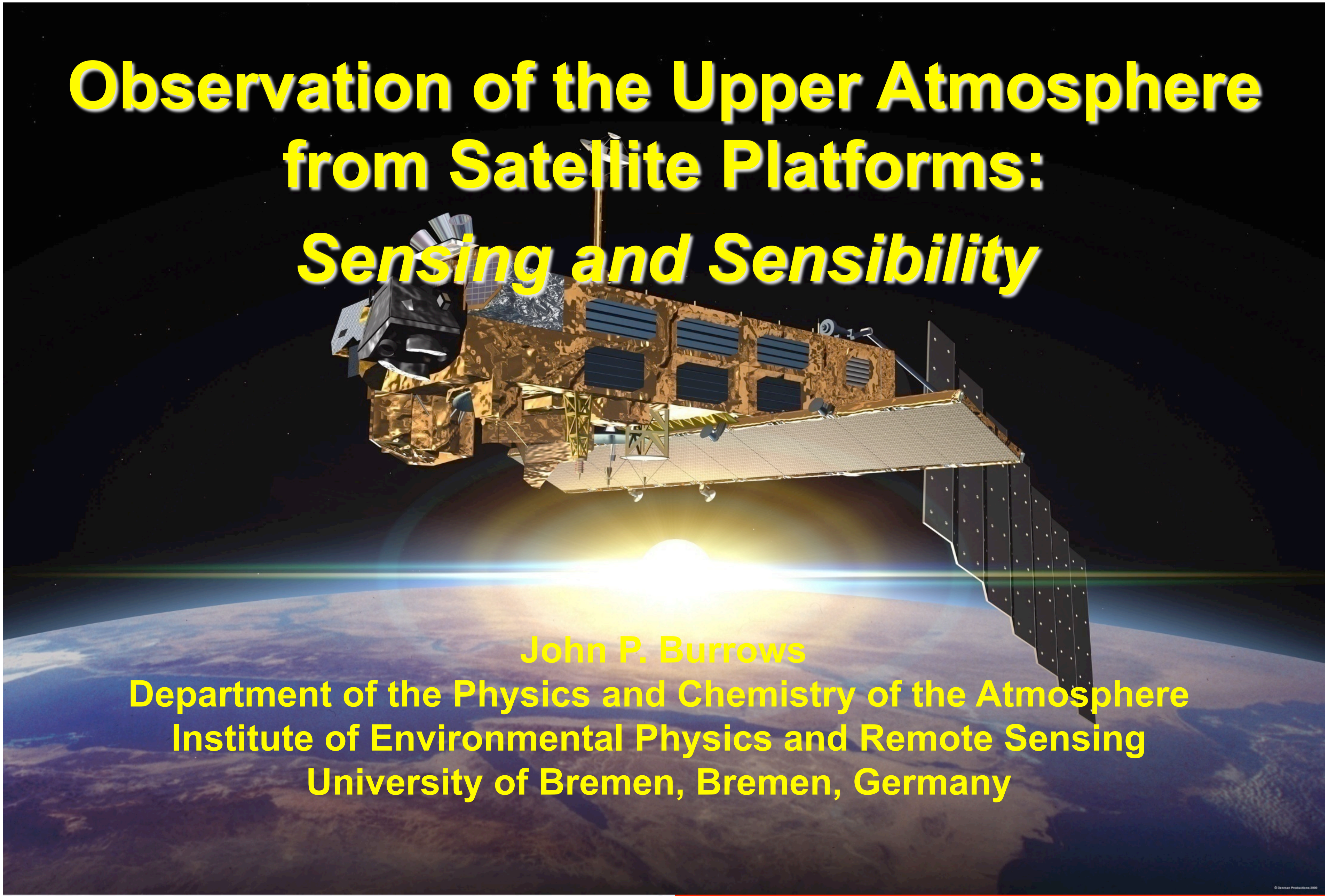

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Observation of the Upper Atmosphere from Satellite Platforms:

Sensing and Sensibility

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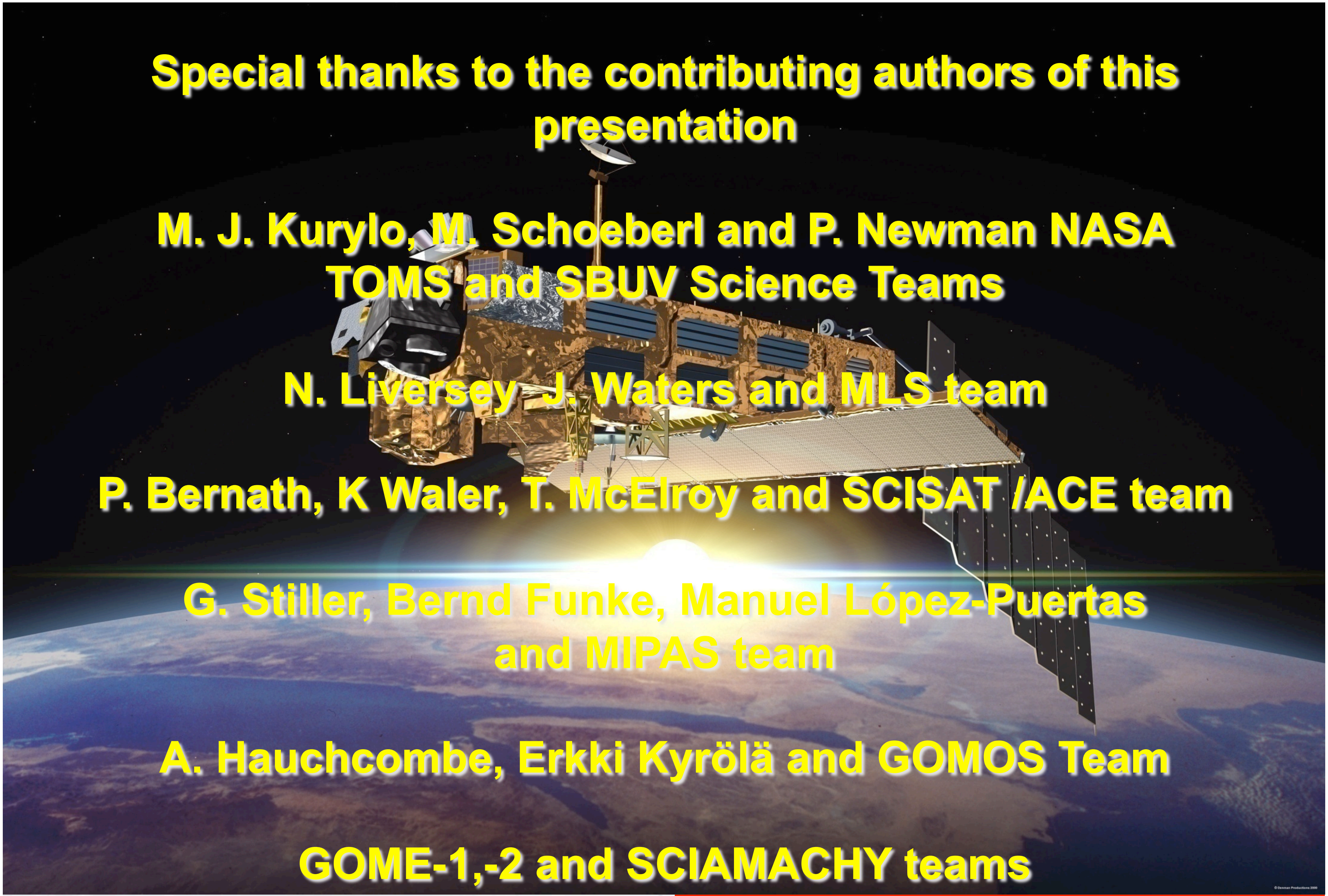


Special thanks to the contributing authors of this presentation

M. J. Kurylo, M. Schoeberl and P. Newman NASA
TOMS and SBUV Science Teams

N. Liversey J. Waters and MLS team

P. Bernath, K Waler, T. McElroy and SCISAT /ACE team

G. Stiller, Bernd Funke, Manuel López-Puertas
and MIPAS team

A. Hauchcombe, Erkki Kyrölä and GOMOS Team

GOME-1,-2 and SCIAMACHY teams

A Golden Pioneering Age of Upper Atmospheric Remote Sensing from Space - the first 50 years

Who are the potential space segment providers?

A) Large Space Agencies for Earth Observation

1957-1959	Sputnik launch Soviet SP later RSA – NASA founded
1963-1975	Europe - Evolution of ESRO/ELDO to ESA
1983-1986	Formation of EUMETSAT for operational obs.
1994-	Formation of NPOESS NOAA/DOD/NASA for operational obs.
1955-2006	Japan- Evolution of JAXA

B) National Agencies

1962-1989	Canada – Evolution to CSA
1960-present	Evolution of National programmes CNES, DLR, NIVR, BNSC (UK), Sweden, Belgium, China, India, Korea etc.

AGolden Pioneering Age of Upper Atmospheric Remote Sensing from Space - the first 50 years

What has been provided!

Soviet

1960 First attempts at O3 monitoring

NASA Ozone Nadir sounding

1963 – 1993 Nimbus 1 to 7 pioneering earth observation

1974 - SBUV-2 Nadir Sounding: BUV (N4) /SBUV(N7)/SSBUV NOAA

1979 – 2006 TOMS - N7, Meteor 3, ADEOS , Earth Probe

T, H2O Nadir Sounding in IR

1974 - SCR (N5) N6

NASA Limb sounding T profile

1976-1988 N6 LRIR - N7 LIMS

A Golden Pioneering Age of Upper Atmospheric Remote „Sensing from Space the first 50 years

What has been provided!

NASA + partners

1979 – 2006 Solar and later Lunar occultation
On different platforms SAMII, SAGE1, II and III
1981 -1989 Explorer: SME - LASP
1985-1994 ATLAS including ATMOS (FTIR) 4 Shuttle Flights
1991 - 2005 UARS (Upper atmospheric research satellite)
Atmospheric composition and T: CLAES, HALOE, ISAMS (UK), MLS
0Winds HRDI and WINDII (CSA)
1998-2003 Explorer: SNOE - LASP

ESA

1995-2003 GOME on ERS-2 ,
Mesospheric Composition: metal emissions, NO
stratospheric composition O3, NO2, OCIO, BrO
troposheric Composition : O3 NO2, SO2, HCHO, (CHO.CHO), H2O cloud (and aerosol) parameters

A Golden Pioneering Age of Upper Atmospheric Remote Sensing from Space
the first 50 years

What has been provided!

JAX
199
200

SNS
200

CSA
200

ESA
200

NAS
200
200
200
200

EUM
200

Major Missions/Initiatives in Planning/Delivery Phases

- 2009 onwards NPOESS + NPP: OMPS 2009 focus NWP

- 2013 onwards NASA Decadal Survey – Missions All EO

- 2020 onwards EUMETSAT/ESA/EU 2018 Post-Metop + GMES Sentinel 5

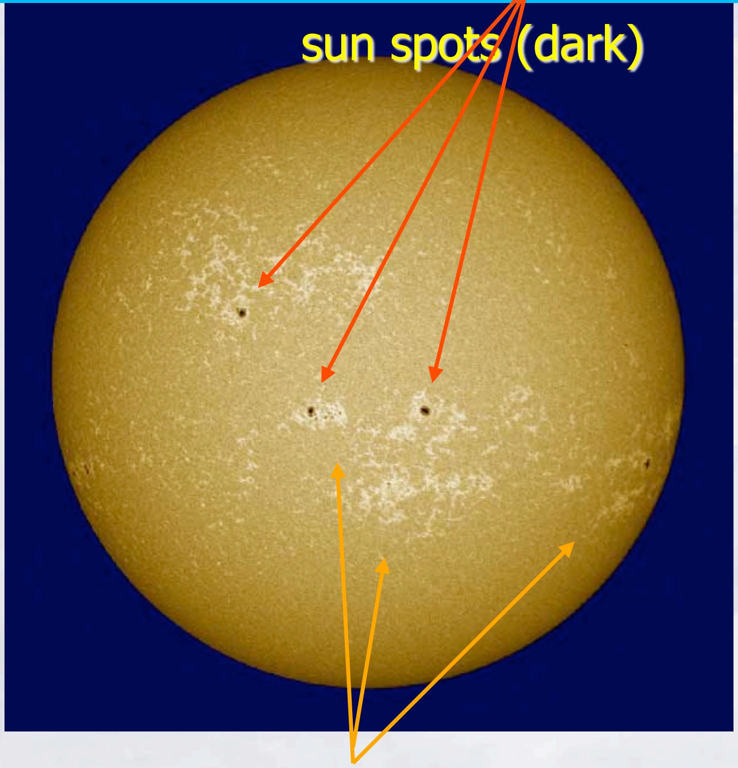
All Excellent missions but current planning results in a reduction in capability in the next decade compared to past decade

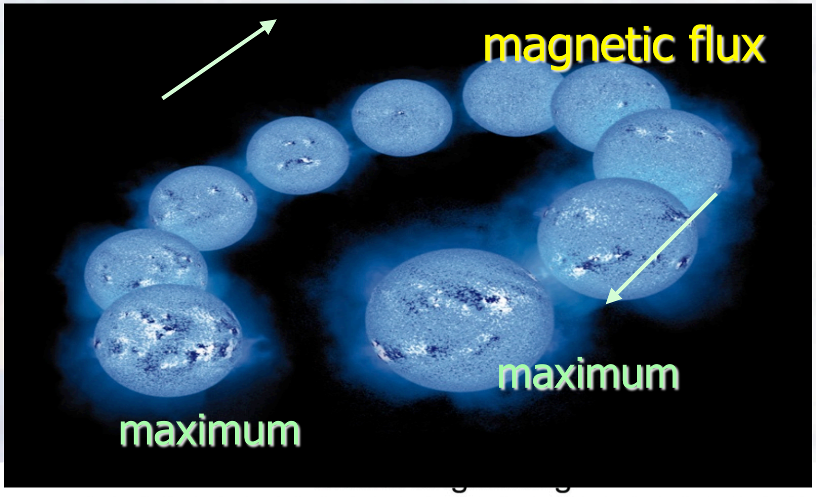
Mainly Nadir sounding - Loss of Occultation

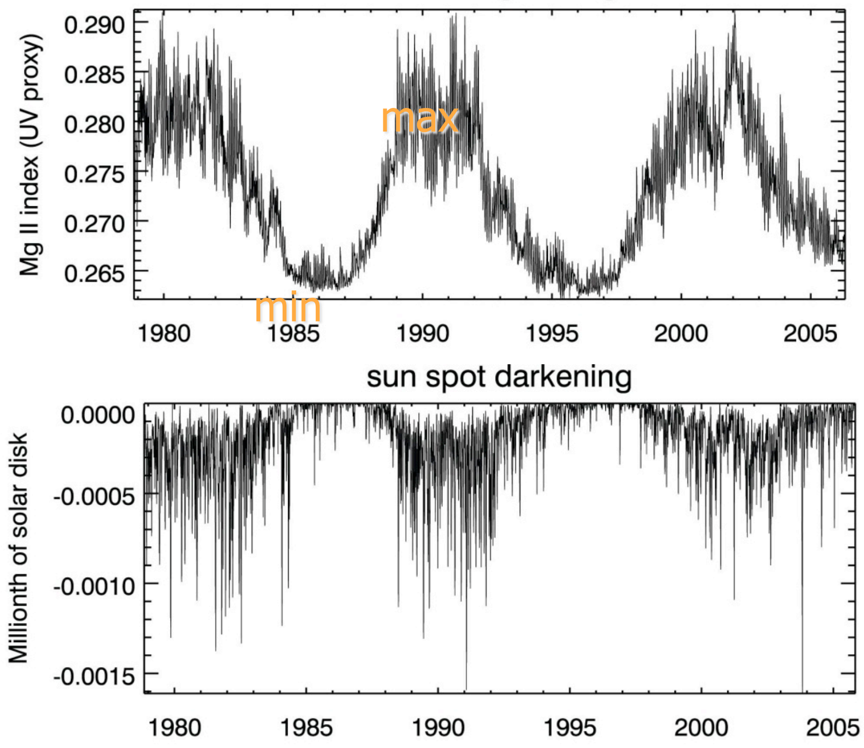
Bologna, Italy

What are the sources for irradiance variations?

