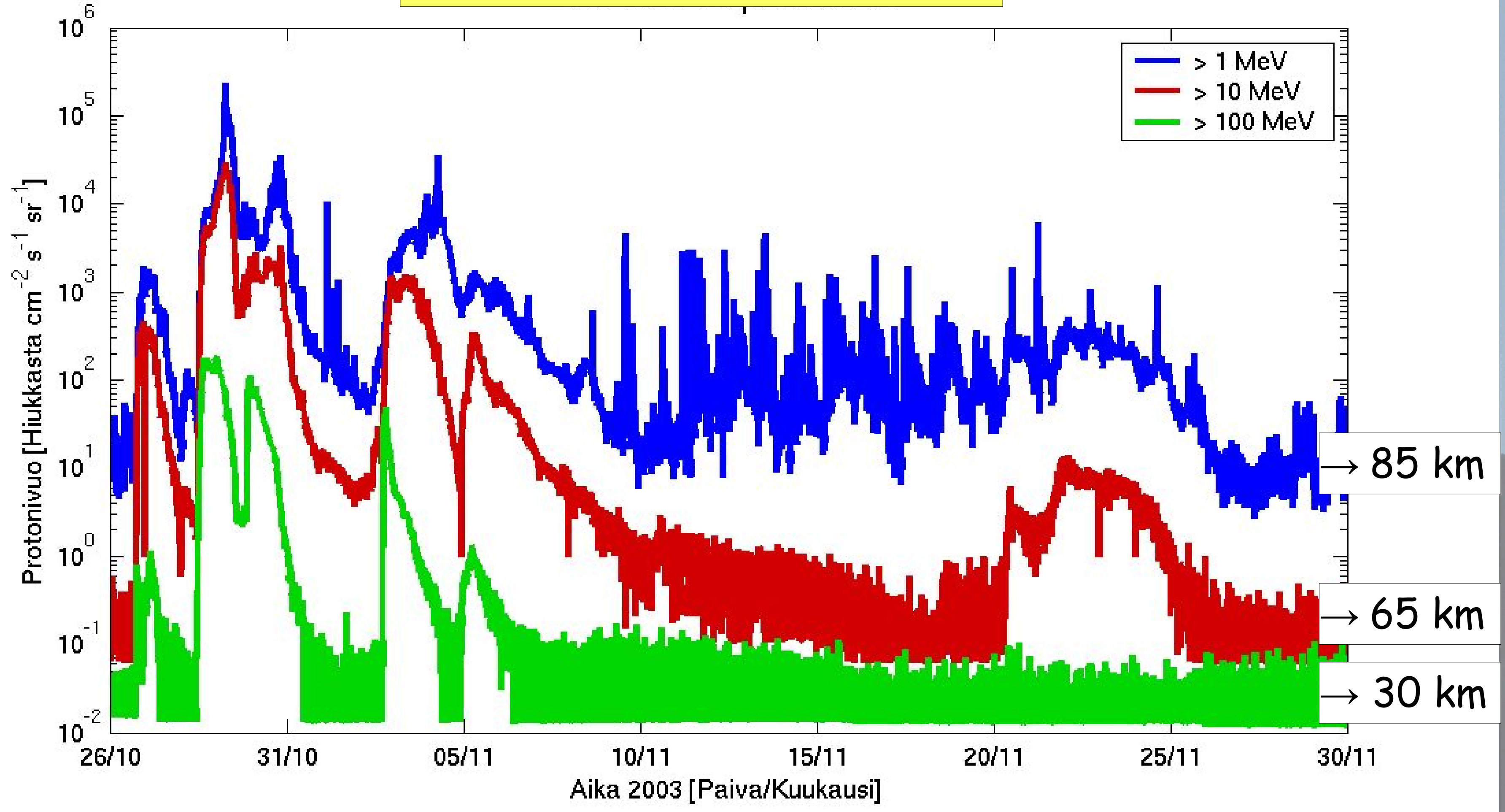
- Simplified circulation in the middle atmosphere:
  - Rising motion in the equator and in the summer pole
  - Downward transport in the winter pole
- Isolated polar vortex formed during winter in the stratosphere – allows large-scale descend



