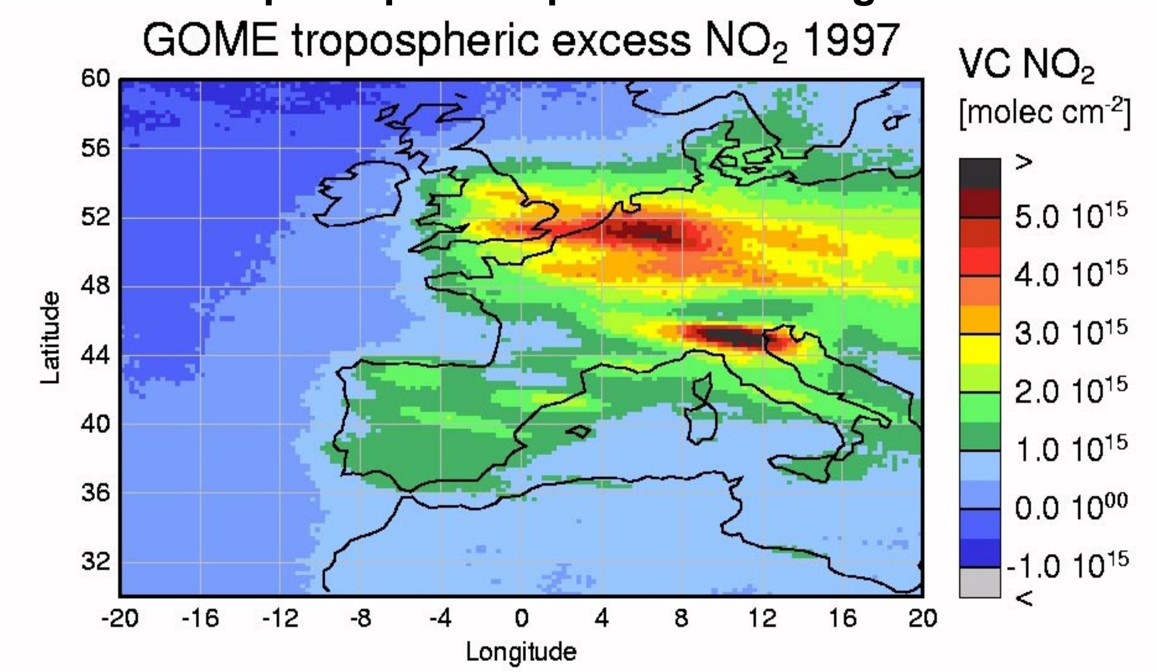
TROPOSAT

THE USE AND USABILITY OF SATELLITE DATA FOR TROPOSPHERIC RESEARCH

An EUROTRAC-2 subproject

http://troposat.iup.uni-heidelberg.de/



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THE AIMS OF TROPOSAT

To explore and encourage the use of satellite data to determine 2- and 3D distributions and time series of trace gases and other parameters in the troposphere and so facilitate future research and environmental monitoring on regional and global scales, in particular through:

- the development of algorithms for the retrieval of tropospheric species and parameters;
- the use of satellite data for understanding atmospheric processes;
- the synergistic use of different instrumentation and platforms for tropospheric measurements;
- the development of validation strategies for tropospheric satellite data products.

In addition TROPOSAT will undertake other **underpinning** and **derived activities** such as the development of appropriate **data assimilation techniques** combining satellite measurements with **modelling**, and specification of the **requirements for future satellite instruments** for tropospheric work.

Tropospheric data from present day satellite instruments have already been used with enormous success in many studies [e.g. Fishman and Brackett 1997, Wagner and Platt 1998, Eisinger and Burrows 1998, Hegels *et al*., 1998].

However they can still largely be regarded as explorative and preliminary.

In particular **instrument – oriented groups** that have conceived, suggested and supported the development of a satellite instrument, often for a decade or more, until it goes into orbit.

It is now important that a larger part of our scientific community appreciate the possibilities so that they may contribute to specifications for future instruments as well as making full use of the data becoming available.

Satellite measurements have, like those made with any other technique, **specific strengths** (like extensive spatial - frequently global -, and temporal coverage) **and weaknesses** (such as frequently giving only data for a total column). These strengths and limitations must be better understood in order to use the data to the best effect in tackling current scientific problems.

Judging from the recent development of the field, it is clear that many new (and frequently unexpected) applications of satellites will be discovered once enough expertise is brought together.

Examples:

- Discovery of huge amounts of BrO in the polar boundary layer during springtime by the GOME instrument,
- Global mapping of the tropospheric distributions of NO_2, HCHO and SO_2 are now close to reality.