- Main contributions come from magnetic surface features

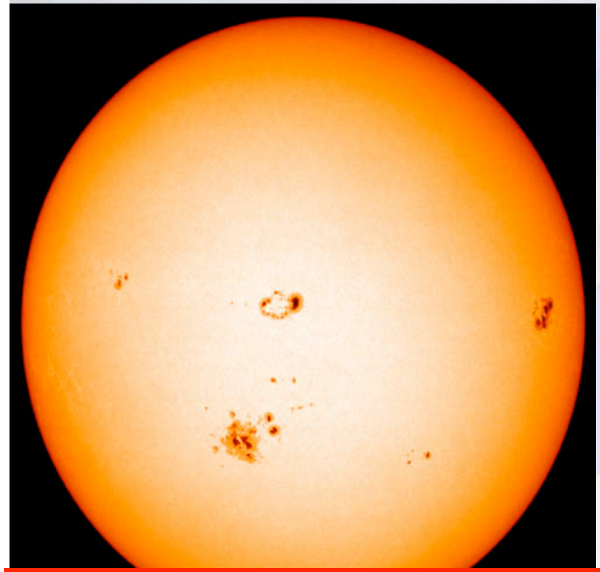






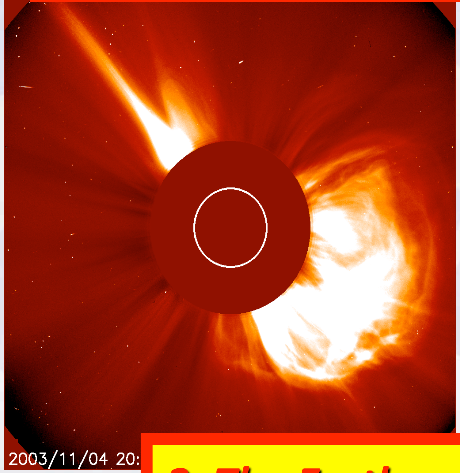
Science #1: Solar Emissions ⇔ Atmosphere

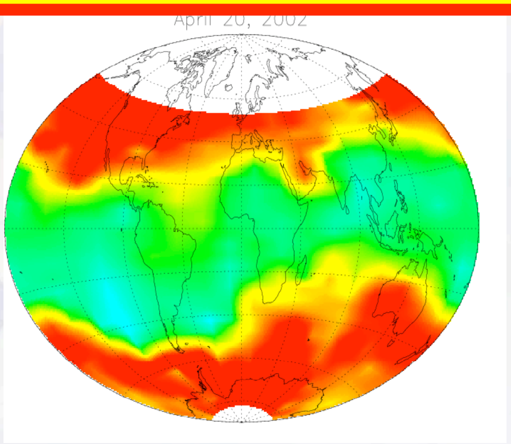
1) **Changes in Solar Emission in particular in the UV**
2) **Coronal Mass Ejections and Solar Proton Events: Example Oct-Nov 2003**



1. **Two solar active regions during 28-29 Oct and 3rd Nov 2003 produced solar flares, coronal mass ejections (CMEs) and solar energetic particles of unprecedented intensity.**

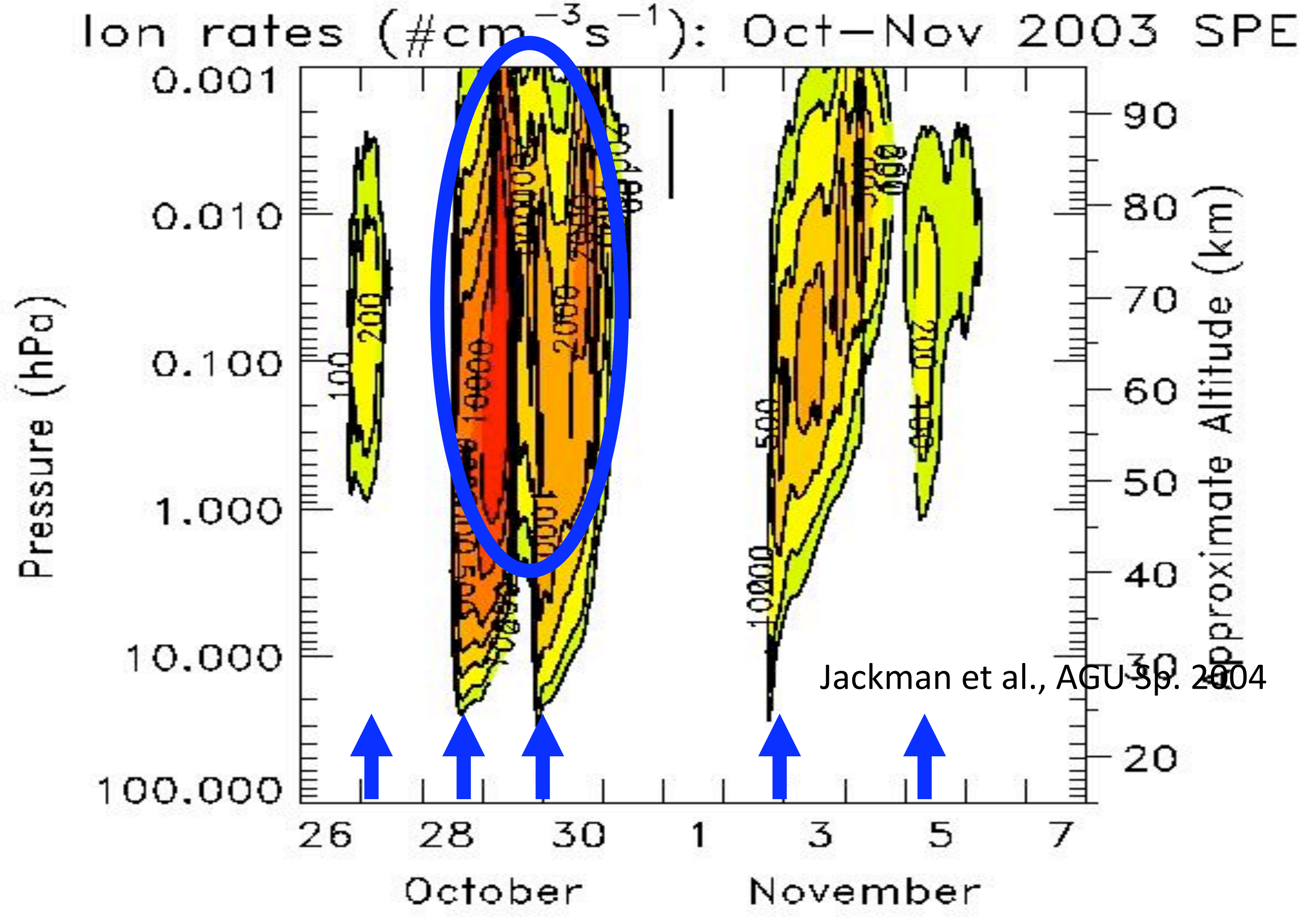
2. CMEs arrived at Earth in 1-2 days producing huge geomagnetic storms and important effects on atmospheric composition in the polar regions.





3. The Earth was bombarded by very energetic protons (and electrons), driven by the earth's magnetic field to both polar regions (g. lat.>60º) where they penetrate down to the lower stratosphere.

Estimated Ion Depostion Rates



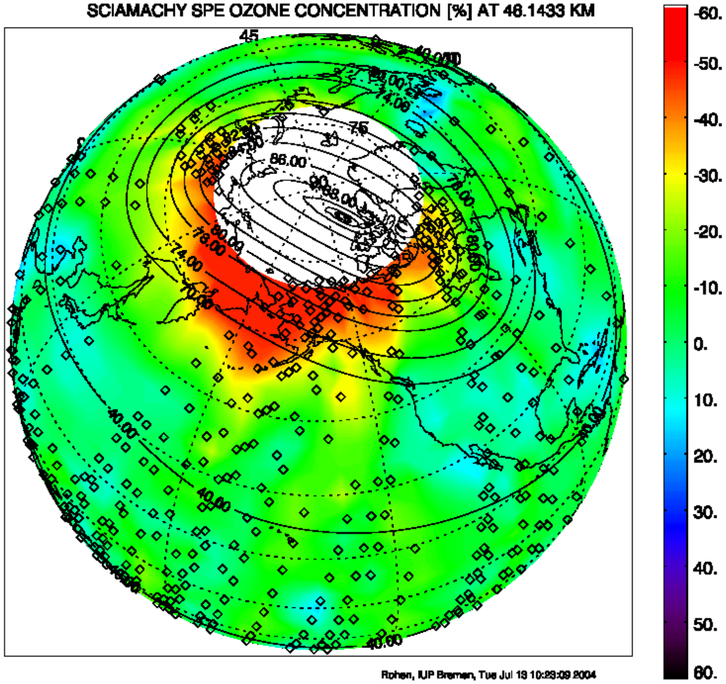
Jackman et al., AGU Sp. 2004

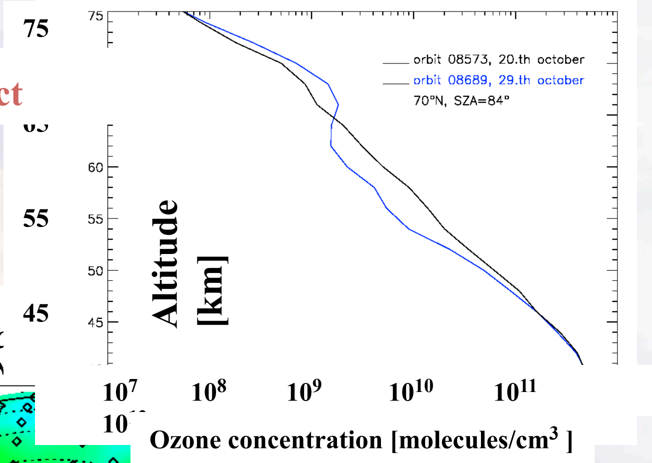
SCIAMACHY: O_3 depletion during Halloween SPE

Reference period: 20.-24.Oct. 2004

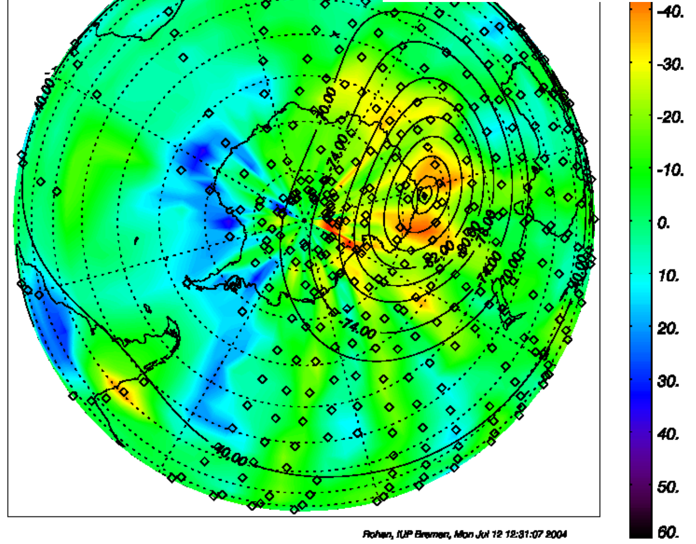
Ozoneprofile at 20. and 29.Oct

SPE event 28.Oct.-6.Nov..2003





SPE event 28.Oc



MIPAS: Solar influence on climate observations during "Halloween" SPE Oct/Nov 2003