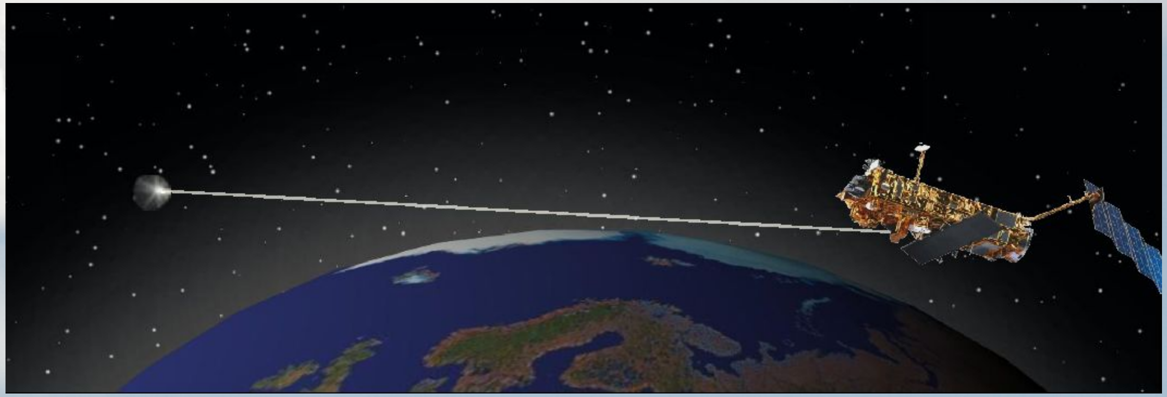


Oct/Nov 2003 Solar Storms

GOES/SEM Proton Flux



Used measurements: GOMOS

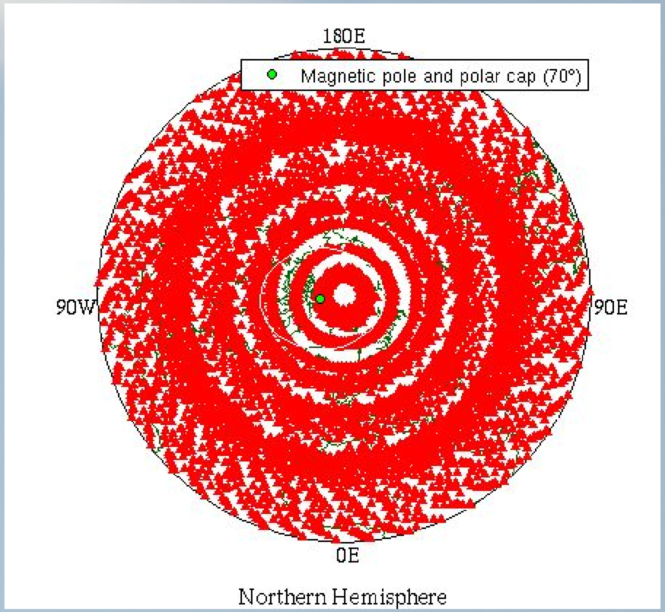


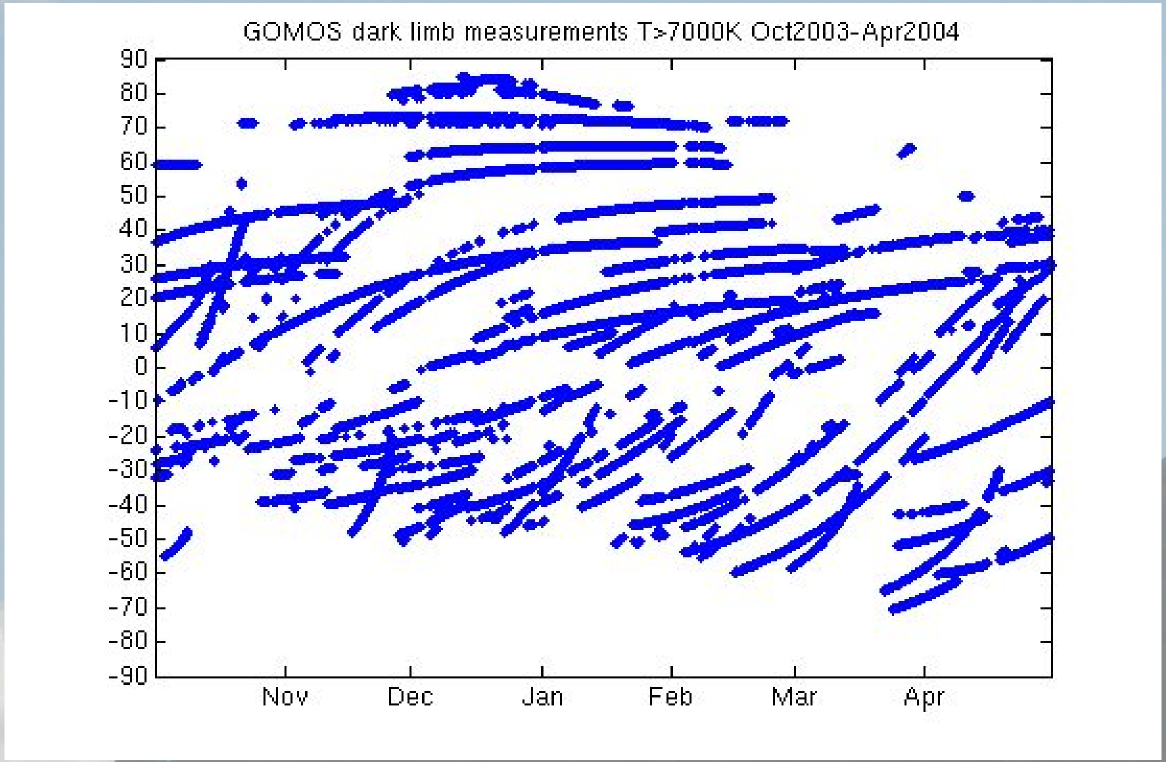
- Stellar Occultation instrument
- Night time O_3 and NO_2 measurements
- All measurements are from occultations where T_{star} > 7000 K (improves accuracy)
- Total number of measurements Oct03-Apr04: 25 949

Available measurements

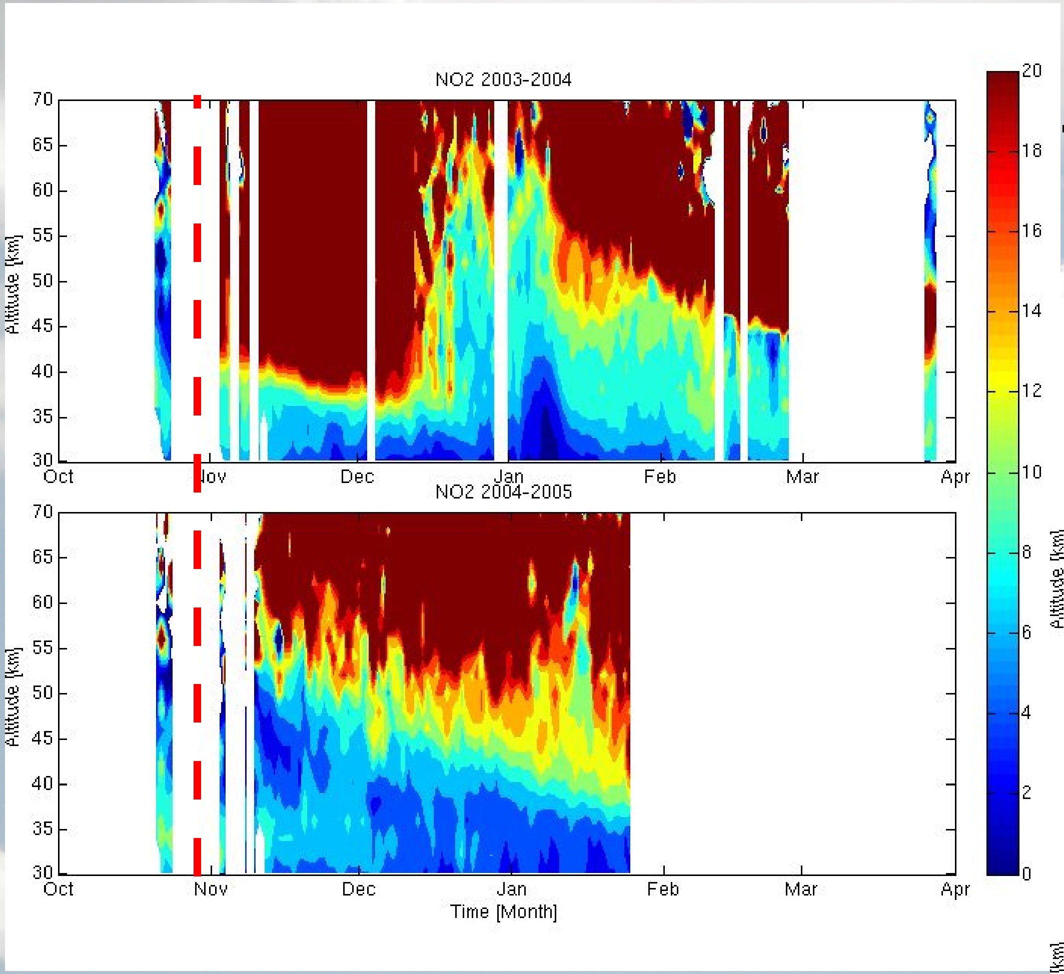
Measurement locations depend on the selection of stars used in occultations

