Observation of the Upper Atmosphere from Satellite Platforms: Sensing and Sensibility

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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
- 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**

<table>
<thead>
<tr>
<th>What has been provided!</th>
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<tbody>
<tr>
<td>Soviet</td>
<td></td>
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<tr>
<td>1960</td>
<td>First attempts at O3 monitoring</td>
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<tr>
<td>NASA</td>
<td>Ozone Nadir sounding</td>
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<tr>
<td>1963 – 1993</td>
<td>Nimbus 1 to 7 pioneering earth observation</td>
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<tr>
<td>1974 - SBUV-2</td>
<td>Nadir Sounding: BUV (N4) /SBUV(N7)/SSBUV</td>
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<td>1979 – 2006</td>
<td>NOAA</td>
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<td>TOMS - N7, Meteor 3, ADEOS, Earth Probe T, H2O Nadir Sounding in IR</td>
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<td>1974 -</td>
<td>SCR (N5) N6</td>
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<tr>
<td>NASA</td>
<td>Limb sounding T profile</td>
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<tr>
<td>1976-1988</td>
<td>N6 LRIR - N7 LIMS</td>
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**Universität Bremen**

**ife**
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)
1996-2003 Explorer: SNOE - LASP

ESA
1995-2003 GOME on ERS-2,
Mesospheric Composition: metal emissions, NO
stratospheric composition O3, NO2, OCIO, BrO

tropospheric 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

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

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 (e.g., lat. >60°) where they penetrate down to the lower stratosphere.
Estimated Ion Deposition Rates

Ion rates (# cm\(^{-3}\) s\(^{-1}\)): Oct–Nov 2003 SPE

Pressure (hPa)

Approximate Altitude (km)

26 28 30 1 3 5 7

October November

Jackman et al., AGU SPARC General Assembly, 31st August - 5th September 2008; Bologna, Italy
SCIAMACHY: O$_3$ depletion during Halloween SPE


SCIAMACHY SPE OZONE CONCENTRATION [%] AT 48,143 KM

Altitude [km]

Ozone concentration [molecules/cm$^3$]


SCIAMACHY SPE OZON


SCIAMACHY SPE OZONE CONCENTRATION [%] AT 48,143 KM

Altitude [km]

Ozone concentration [molecules/cm$^3$]


SCIAMACHY SPE OZONE CONCENTRATION [%] AT 48,143 KM

Altitude [km]

Ozone concentration [molecules/cm$^3$]
MIPAS: Solar influence on climate observations during “Halloween” SPE Oct/Nov 2003

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

81 August – 30 September 2008; Bologna, Italy
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 NO₂ and O₃

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 NO₂.

Large intrusions of NO₂ into the stratosphere are common in polar atmosphere (here Arctic).

Hauchecorne et al., GRL, 34, L03810, 2007.
Verronen et al., GRL, 33, 24, L24811, 2006

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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.
Science #2: Comets, Dust, Meteorites ↔ Upper Atmosphere

Comets, (photographs show), leave a trail of dust in the sun as their orbit crosses the earth. The meteor showers of the material, originates from Mars, and from Earth trails.
SCIAMACHY Limb: First Observations of Mg and Mg+
Results: Total influx of cosmic dust

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

P < 7.1 t/d

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

(Plane and Helmer, 1995)
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

<table>
<thead>
<tr>
<th>Year</th>
<th>Noctilucent cloud occurrence rate</th>
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<tbody>
<tr>
<td>2002</td>
<td><img src="image" alt="2002 Clouds" /></td>
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<td>2007</td>
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*Picture taken by P. Parviainen*
Science 3: Stratopsheric Chemistry, Transport, and Dynamics – Ozone Recovery?

Ozone Production & Catalytic Destruction

Ozone Production

3(O₂ + hv → O + O)  2(O + O₂ + M → O₃ + M)
Net: 3O₂ + 3hv → 2O₃

Upper stratospheric & mesospheric destruction cycles

Reservoir
N₂O, NO, HCl, HCN, CH₃Cl, CH₂Cl₂, HBr, HOCl, NO₂, BrONO₃

Perturbed lower stratospheric destruction cycles

Cl, ClONO₂, BrCl, HOCl, HBr, HOBr

Stratosphere

Ozone
H + NO
O₂ + O
OH
+ hv

Cl + Br
ClO + BrO
ClO + BrO
ClO₂ + ClO
ClO + O₂
Cl + ClO
Br + ClO
Br + BrCl
Br₂ + ClO
BrCl + O₂
BrO + O₂

Net: O + O₂ → 2O₃

Tropopause

Chemistry

CFC, Halons
N₂O

Dynamics

Trop.-Strat. Exchange

Tropospheric Emission (natural & anthropogenic)

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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

GOME TOZ ratio (NH: Mar/Sep, SH: Sep/Mar)

GOME

SH (triangles)

NH (circles)

October

March

Update Weber et al. 2003

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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
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

Quantify aspects of how composition affects climate

- MLS ~178 hPa O$_3$, 9 May 2008

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

SCISAT/ACE: Global Distribution of Phosgene, Cl$_2$CO

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

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Stratospheric aerosol extinction profiles from OSIRIS on ODIN

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).

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

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SCIAMACHY Limb: Stratospheric Columns and Cloud Top Heights

Stratopheric Ozone

NO2

Cloud Top Height and PSC occurrence

BrO

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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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QBO in SCIAMACHY $O_3$ time series

SCIAMACHY stratosphere anomaly, deseasonalized, 20°S to 20°N

Dikty et al., 2008
MLS: Observations of Tape Recorders

Modulation of tropospheric stratospheric exchange at the equator - TTL region M. Schoeberl and the MLS team
Comparison to previous aircraft observations as published by Wagh and Hall, 2002

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

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
MIPAS: Troposphere – stratosphere transport of water vapor

Water vapor tape recorder
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 started in 2001 now ended?
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
ACE is an upper tropospheric “air quality” mission measuring global CH$_4$, CH$_3$OH, HCN, C$_2$H$_2$, C$_2$H$_4$, C$_2$H$_6$, H$_2$O$_2$, HCOOH, H$_2$CO.

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)

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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

- A 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!!!!
- 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