NO_x

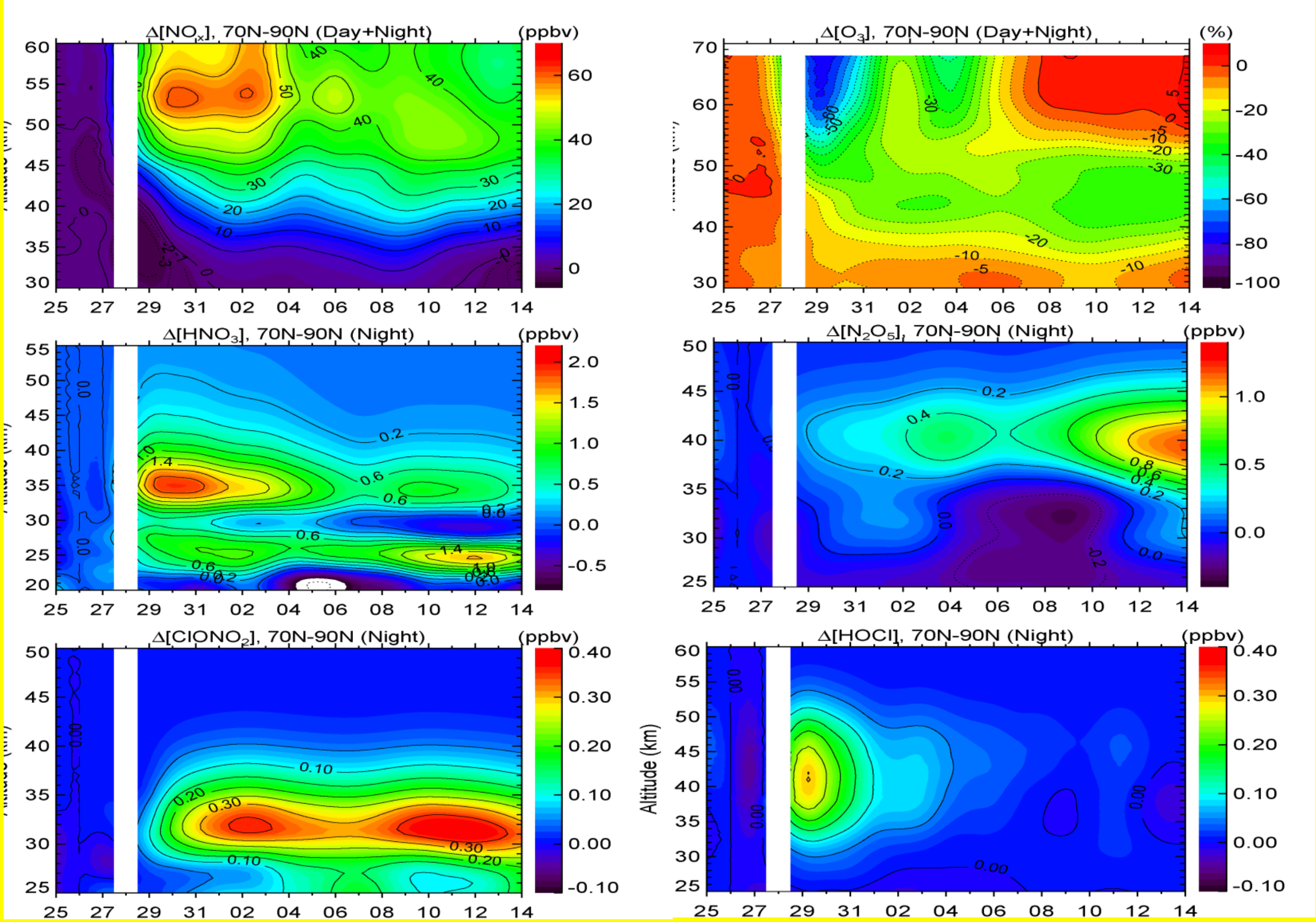
O_3

HNO_3

N_2O_5

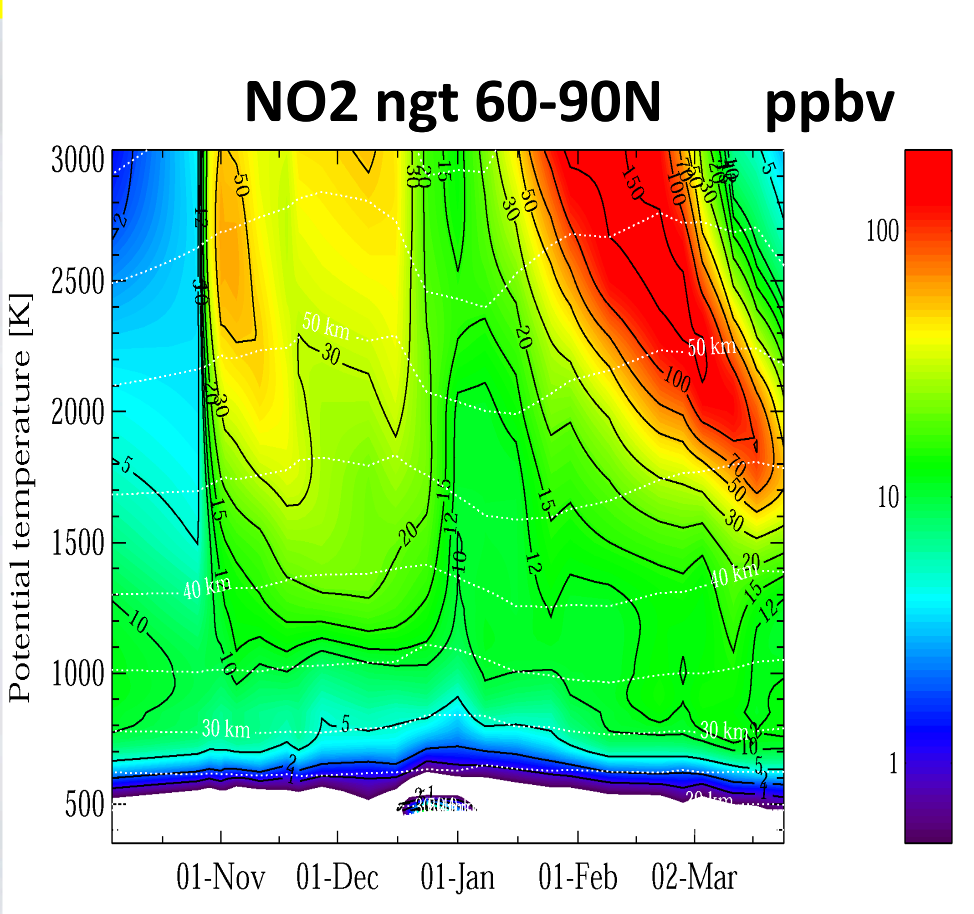
$ClONO_2$

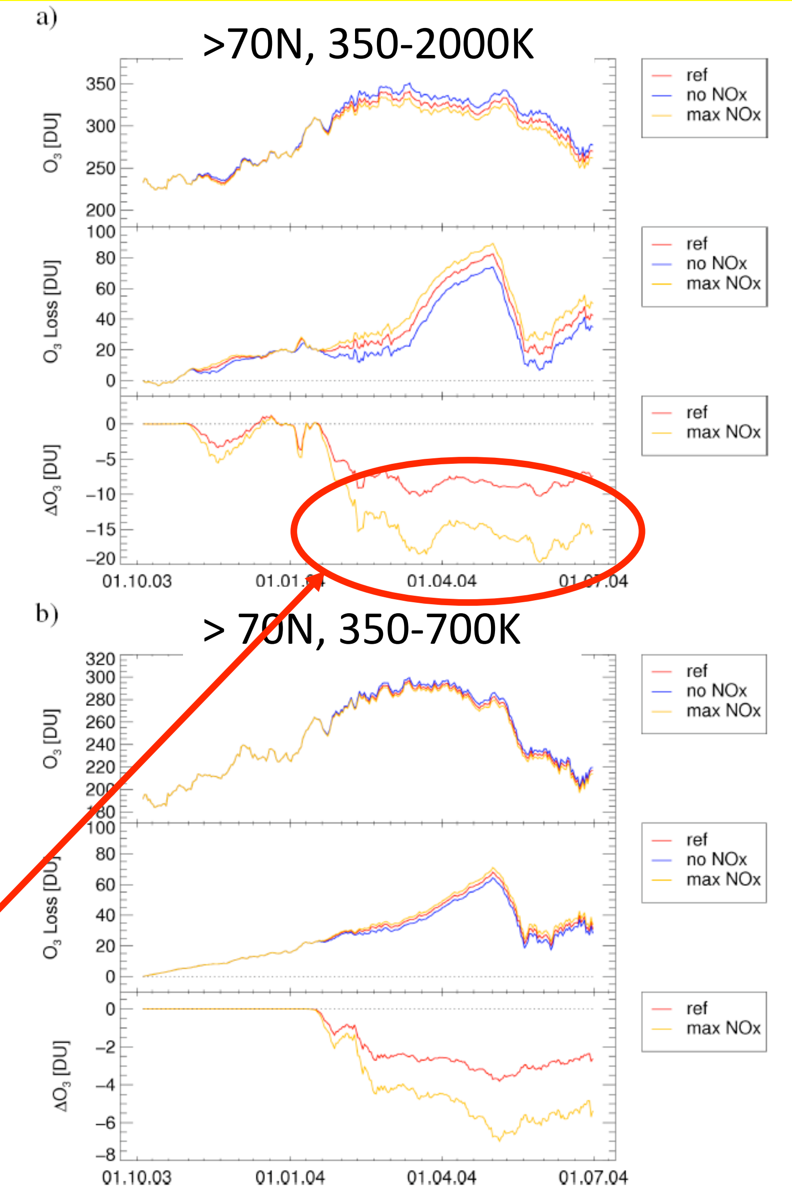
HOCl



Lopez-Puertas et al., JGR-A, 2005 a,b; von Clarmann et al., JGR-A, 2005

MIPAS Energetic particle precipitation and its impact on stratospheric ozone chemistry

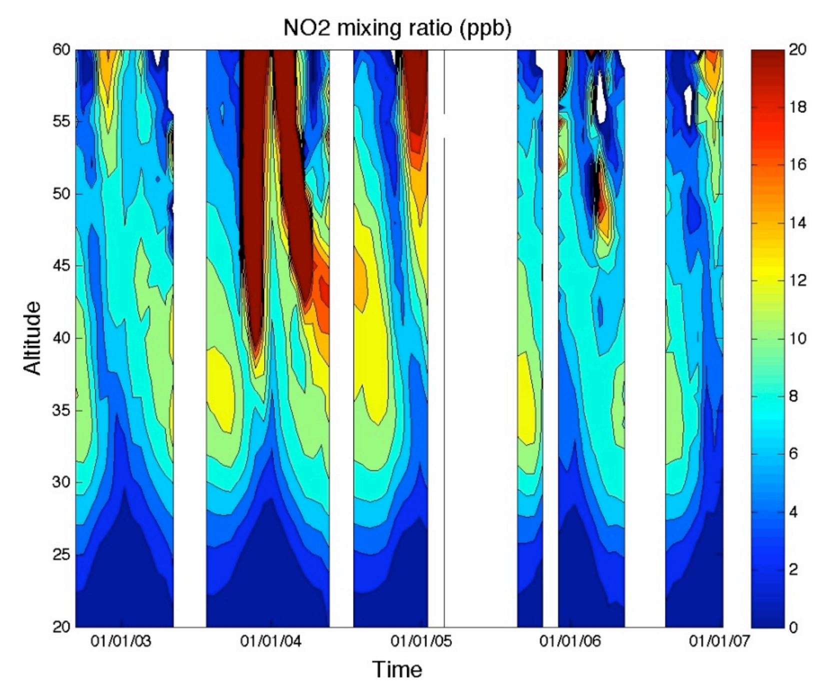




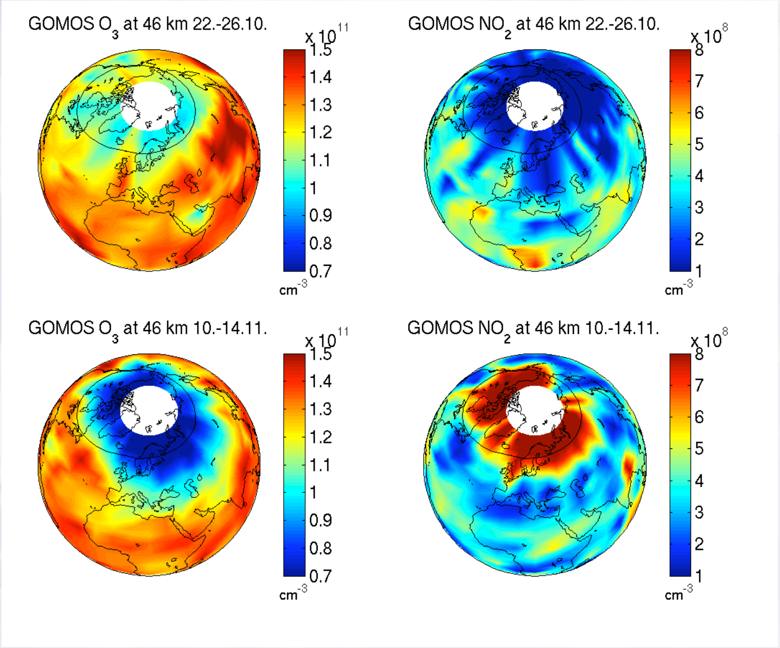
Downward transport of EPP produced NOx from MLT during Arctic winter 2003/2004
Impact on the stratospheric ozone budget:
Additional loss of ~ 20 DU ozone

Vogel et al., ACPD 2008

GOMOS: Particle precipitation and stratospheric NO_2 and O_3



Solar protons precipitating into Earth's atmosphere create ions, which modify the chemistry of the upper atmosphere. Locally large ozone losses are produced via the large increase of NO and NO_2.



Large intrusions of NO_2 into the stratosphere are common in polar atmosphere (here Arctic).

Seppälä, A., et al.,, GRL, 31, L19107, 2004.
Hauchecorne et al., , GRL, 34, L03810, 2007.
Verronen et al., GRL., 33, 24, L24811, 2006

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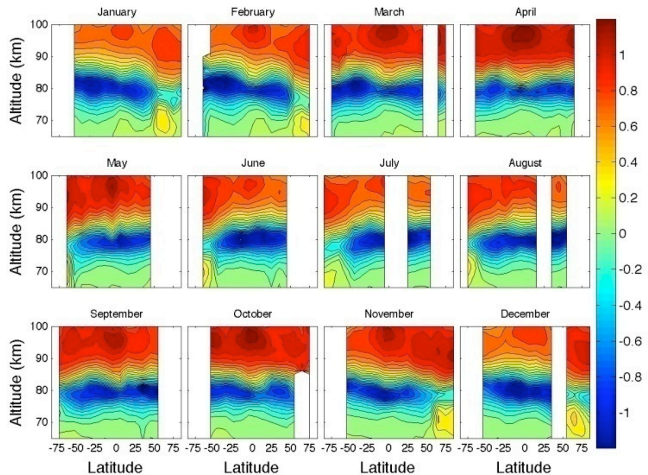
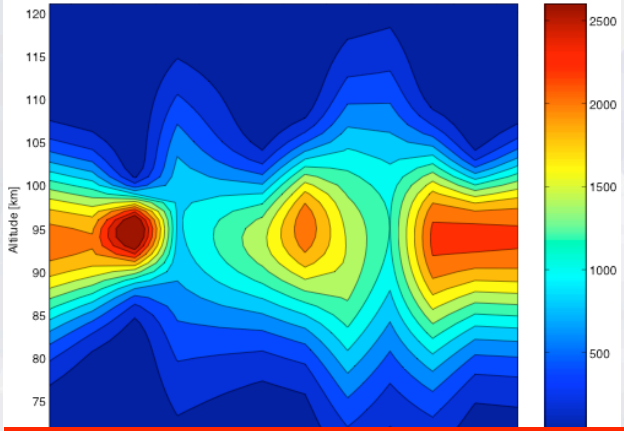
GOMOS:Mesospheric observations

O3 mixing ratio (log)



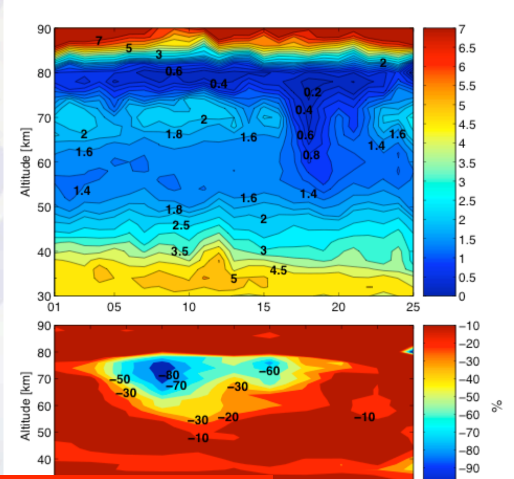
Ozone in the mesosphere and lower thermosphere has a large diurnal cycle. The values at night are much larger than during daytime. GOMOS observations provide an excellent data source for this region. The sodium layer and noctilucent clouds (NLC) have also been observed from GOMOS measurements.

Sodium layer



Fussen et al., GRL, 31, 24, L021618, 2004.

Destruction of tertiary zone maximum by solar protons



Seppälä et al., GRL, 33, 7, L07804, 2006.

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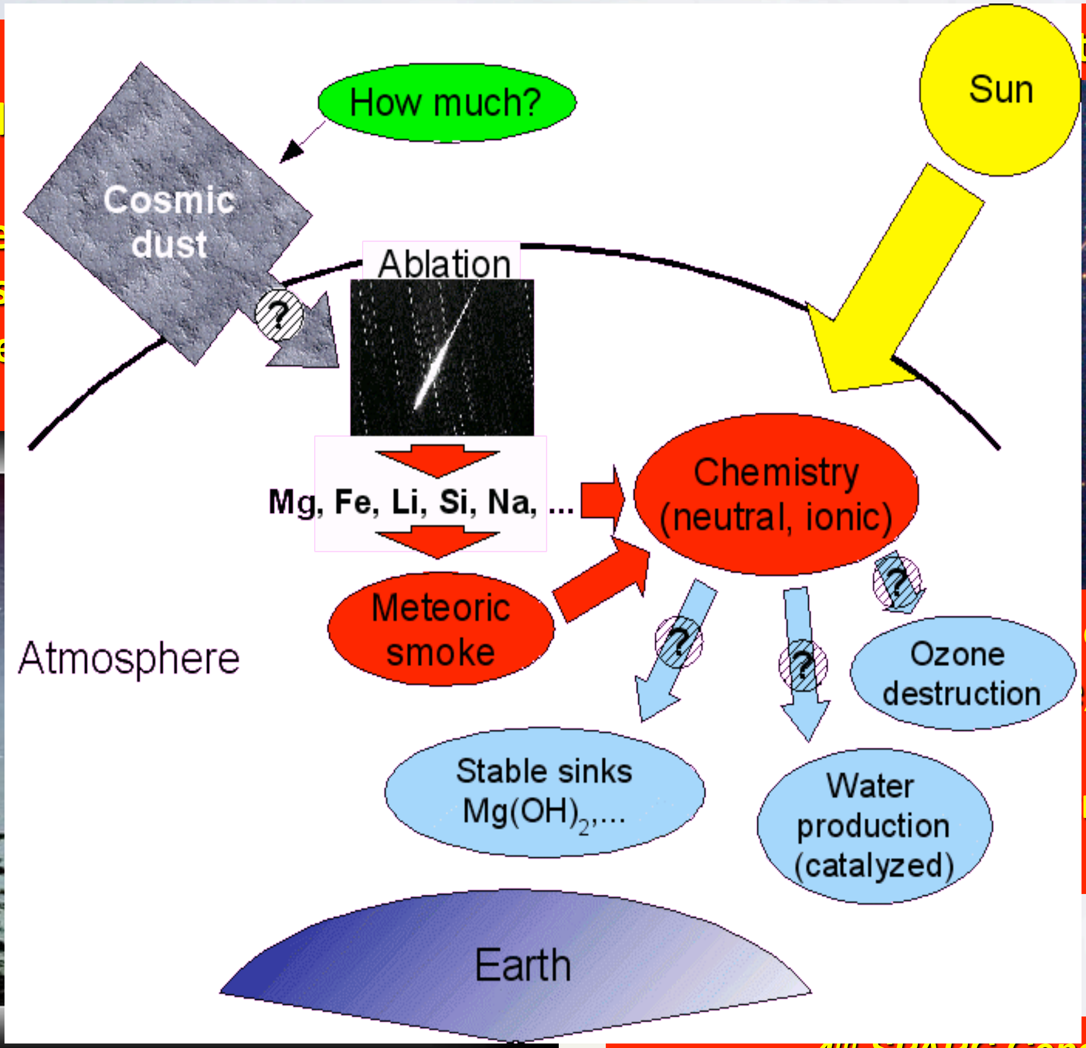
Science #2: Comets, Dust, Meteorites ⇔ Upper Atmosphere

Comets, (photo
leave a trail of d
the sun as their
sublimates. The
meteor showers
orbit crosses the



t 72 km s^{-1}

of the material
, originates from
Mars, and from
rails.

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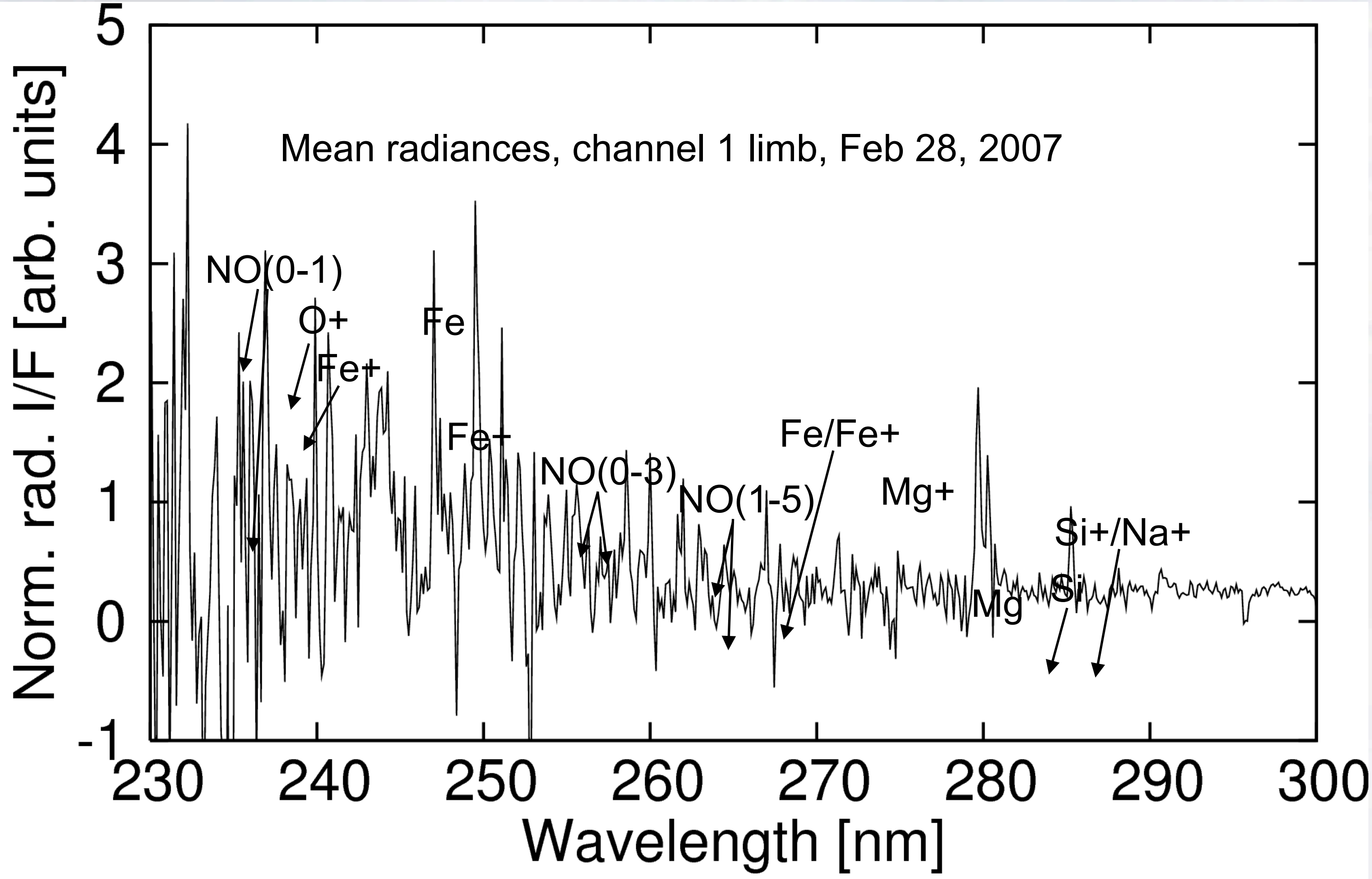
Emission signals identified - SCIAMACHY spectra