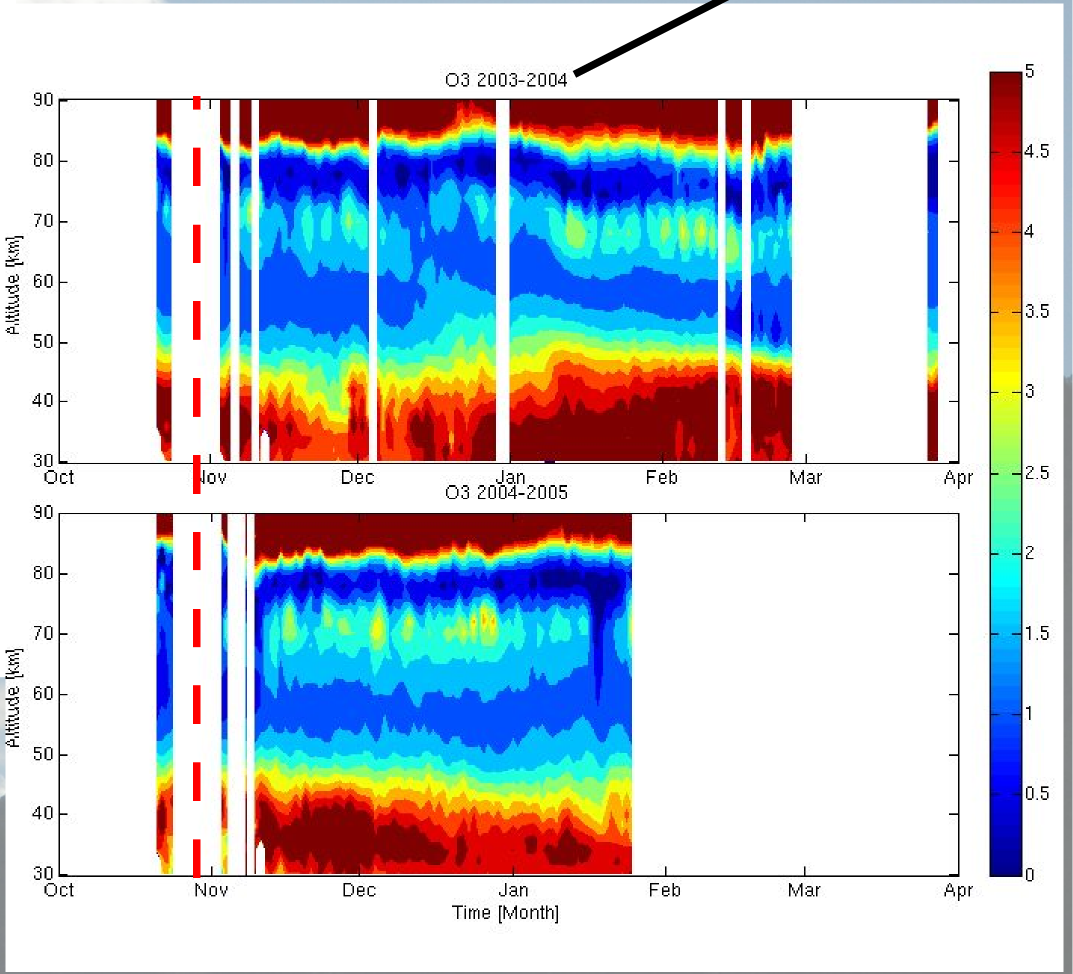
Oct-Dec 2003

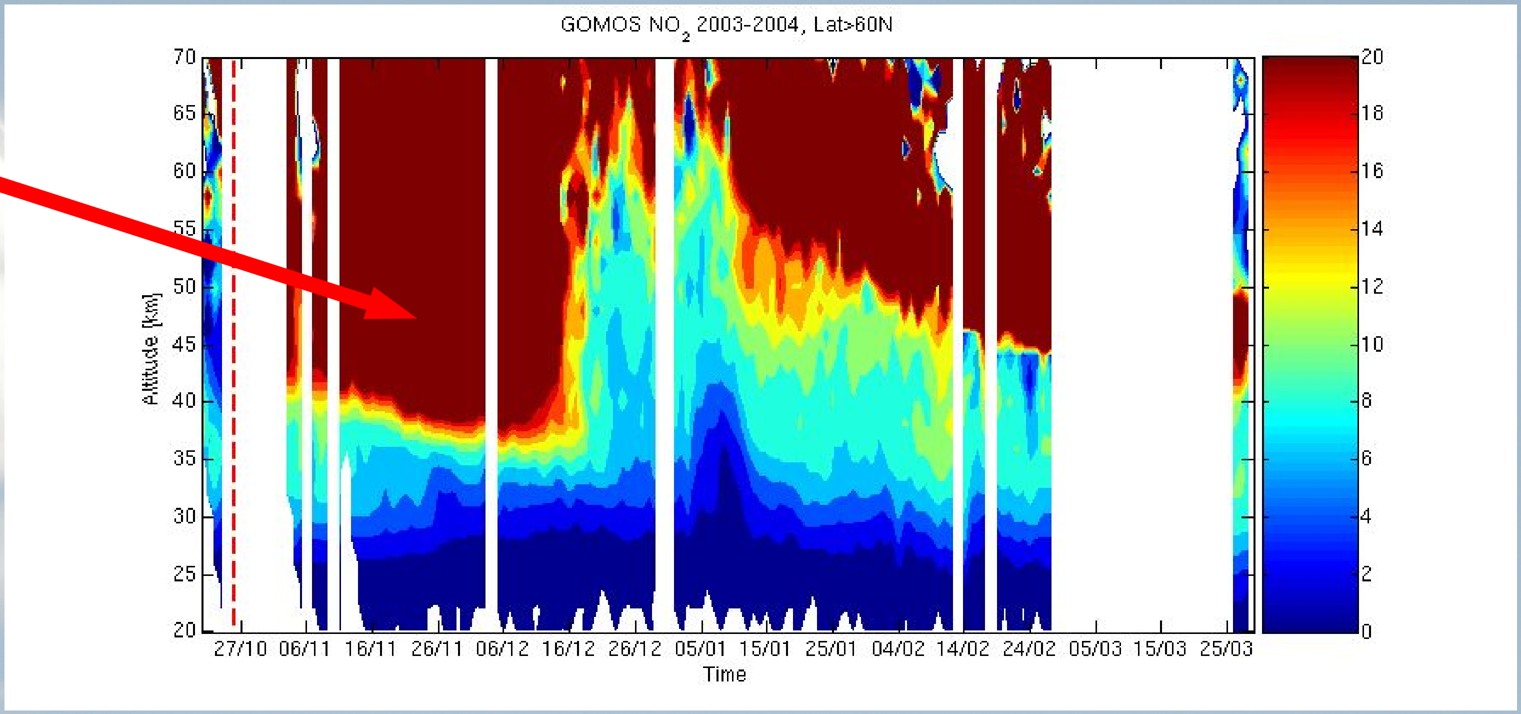




GOMOS NO_2 & O_3 Northern Hemisphere






GOMOS NO2 2003-2004, Lat>60N
Altitude [km]
70
65
60
55
50
45
40
35
30
25
20
27/10 06/11 16/11 26/11 06/12 16/12 26/12 05/01 15/01 25/01 04/02 14/02 24/02 05/03 15/03 25/03
Time
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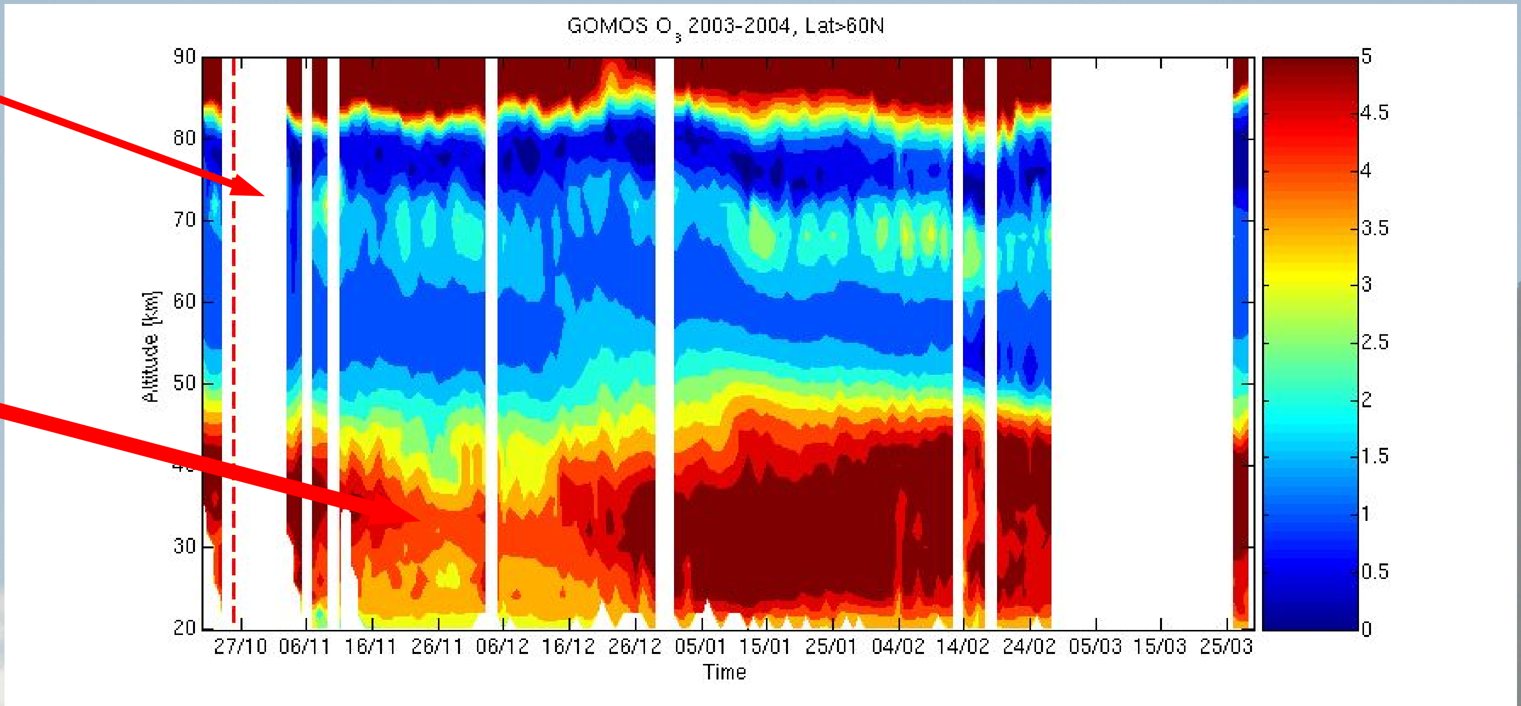
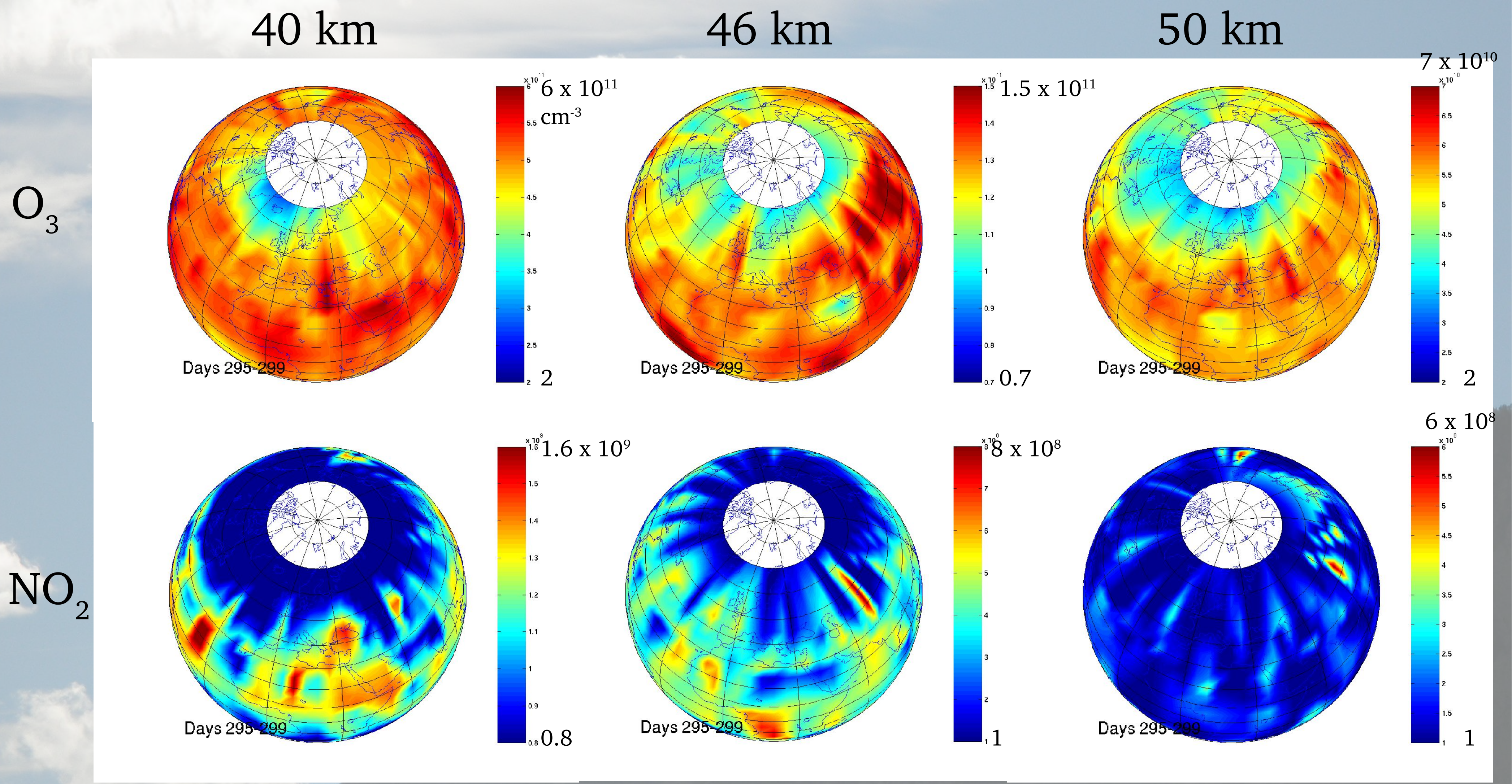

GOMOS O3 2003-2004, Lat>60N
Altitude [km]
90
80
70
60
50
30
20
27/10 06/11 16/11 26/11 06/12 16/12 26/12 05/01 15/01 25/01 04/02 14/02 24/02 05/03 15/03 25/03
Time
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0