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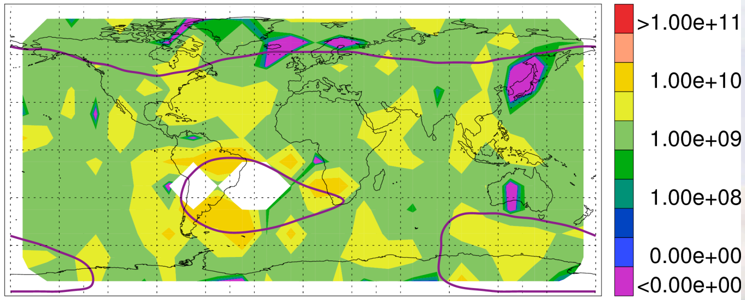
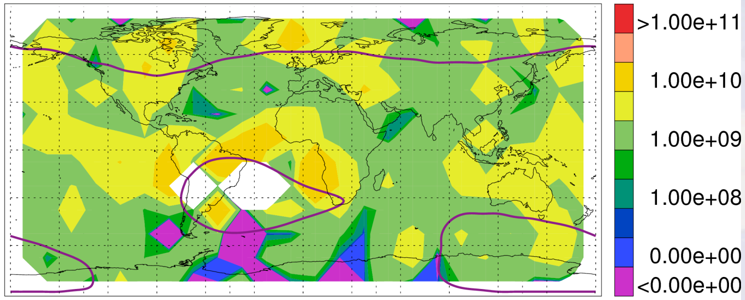
SCIAMACHY Limb: First Observations of Mg and Mg+

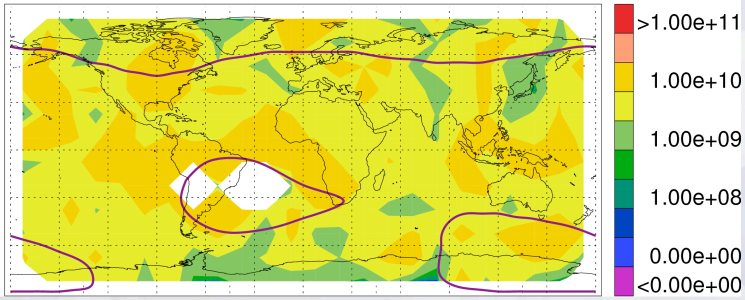
200603 MgII thermospheric column [cm^{-2}]



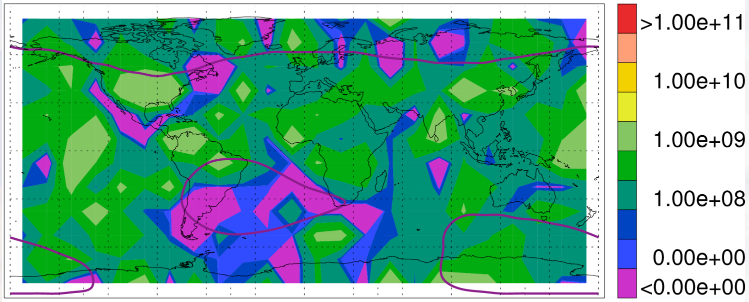
200603 MgII mesospheric column [cm^{-2}]



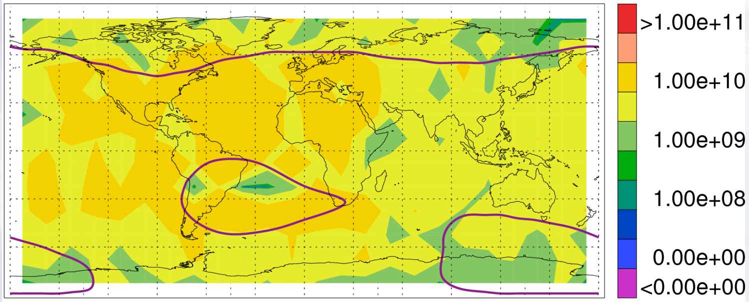
200603 MgII total column [cm^{-2}]



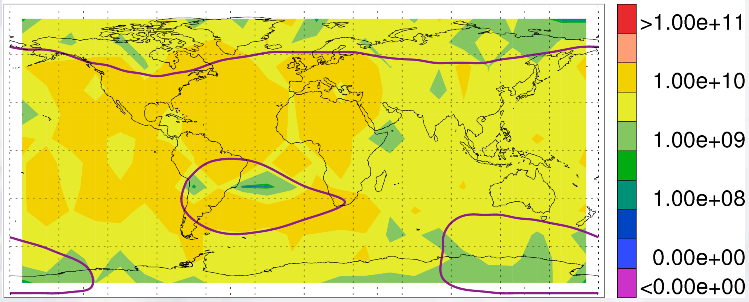
200603 MgI thermospheric column [cm^{-2}]



200603 MgI mesospheric column [cm^{-2}]



200603 MgI total column [cm^{-2}]



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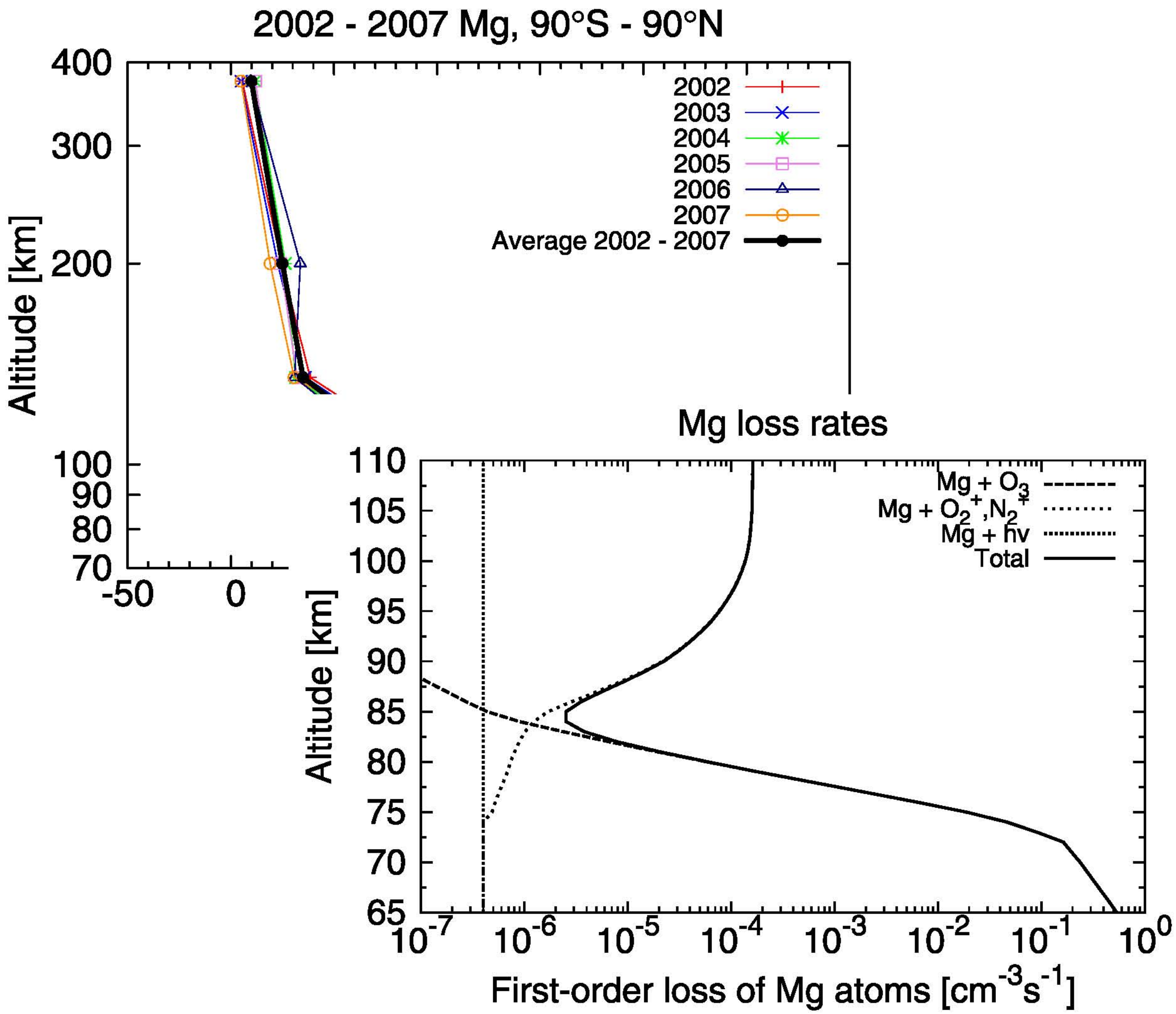
Results: Total influx of cosmic dust



(Plane and Helmer, 1995)

Total influx : < 55 t/d
(13% Mg in cosmic dust)

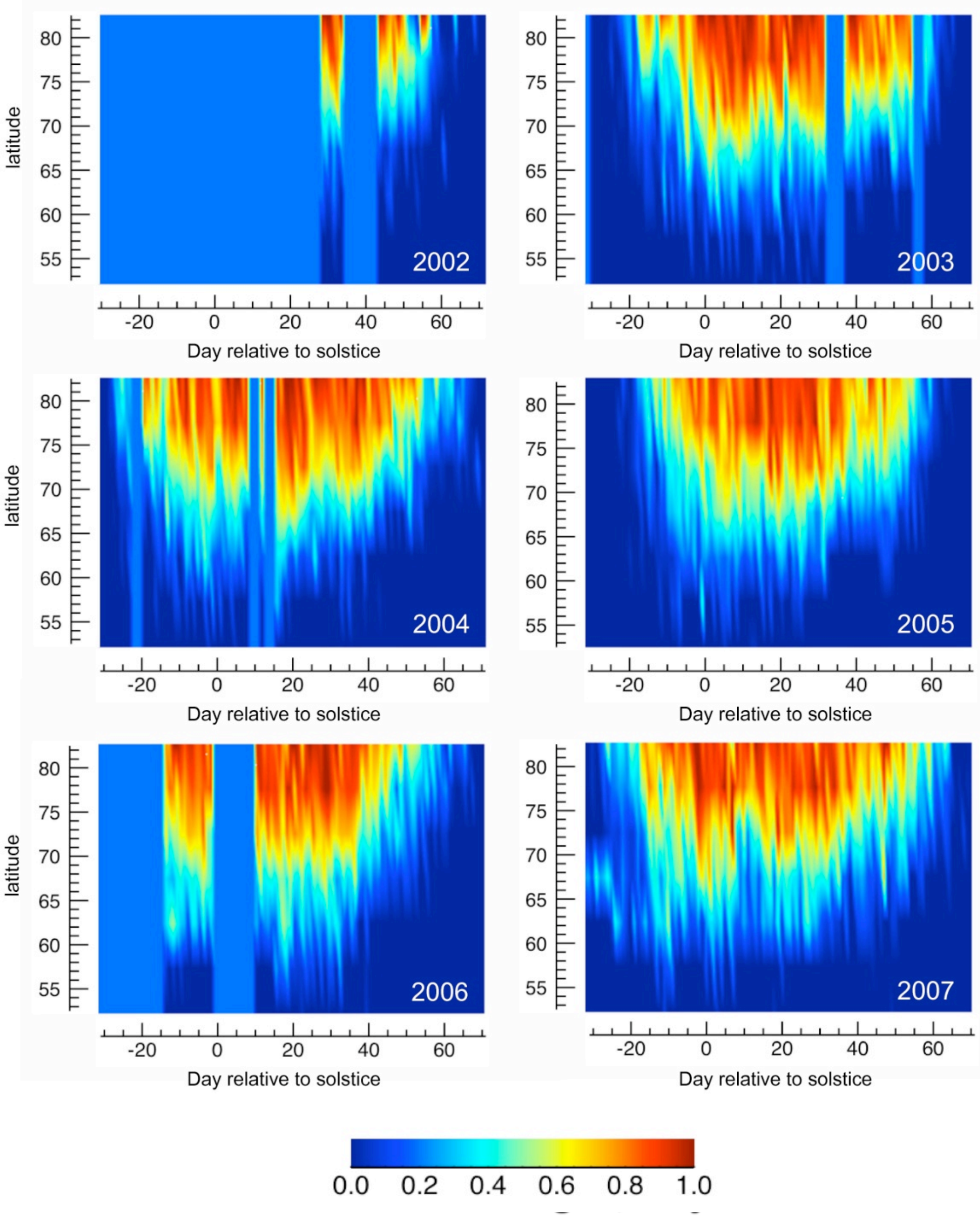
P < 7,1 t/d

$$0 = \frac{d[\mathrm{Mg}]}{dt} = P - [\mathrm{Mg}]L$$

SCIAMACHY: Polar mesospheric Noctilucent Clouds early indicators of global change

- Occurrence near 85 km at polar latitudes during summer
- SCIAMACHY allows cloud detection, particle size and ice mass retrievals

Picture taken by P. Parviainen



Noctilucent cloud occurrence rate

Robert et al., JASTP, 2008

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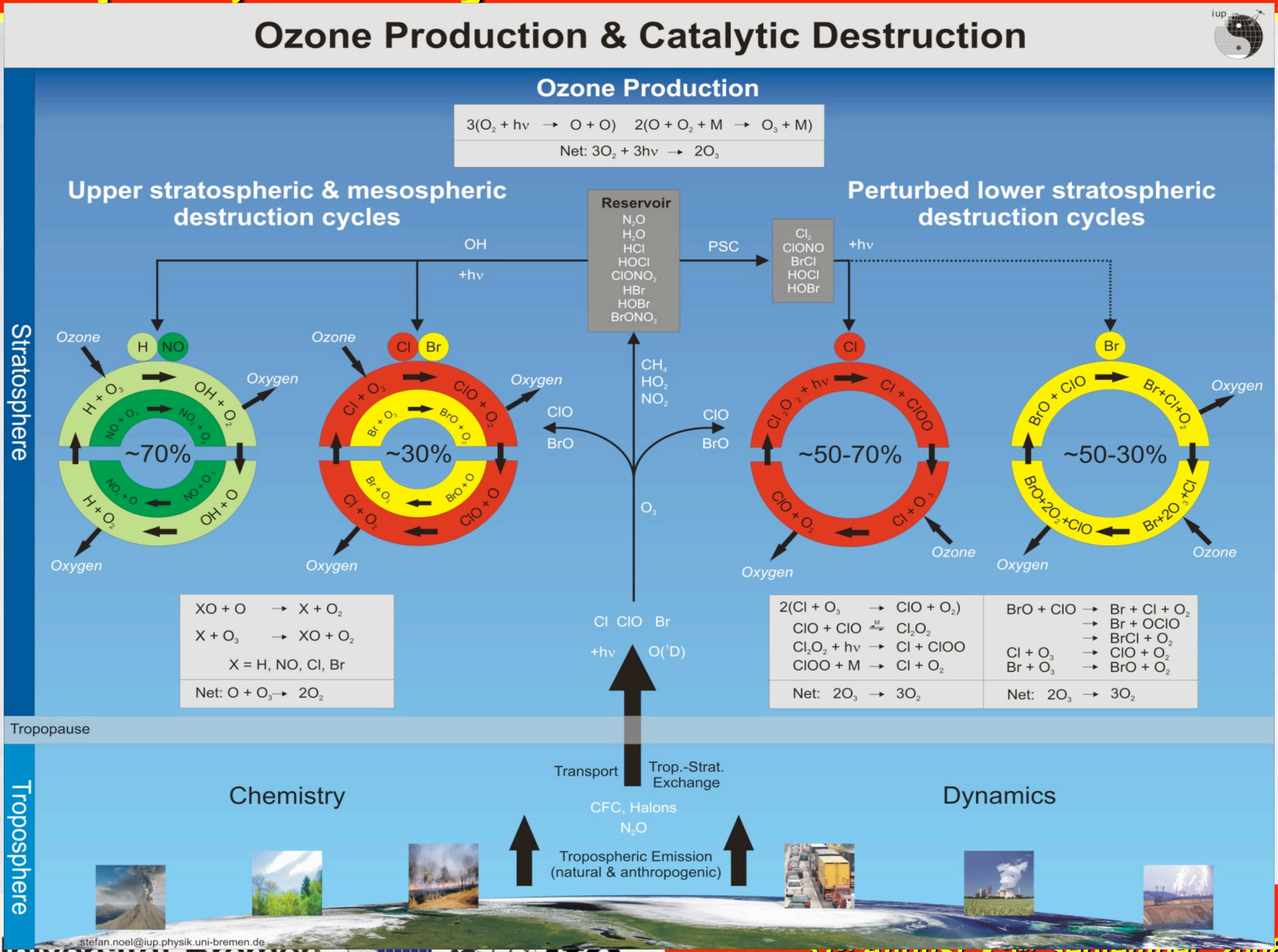
Science 3: Stratopsheric Chemistry, Transport, and Dynamics – Ozone Recovery?