O_3 and NO_2 – October before SPE

Each plot shows 5 days of measurements

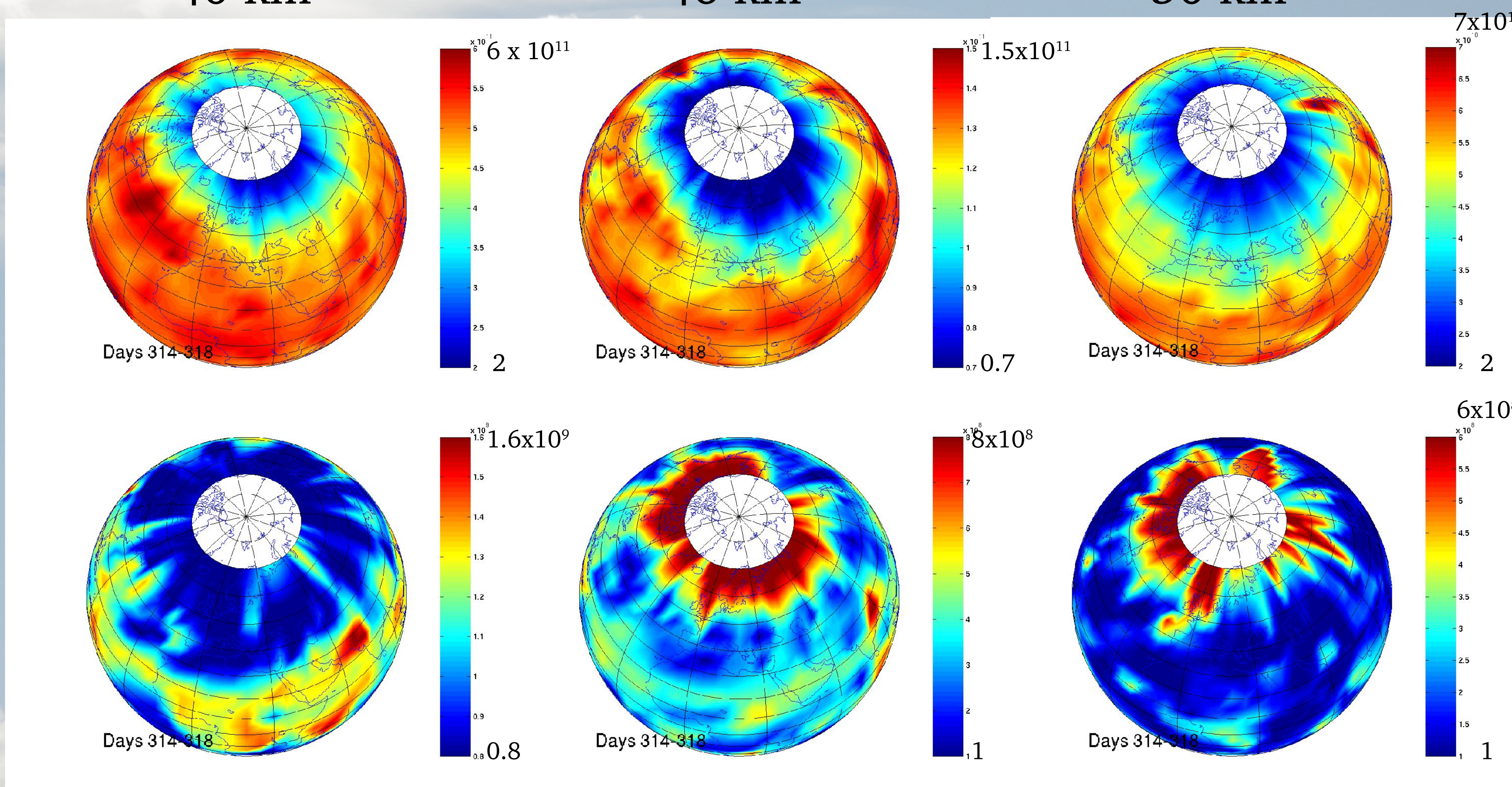


O_3 and NO_2 - November