Ozone Production & Catalytic Destruction

Ozone Production

$3(O_2 + h\nu \rightarrow O + O)$ $2(O + O_2 + M \rightarrow O_3 + M)$

Net: $3O_2 + 3h\nu \rightarrow 2O_3$

Upper stratospheric & mesospheric destruction cycles

$XO + O \rightarrow X + O_2$

$X + O_3 \rightarrow XO + O_2$

X = H, NO, Cl, Br

Net: $O + O_3 \rightarrow 2O_2$

Perturbed lower stratospheric destruction cycles

$2(Cl + O_3 \rightarrow ClO + O_2)$

$ClO + ClO \overset{M}{\rightleftharpoons} Cl_2O_2$

$Cl_2O_2 + h\nu \rightarrow Cl + ClOO$

$ClOO + M \rightarrow Cl + O_2$

Net: $2O_3 \rightarrow 3O_2$

$BrO + ClO \rightarrow Br + Cl + O_2$

$\rightarrow Br + OClO$

$\rightarrow BrCl + O_2$

$Cl + O_3 \rightarrow ClO + O_2$

$Br + O_3 \rightarrow BrO + O_2$

Net: $2O_3 \rightarrow 3O_2$

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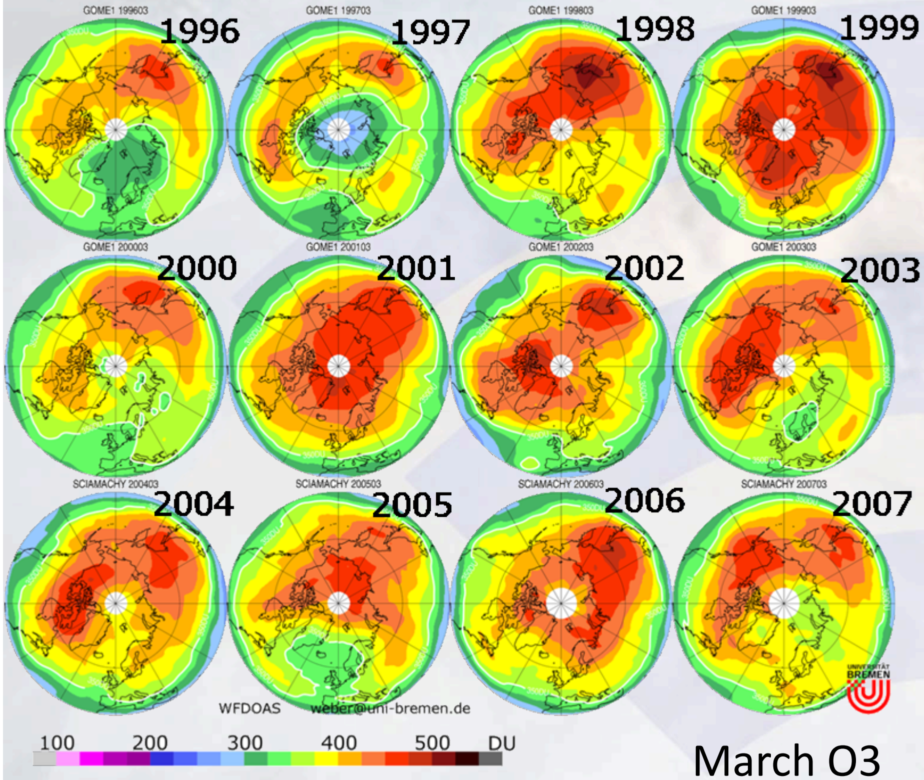
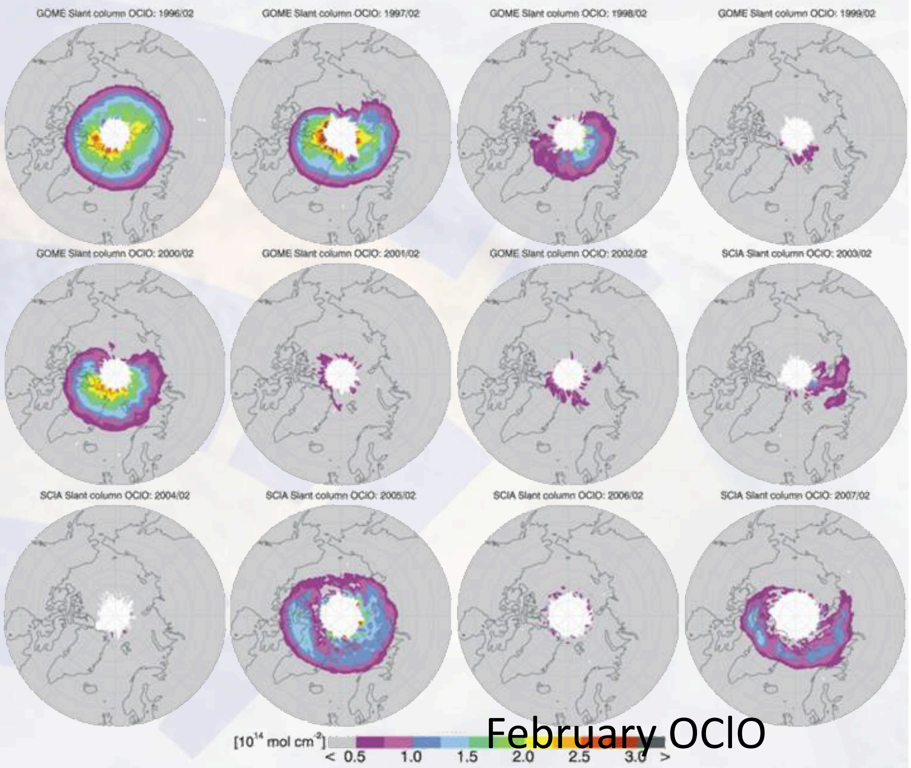
NH March total O3 and February OClO from GOME/SCIAMACHY



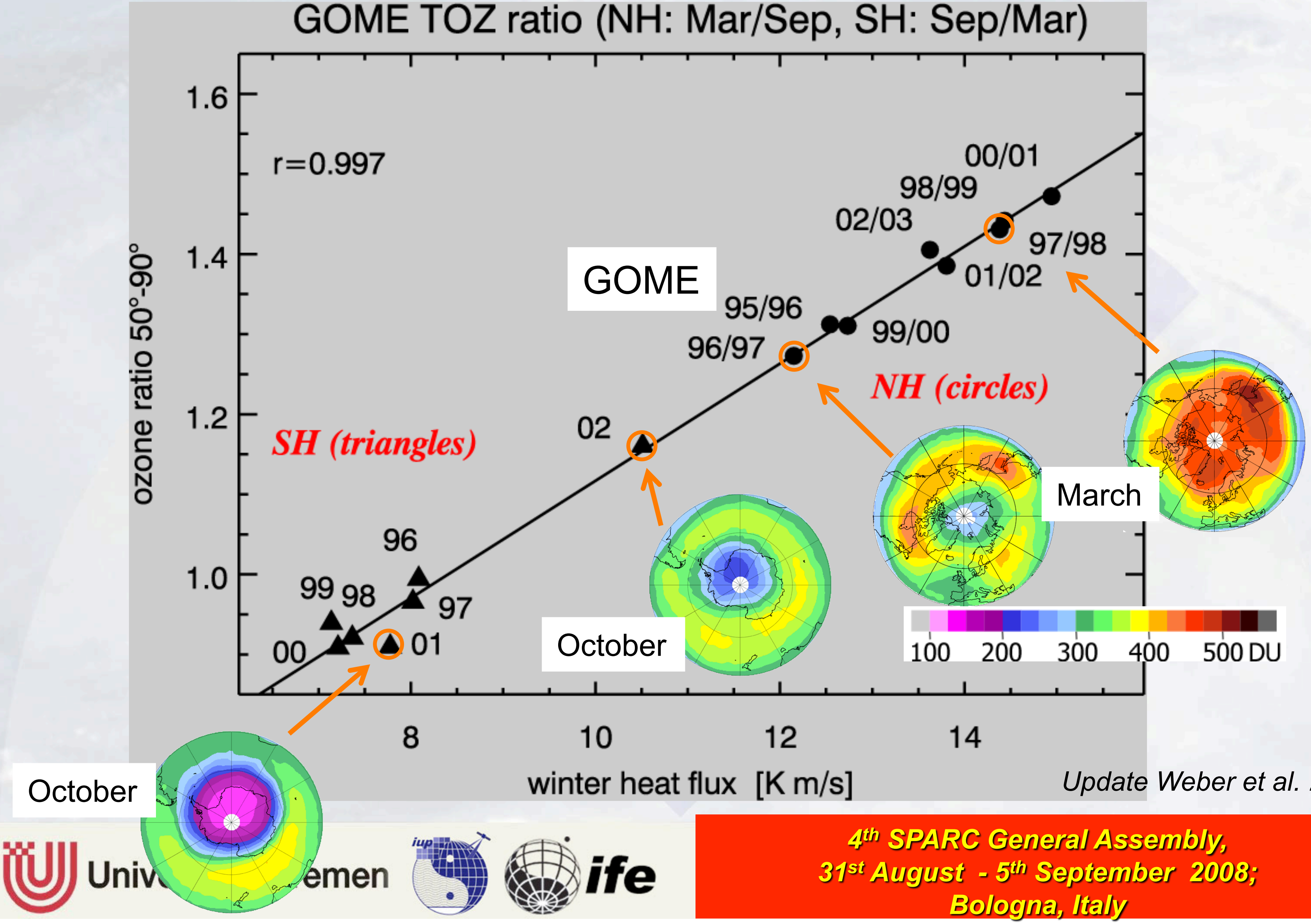
March O3



February OClO

- About half of the Arctic winters show low ozone and high chlorine activation („cold“ winters), the other half high ozone and little or no chlorine activation („warm“ winters)
- Inter-annual variability in PSCs, chlorine activation and ozone transport

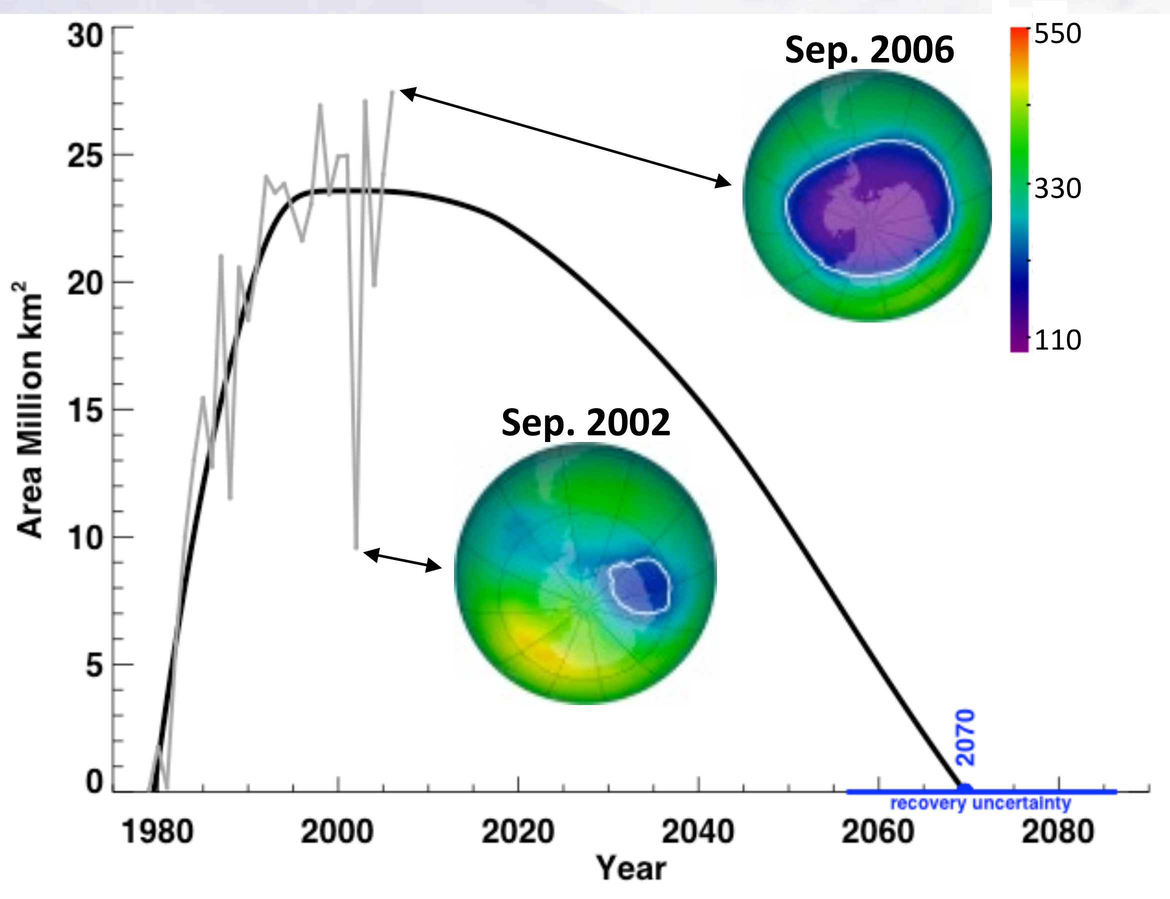
Chemical-dynamical coupling



Update Weber et al. 2003

Ozone Hole Recovery

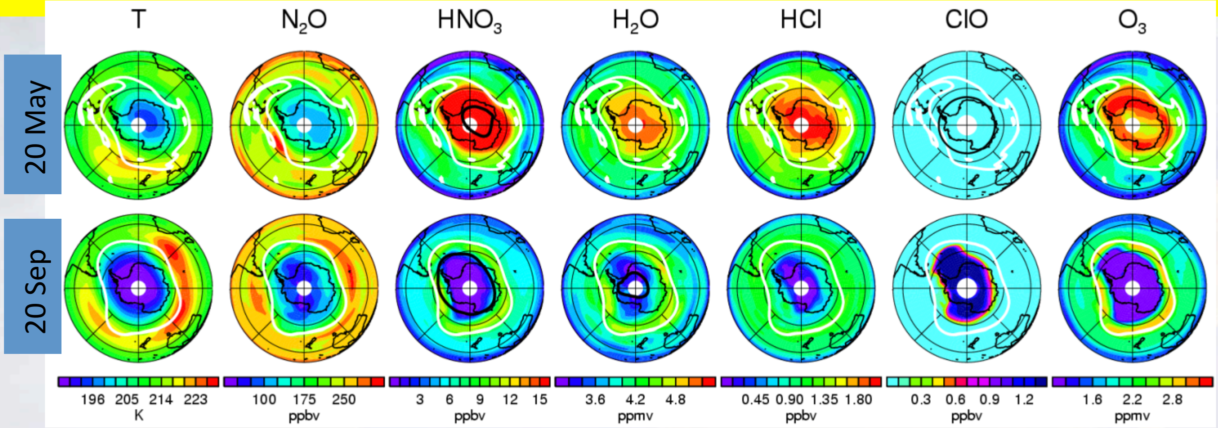
- **Antarctic ozone depletion (the "ozone hole") is caused by human-produced chlorine and bromine gases (CFC's). Ozone screens harmful ultraviolet radiation. Now that CFC's are banned when will the ozone hole recover?**
- **We have developed a parametric model of the ozone hole area that is based upon satellite, ground, and aircraft observations of ozone and chlorine and bromine species.**
- **From this model, we estimate that the ozone hole area will begin to decrease in 2023, and will be fully recovered to 1980's levels by 2070.**
- **Recent occurrences of particularly small (2002) or large (2006) ozone holes are not indicative of a long-term trend.**
- **P. Newman R. KAWA and SBUV TOMS + OMI O3 scientists and colleagues NASA**



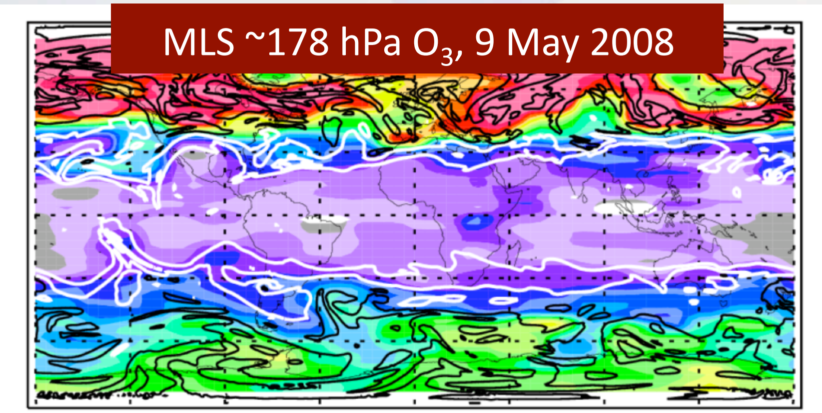
Dr. Paul A. Newman (NASA/GSFC)

Scientific goals of Aura MLS

Track the stability of the stratospheric ozone layer

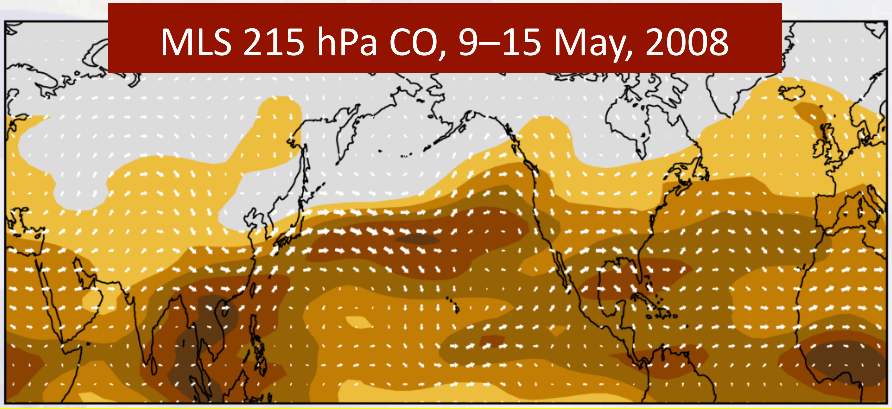


MLS observations of the 2006 Antarctic ‘ozone hole’ development in the lower stratosphere



MLS ~178 hPa O_3, 9 May 2008

Quantify aspects of how composition affects climate

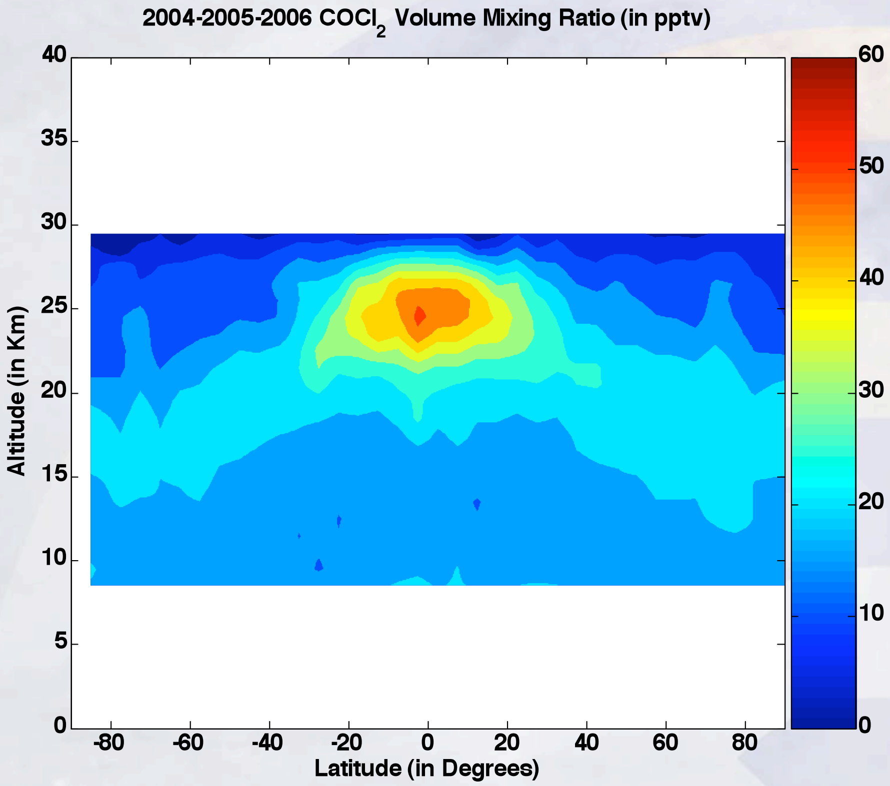


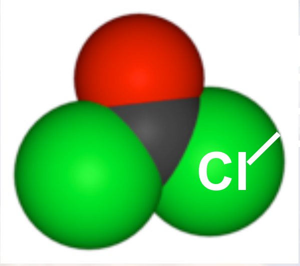
MLS 215 hPa CO, 9–15 May, 2008

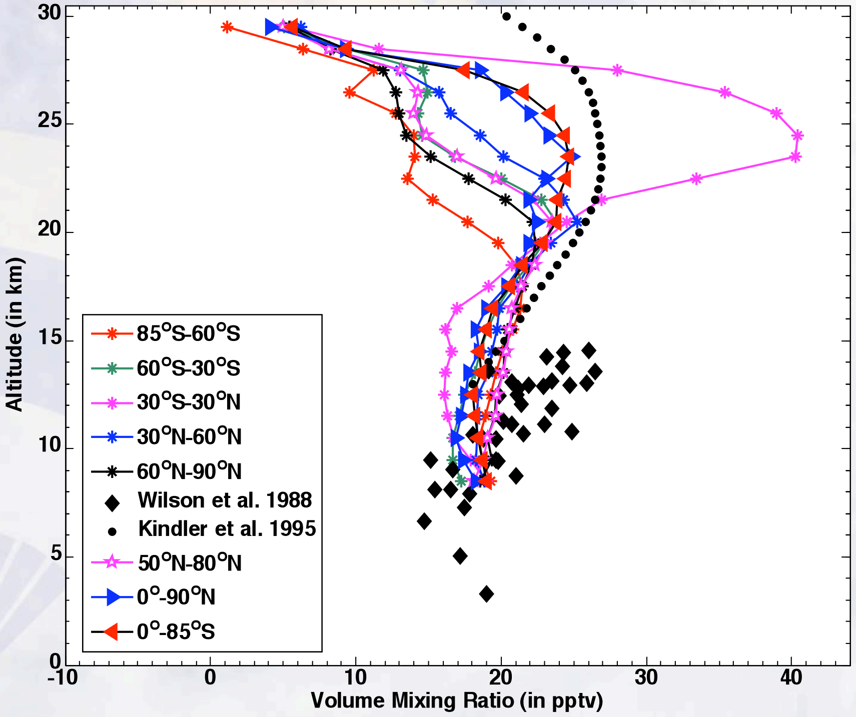
Study the behavior and transport of air pollution in the upper troposphere

SCISAT/ACE: Global Distribution of Phosgene, Cl_2CO

Fu et al. GRL, 34, L17815 (2007)


2004-2005-2006 $COCl_2$ Volume Mixing Ratio (in pptv)





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Stratospheric aerosol extinction profiles from OSIRIS on ODIN

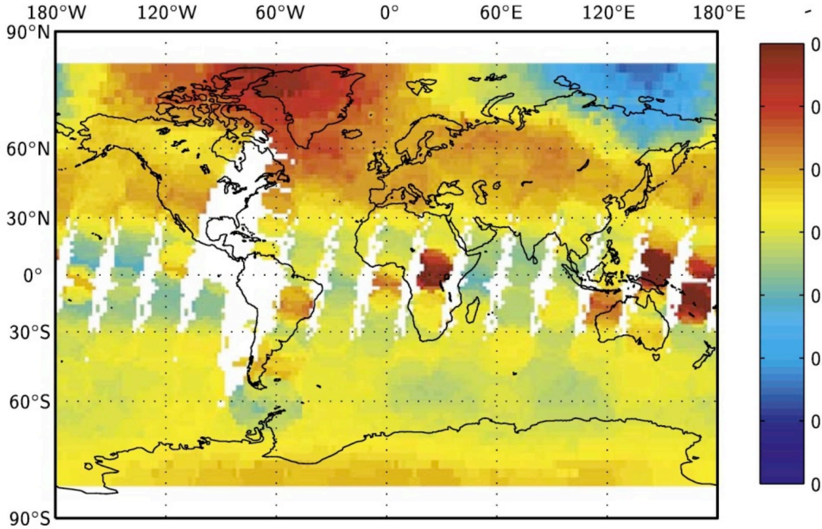


Figure 18. Global map of OSIRIS retrieved extinction (10^{-3} km^{-1}) at 750 and 20 km altitude for the time period 27 February to 3 March 2006. The color white represents missing data.

Bourassa et al., JGR, 2007

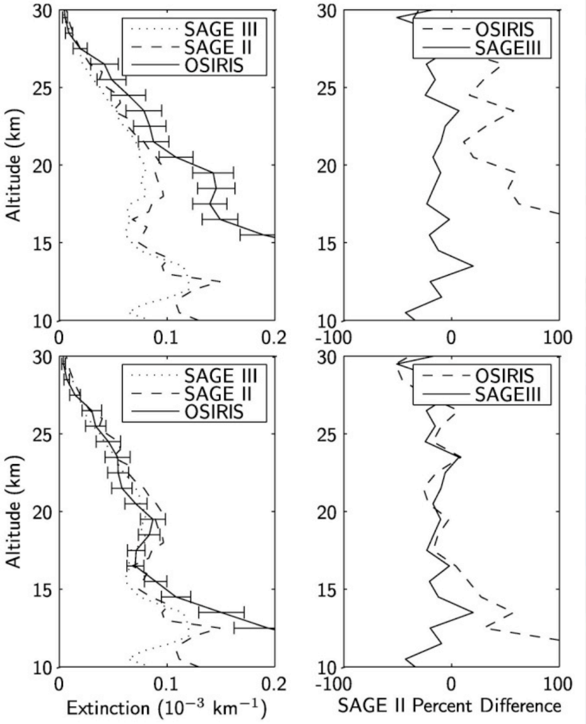
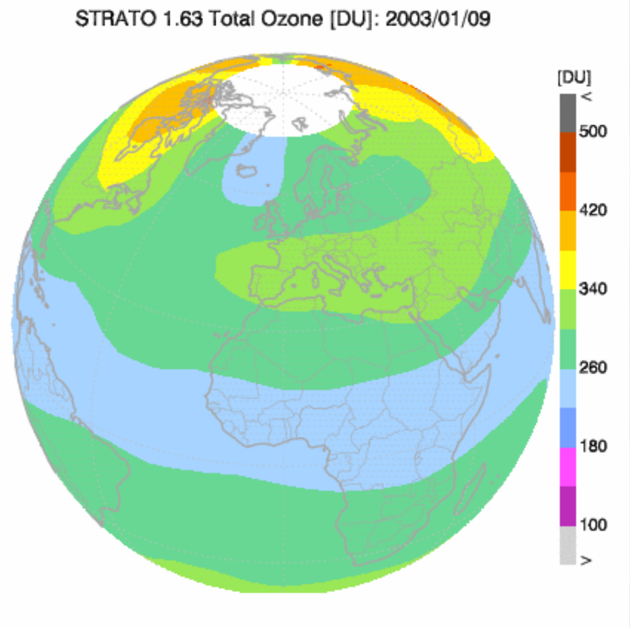
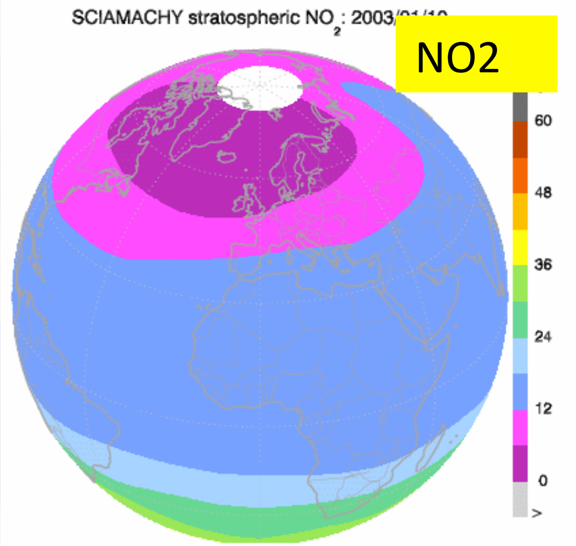


Figure 17. A comparison of coincident midlatitude SAGE II, SAGE III and OSIRIS aerosol 1020 nm extinction profiles. OSIRIS number density is converted to extinction using corresponding Mie cross sections. In the top panels, the OSIRIS retrieval uses the size distribution of *Bingen et al.* [2004] used for the modeling work. For the lower panels, the retrieval is performed using background layer size distribution parameters consistent with in situ measurements by *Deshler et al.* [2003] in 2001 (mode radius of 0.08 micron, mode width of 1.6 at all altitudes).

SCIAMACHY Limb: Stratospheric Columns and Cloud Top Heights

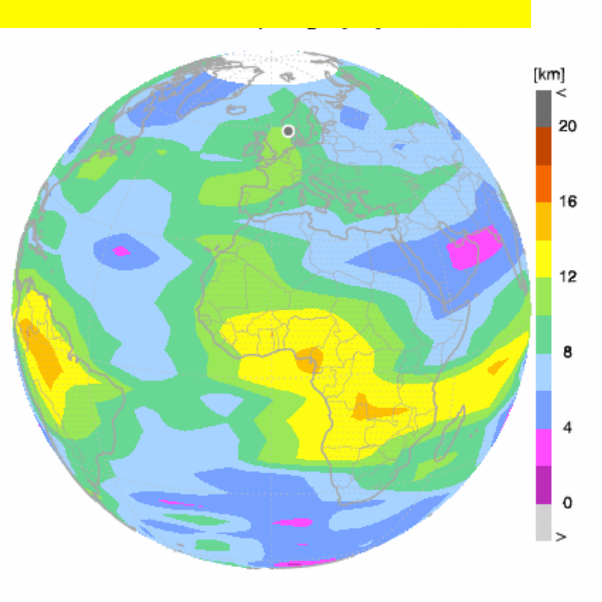

STRATO 1.63 Total Ozone [DU]: 2003/01/09

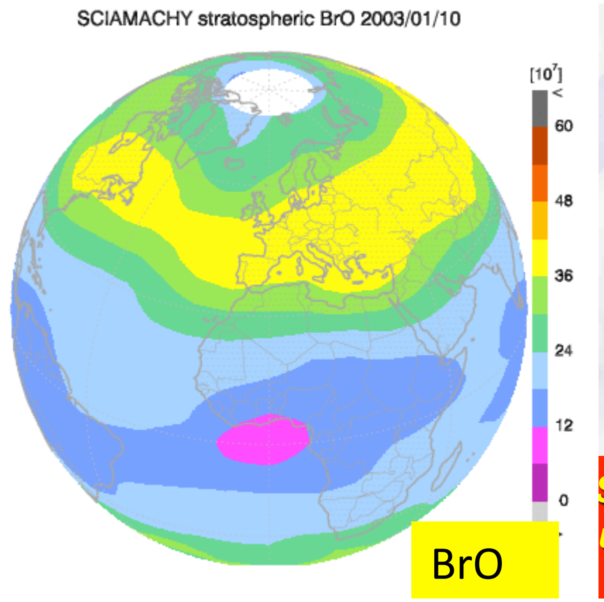
Stratopheric Ozone


SCIAMACHY stratospheric NO$_2$: 2003/

NO2

Cloud Top Height and PSC occurence



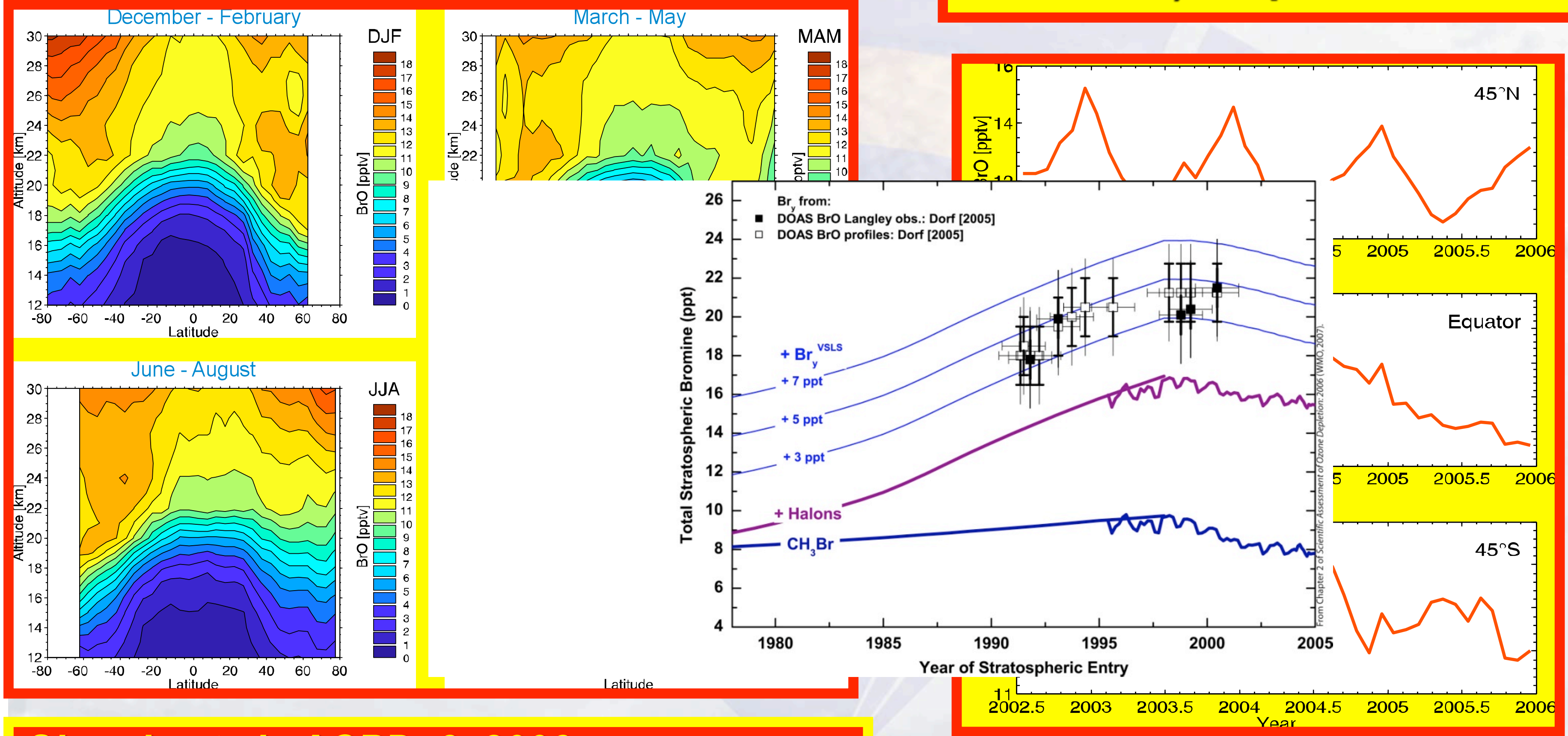

SCIAMACHY stratospheric BrO 2003/01/10

BrO

SCIAMACHY: BrO Climatology

Average BrO mixing ratio, 2002 - 2005

BrO at 23 km (annual zonal means) response to MP?