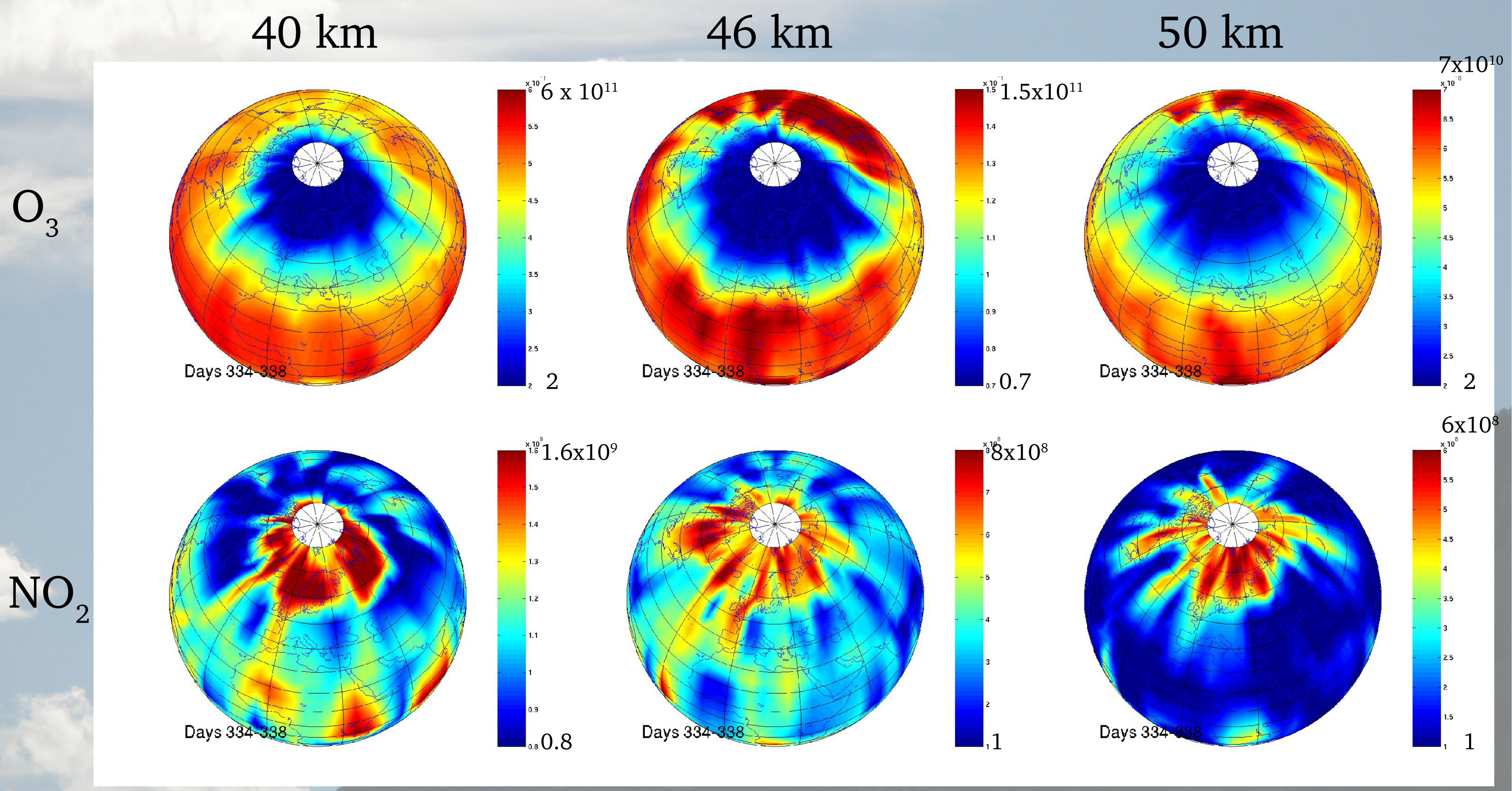
40 km 46 km 50 km

O_3

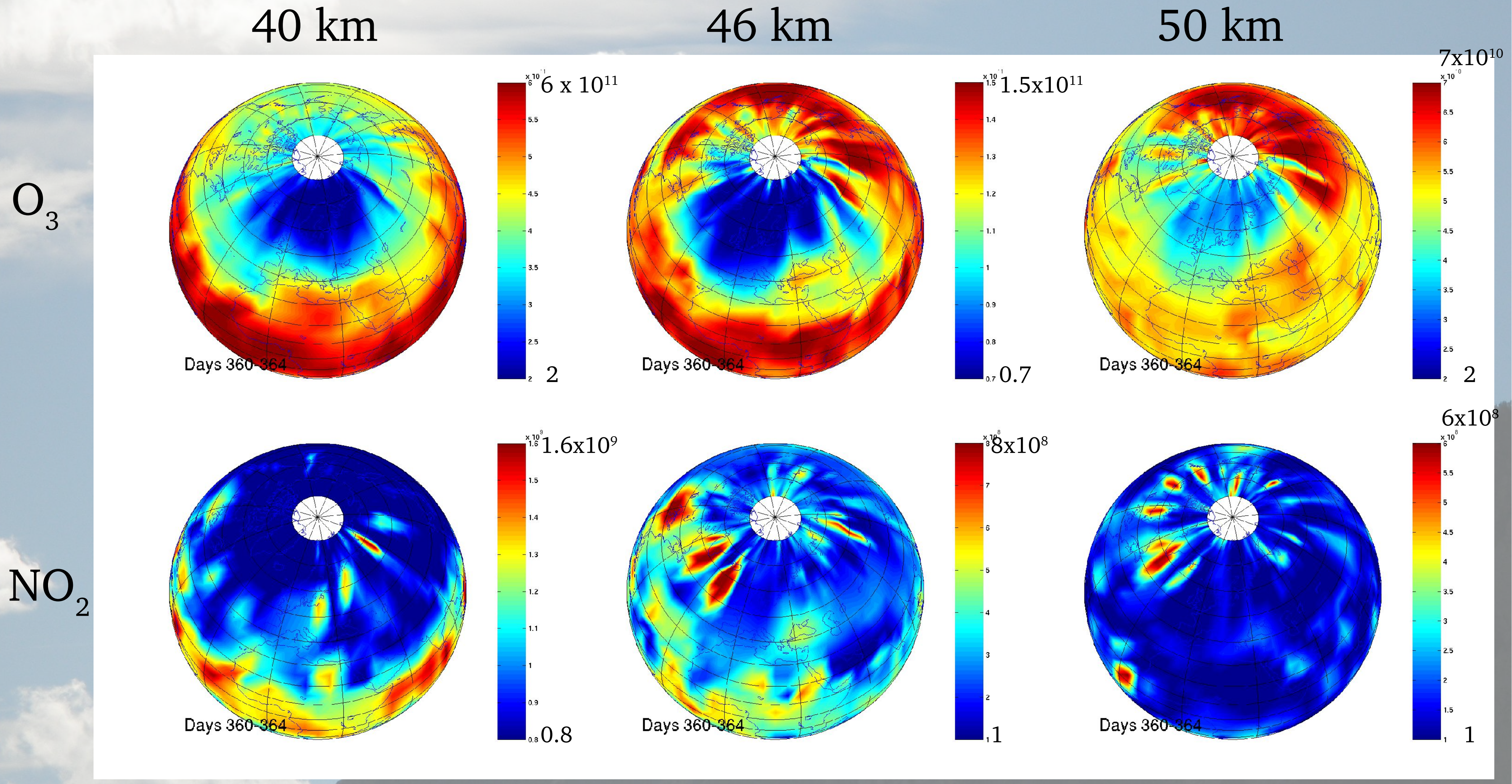
NO_2



O_3 and NO_2 – Early December



O_3 and NO_2 – End of December



Column density 36-50km (70N-75N)

O_3

- GOMOS

-- FinRose-CTM

(no protons)

-.-Climatology

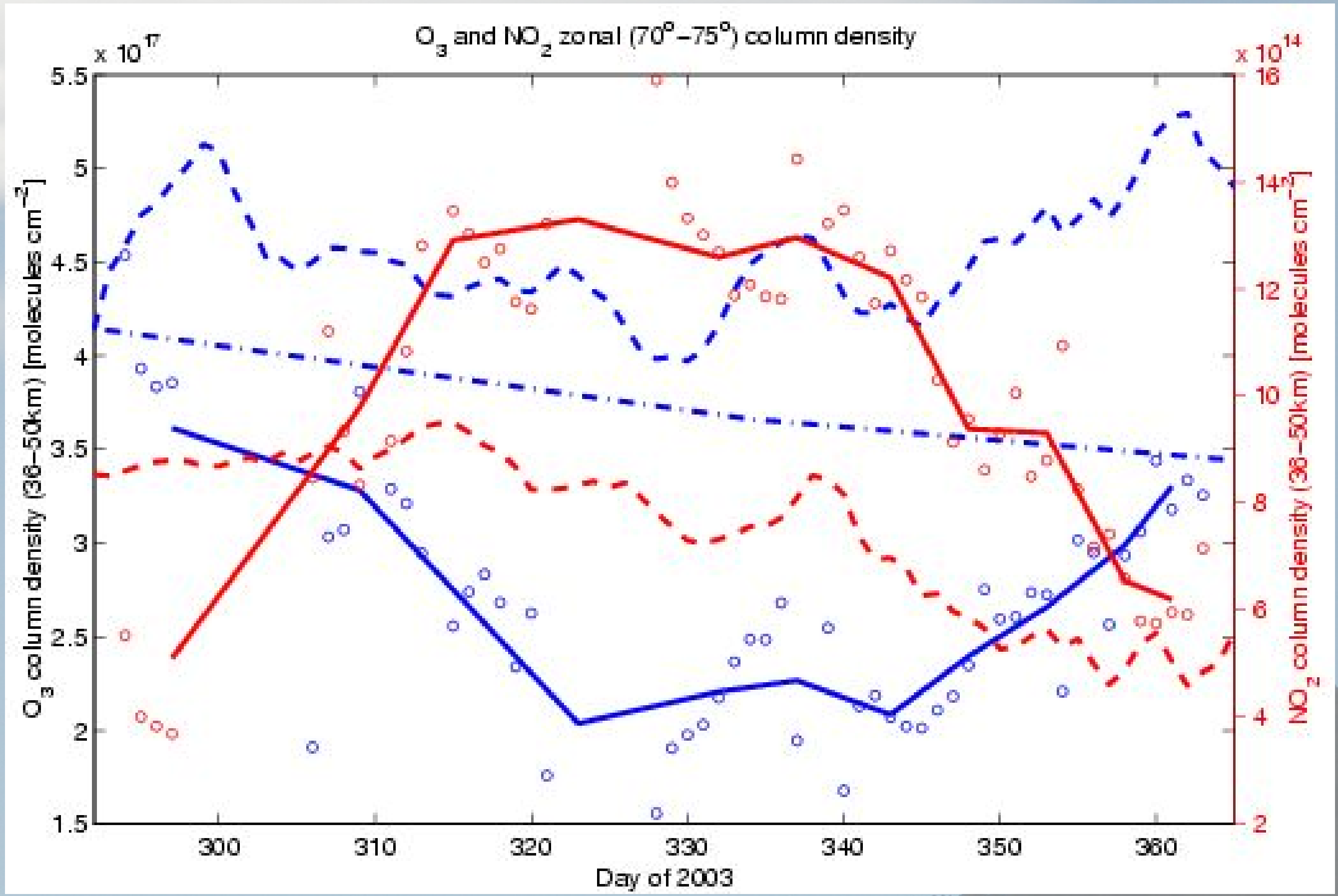
(no protons)