Sheode et al., ACPD, 6, 2006
Sinnhuber et al., GRL, 32, 2005

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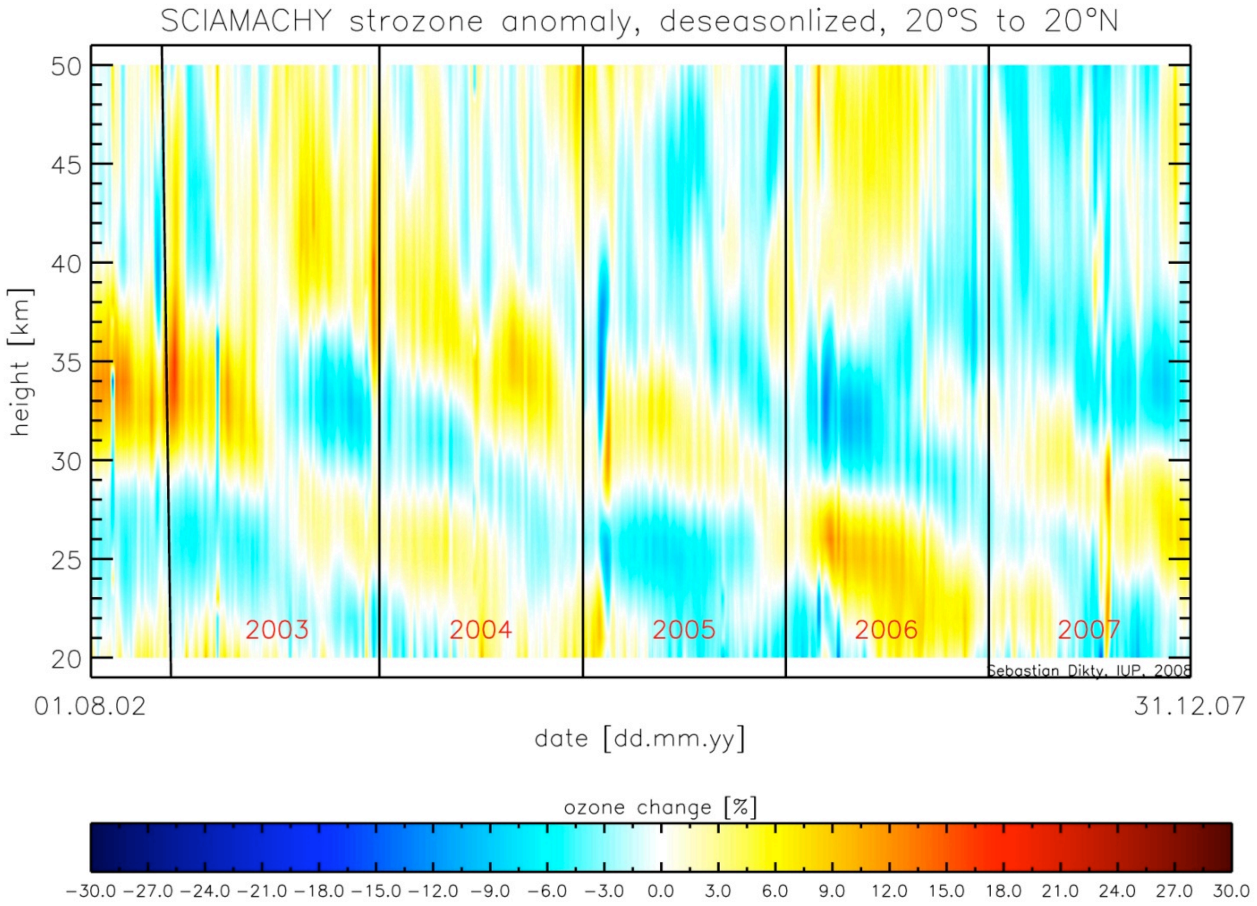
Bologna, Italy

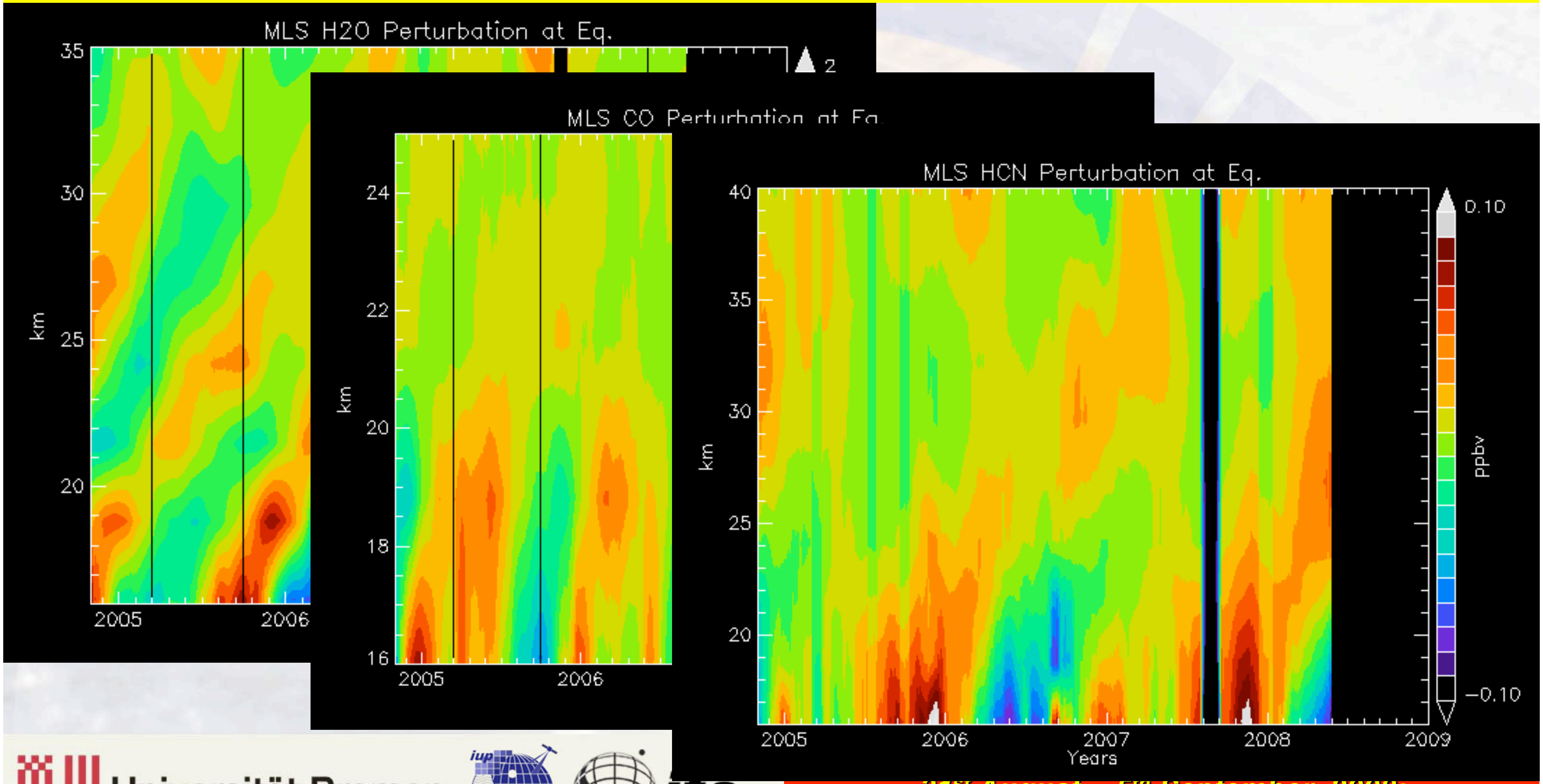
QBO in SCIAMACHY O_3 time series



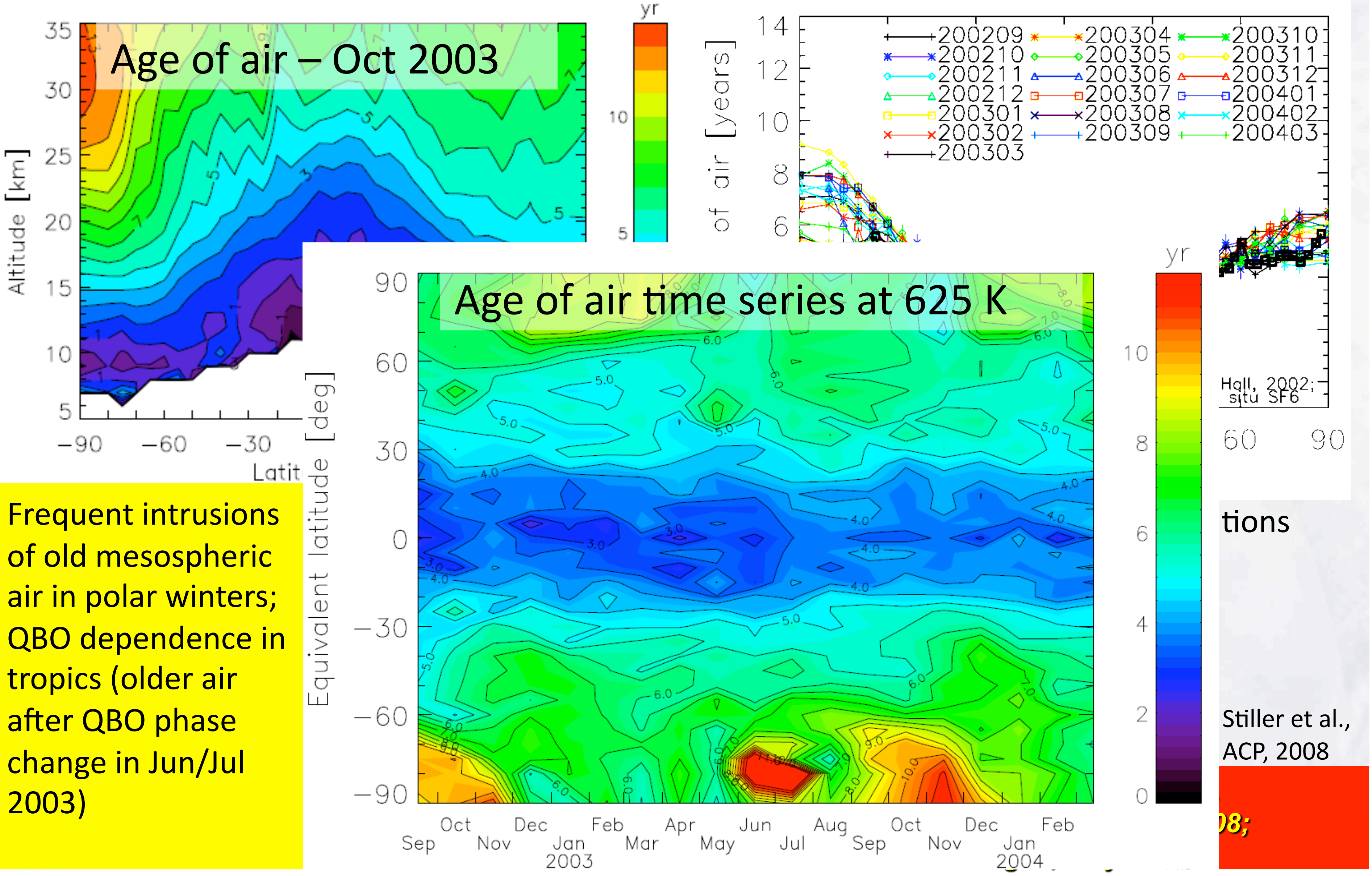
Dikty et al., 2008

MLS: Observsations of Tape Recorders

Modulation of tropospheric stratospheric exchange at the equator - TTL region M. Schoeberl and the MLS team



MIPAS: Stratospheric dynamics – global mean age of stratospheric air from SF6



tions

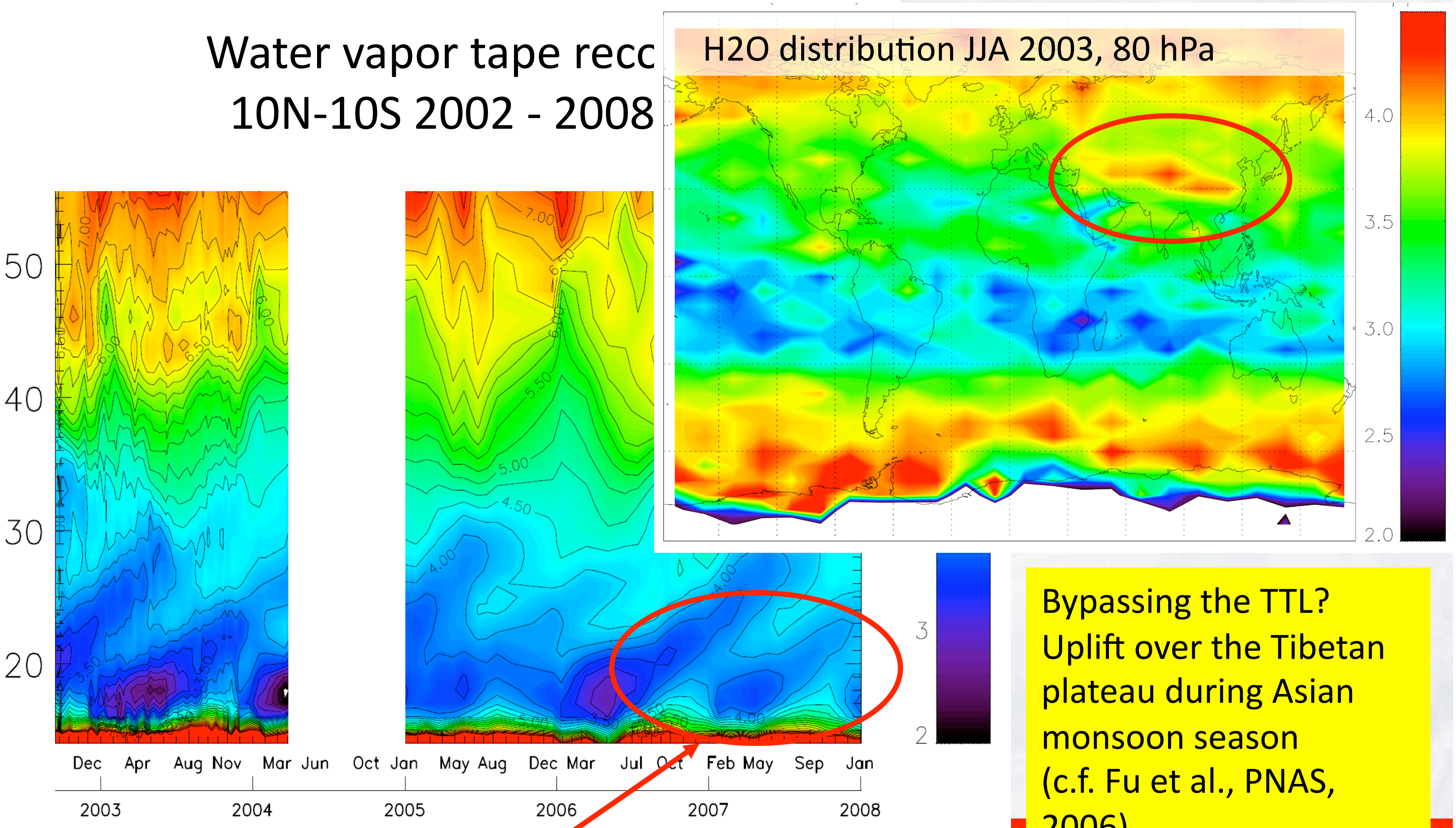
Frequent intrusions of old mesospheric air in polar winters; QBO dependence in tropics (older air after QBO phase change in Jun/Jul 2003)

Stiller et al., ACP, 2008

08;

MIPAS: Troposphere – stratosphere transport of water vapor

Water vapor tape recc
10N-10S 2002 - 2008



H2O distribution JJA 2003, 80 hPa

Bypassing the TTL?
Uplift over the Tibetan plateau during Asian monsoon season
(c.f. Fu et al., PNAS, 2006)

Has dry phase starting in 2001 now ended?