NO_2

- GOMOS

-- FinRose-CTM

(no protons)



(Seppälä *et al. Geophys. Res. Lett.*, 2004)

Column density 36-50km - Scandinavia

O_3

- GOMOS

-- FinRose-CTM

(no protons)

-.-Climatology

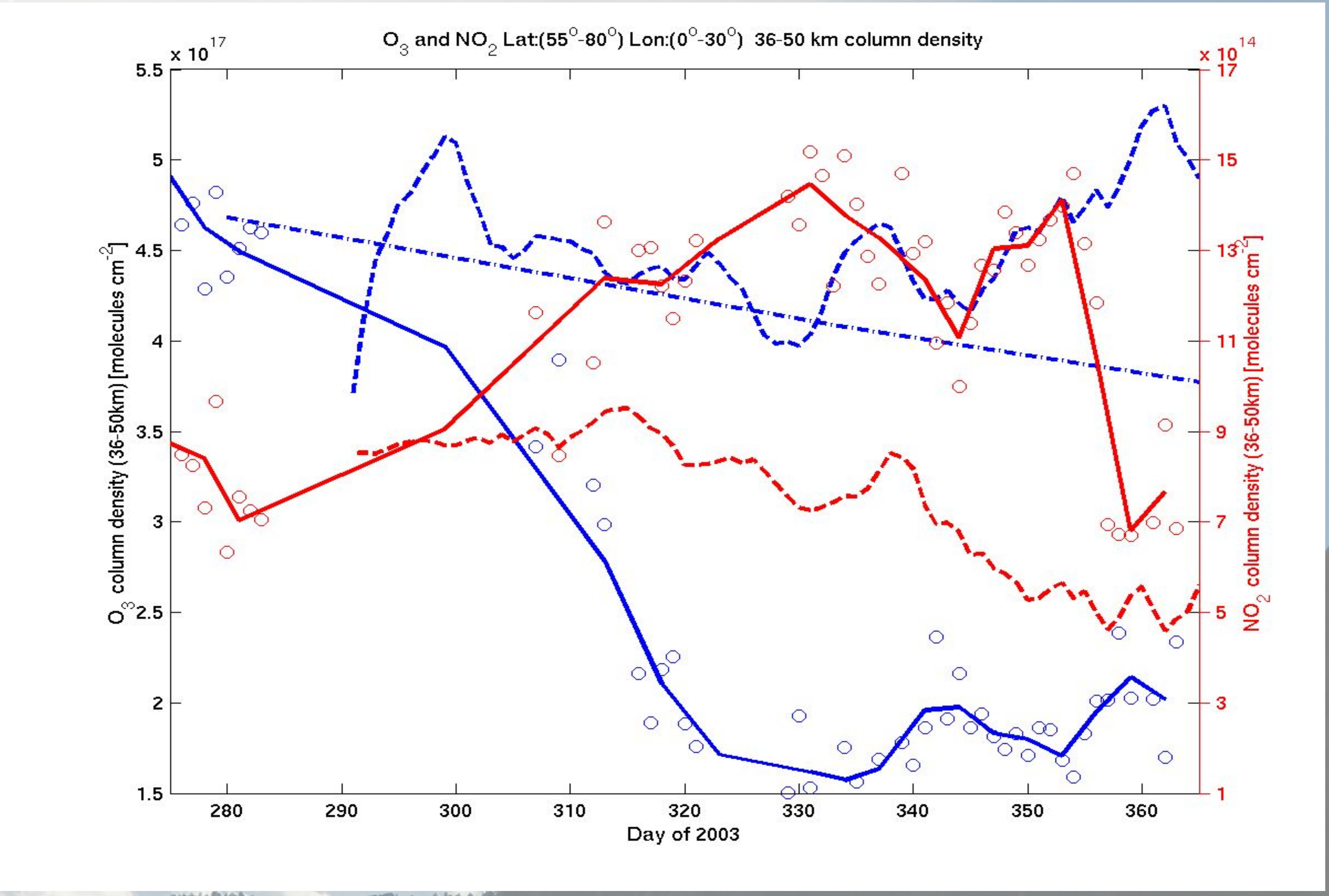
(no protons)

NO_2

- GOMOS

-- FinRose-CTM

(no protons)



Open Questions

What are the long term effects (years) of particle precipitation on atmospheric dynamics and temperature?

- Some model studies have been published, first measurement papers to come..

The role of lower energy particle precipitation in observed winter time NO_x enhancements?

- Satellite observations (from recent years) of large NO_x enhancements in the winter pole, not related to solar storms
- Effect on ozone?

Further reading and references

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