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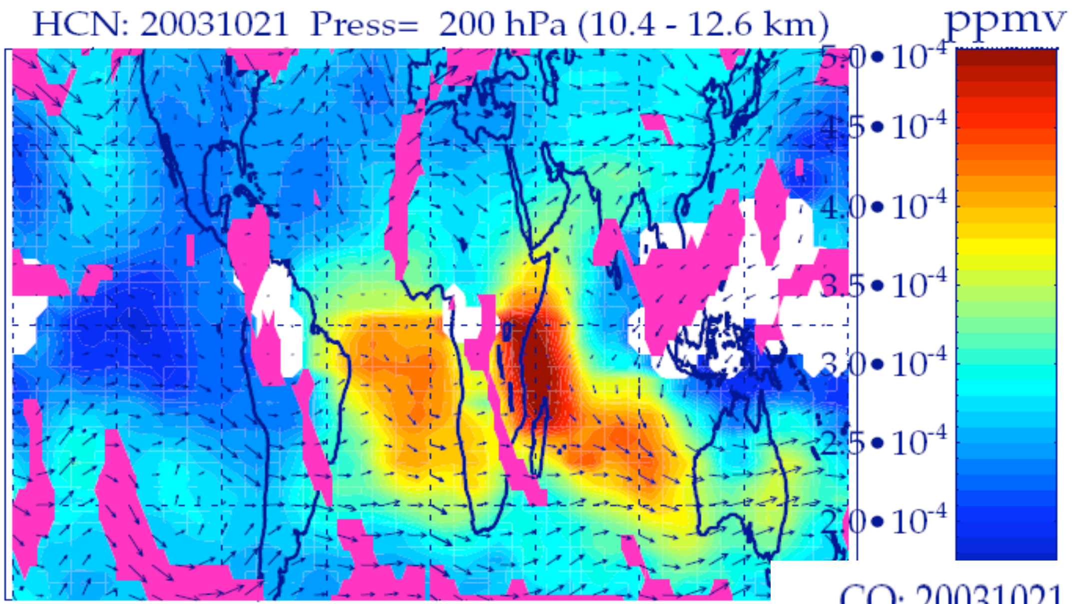
MIPAS: Upper tropospheric pollution and ozone production by biomass burning



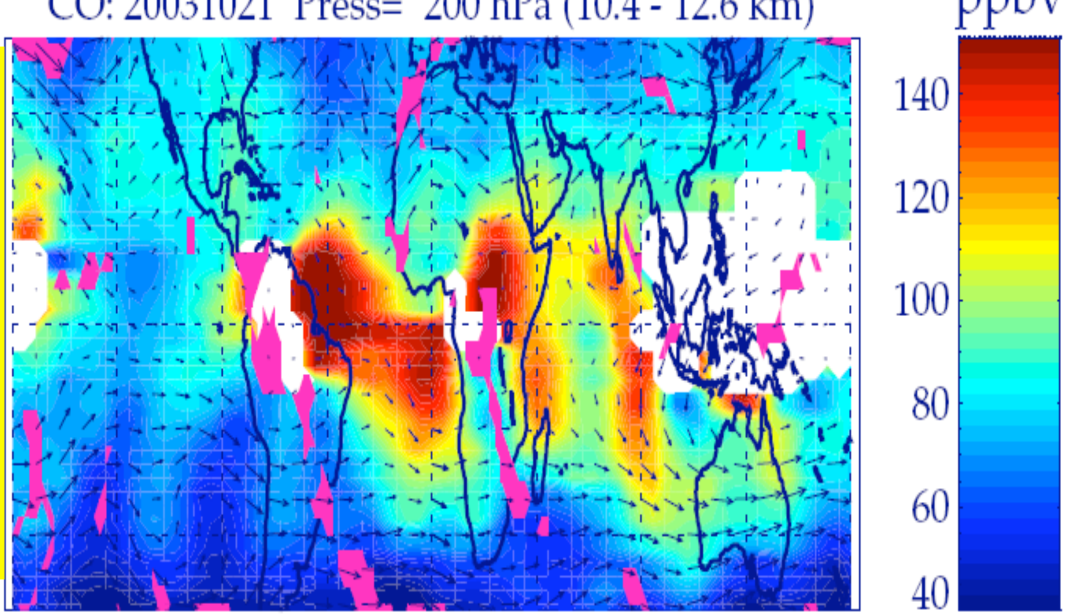
HCN plumes from biomass burning in S-America and Africa transported into UT (10-12 km)

21 Oct 2003

HCN lifetime: several months

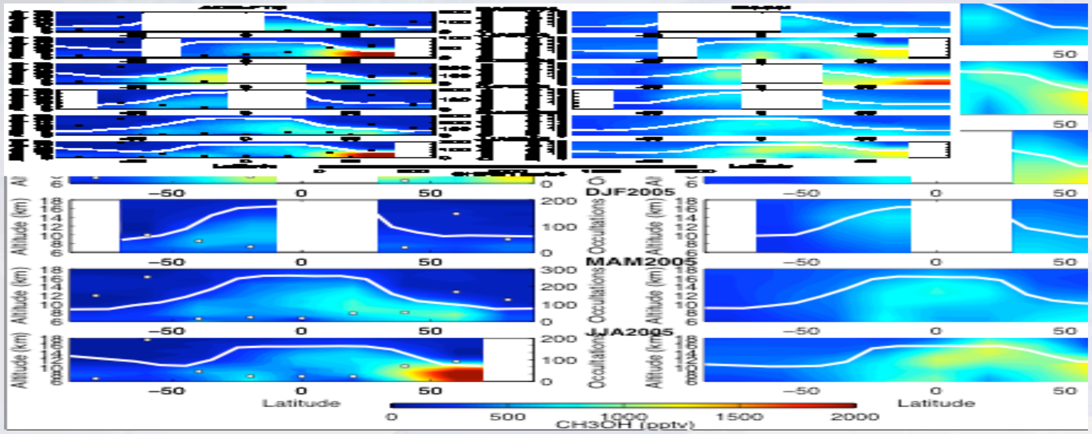
CO plumes in UT 10-12 km
for the same day: additional pollution South of India towards Australia indicates non-biomass burning sources
=>

Source types can be identified by synergistic view of various pollutants



SCISAT/ACE: Global Methanol

ACE is an upper tropospheric “air quality” mission measuring global CH_4, CH_3OH, HCN, C_2H_2, C_2H_4, C_2H_6, H_2O_2, HCOOH, H_2CO.

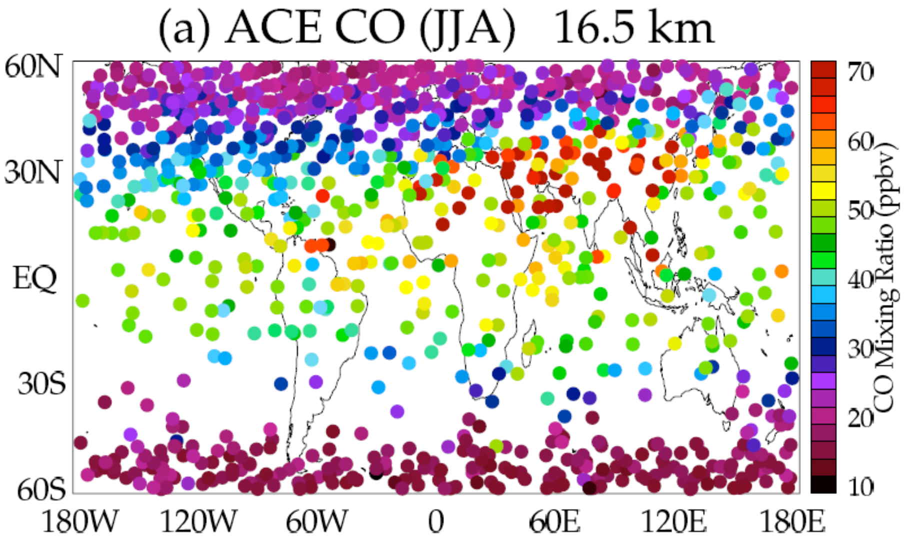


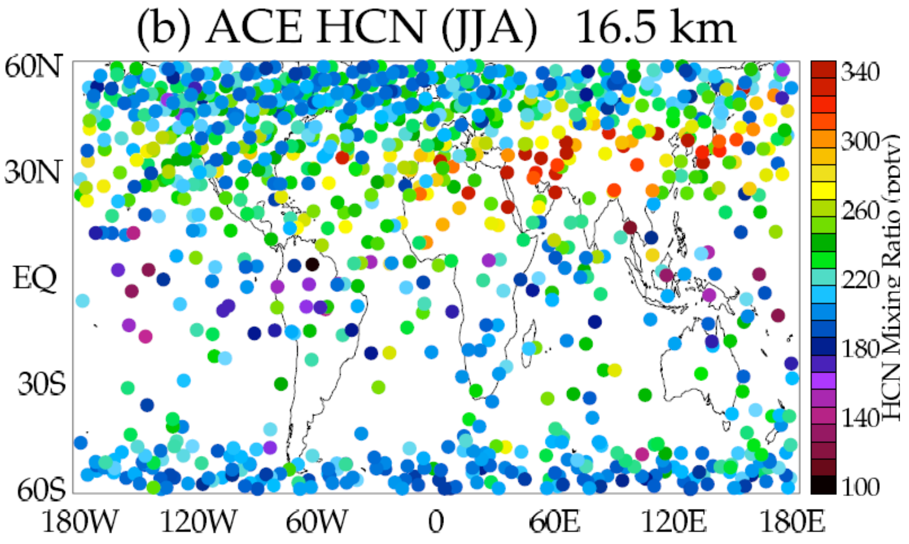
Dufour et al. ACP, 7, 6119 (2007)

LDMz-INCA model

(D. Hauglustaine)

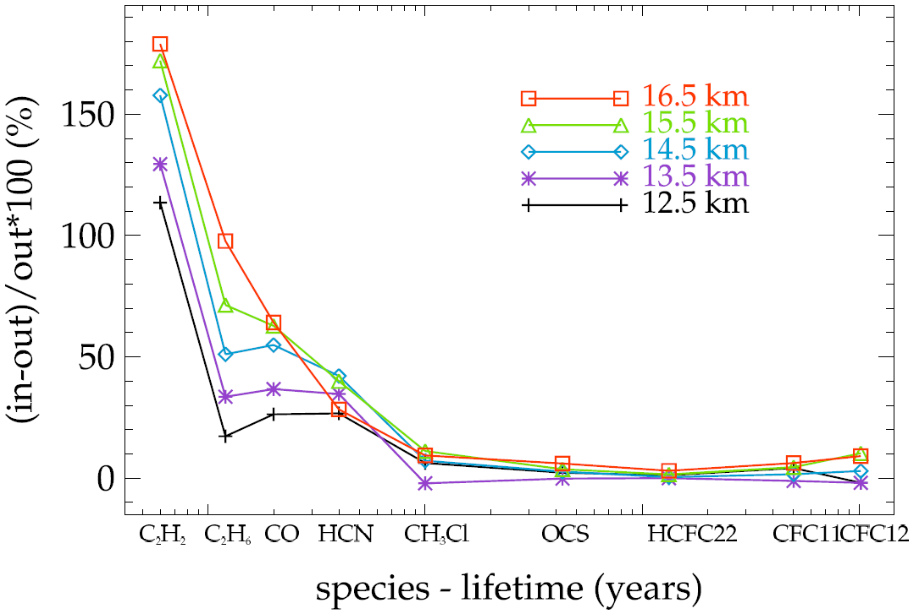
SCISAT/ACE: Asian Monsoon Anticyclone


(a) ACE CO (JJA) 16.5 km

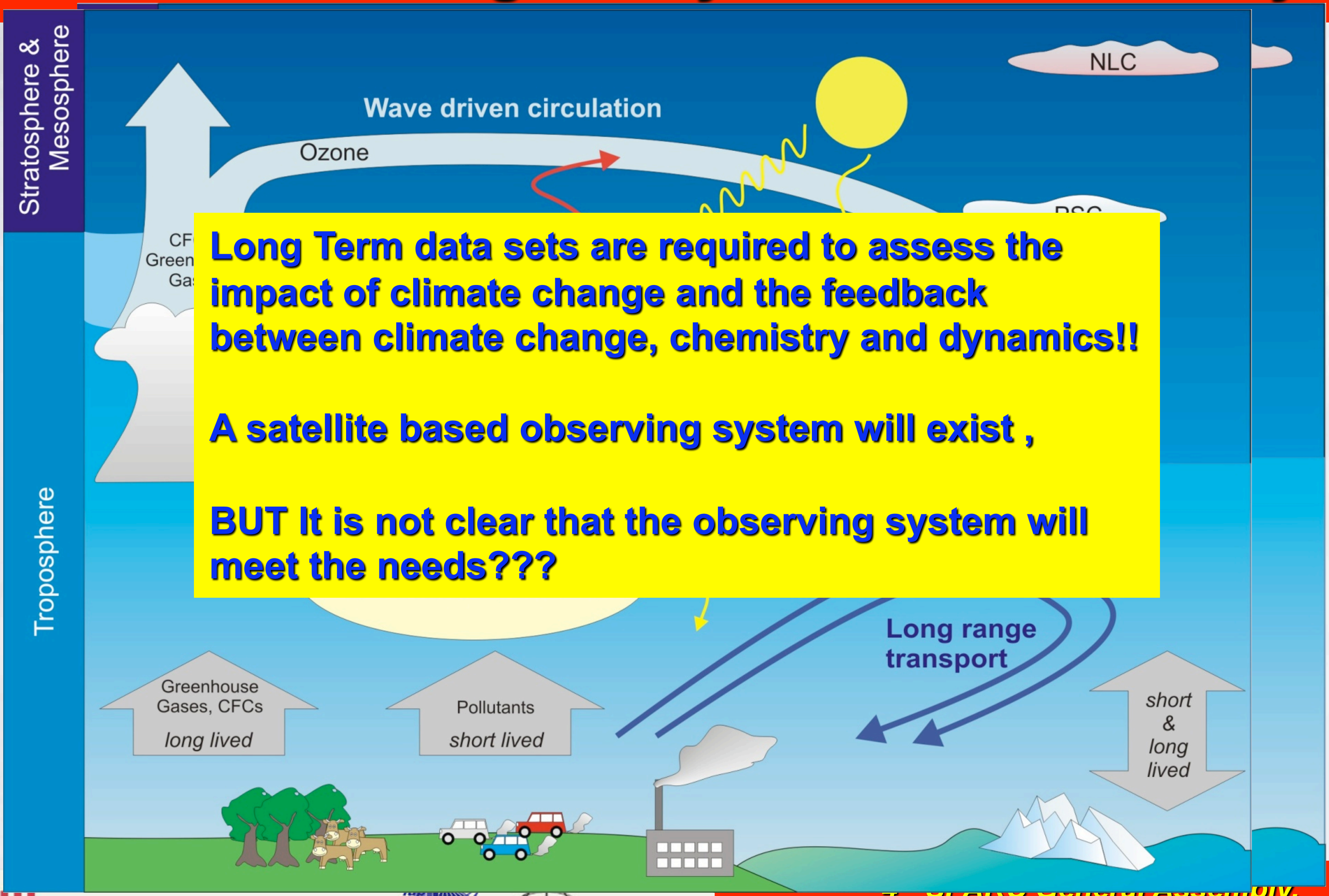

(b) ACE HCN (JJA) 16.5 km

ACE-FTS

Park et al. ACP, 8, 757 (2008)



The Challenge for the next decades:
Climate Change ⇔ Dynamics ⇔Chemistry



Long Term data sets are required to assess the impact of climate change and the feedback between climate change, chemistry and dynamics!!

A satellite based observing system will exist ,

BUT It is not clear that the observing system will meet the needs???

Summary and Conclusions

- Â golden pioneering age for the remote sensing of the region from the UT/LS to the Thermosphere – Development of techniques and Flagship missions – Space observations provide Global long term observations!!!!
- Passive Remote Sensing of key constituents – Trace Gases, aerosol and cloud properties using Microwave, Submm, TIR, and Solar Backscattered, solar, lunar and stellar occultation.
- Improving observations on the interactions between solar irradiance, CME/SPE and upper atmosphere.
- Currently Natural and anthropogenic (halogen release) destruction of the stratospheric Ozone and Ozone Hole chemistry relatively well observed from space. However improved data to test our knowledge of feedback.
- Montreal Protocol is working but identification of unambiguous Ozone recovery, complex because of changing dynamics.
- Climate Change and Chemistry feedback in and impact on the upper atmosphere is challenging – much more difficult than halogen destruction of Ozone – time scales => long consistent data sets are required => Much work to be done!!

Three Phases (Socio-Economic/Sociological Hypotheses) of Space Missions

- **Incredulity**
  - – You can't possibly do that!
  - – Is it worth doing anyway?
- **Acceptance**
  - – Well… it might be worth doing … maybe you can.
- **Demand**
  - – Is that the best you can do?
    Why isn't it better!! – did you mess up or what?!

J. Drummond and J.P. Burrows