THE SCIENTIFIC OBJECTIVES OF TROPOSAT

- A good fraction of the effort in TROPOSDAT is devoted to the exchange of information, reviewing the problems, and the education of the scientists in areas that will require the use of satellite data in the future.
- TROPOSAT is not a usual EUROTRAC-2 project, since its aim is to encourage the appropriate use of satellite data by scientists throughout EUROTRAC-2 and the community in atmospheric chemistry research.
- Similarly it hoped to make the agencies responsible for atmospheric policy development in Europe aware of the potential of satellites for providing, in the future, reliable data for monitoring the atmospheric environment.
- In practice the scientific results of TROPOSAT will be new areas of application of satellite measurements in tropospheric research, and new and improved algorithms for these applications and validation of the results.
- TROPSAT will – of course - (*e.g.* through the determination of the distributions of NO_x, SO_2, and aerosol) contribute directly to studies of photo-oxidants, aerosols and acidifying substances with EUROTRAC-2 (scientific tasks 1, 3 and 6, see sect. 5 of EUROTRAC-2 project description.)
- The work of TROPOSAT is divided between four task groups plus underpinning activities.

TROPOSAT Statistics:

Founded as 13th EUROTRAC-2 Subproject in 2000

As of today 43 participating groups

In 1991 alone 41 publications and 7 Ph.D. Theses

Five TROPOSAT plenary meetings

Next meeting: Nov. 21/22 at KNMI in Utrecht

TROPOSAT-TASK-GROUPS

Task group 1: Development of algorithms for the retrieval of tropospheric species and parameters. **A. Richter and T. Wagner**

Satellite measurements rely – to a much larger extent than conventional measurements – on sophisticated algorithms to extract the desired quantities from the raw data.

In particular task group 1 studies:

a) **Cloud shielding** of the troposphere decreases the apparent amounts of tropospheric species (*e.g.* BrO, Wagner and Platt [1998], Koelemeier et. al. [1999])

b) **Albedo/wavelength effect:** Measurements at different wavelengths have a different sensitivity for the troposphere because of the wavelength dependence of ground albedo and Rayleigh-scattering (*e.g.* NO_2, Richter *et al*. [2000]).

c) **Temperature effects:** For several species the T-dependence of the absorption cross section causes slightly different absorption structures for species in the cold stratosphere and warm troposphere (*e.g.* NO_2, Richter [1997]).

d) **Different temporal/spatial patterns:** For several species the lifetime in the troposphere is significantly smaller than in the stratosphere. Small scale spatial patterns can be attributed to the troposphere (*e.g.* BrO, NO_2, Wagner and Platt [1998], Leue [1999]).

e) **Combination of limb/nadir observations:** The latter are typically sensitive to the total column, while limb measurements yield the stratospheric column. From the difference e.g. SCIAMACHY will determinate the tropospheric columns for nearly all target species.

Focus on development and refinement of algorithms for:

- the spectral de-convolution and the better understanding of instrumental effects;
- radiation transport modelling is important in converting the recorded radiances or ‘apparent (or slant) trace gas column densities’ into vertical column densities or trace gas concentration profiles;
- cloud or haze detection and correction;
- deriving further quantities from the primarily measured and evaluated data, such as the calculation of UV levels and photolysis frequencies [*e.g.* Meerkoetter *et al*. 1997] or trace gas source strengths.

Task group 1: Development of algorithms

A. Richter and T. Wagner

Albert P.H. Goede	Retrieval of greenhouse and related gas parameters from SCIAMACHY/ENVISAT
Rodolfo Guzzi	Retrieval of Aerosol Load and Profile from Space
Anton Kaifel	Neural Networks Ozone Retrieval System for GOME Spectra (NNORSY-GOME)
Hennie Kelder	Retrieval and data assimilation algorithm development for tropospheric ozone and NO_2 from GOME and SCIAMACHY
Johannes Keller	Retrieval of tropospheric aerosol properties from space
Gerrit de Leeuw	Retrieval of Aerosol Properties over Europe
Jochen Landgraf	The use of GOME and SCIAMACHY Data to obtain Ozone Profiles and Carbon Monoxide and Methane Columns
Andreas Richter	Quantification of tropospheric measurements from nadir viewing UV/vis instruments
Martin Riese	retrieval of upper tropospheric H_2O, HNO_3, and CFC-11 distributions from infrared limb observations and synergetic use of the results
M. van Roozendael	Retrieval of tropospheric BrO and NO_2 from nadir UV-visible observations
Gabriele P. Stiller	Study on the retrievability of upper tropospheric species and parameters from MIPAS/ENVISAT data
Olaf Tuinder	Assessment of the Global Distribution of Trop. OH Radicals from GOME and SCIAMACHY Observation
Arnolds Ubelis	Ground Validation Station for Satellite based atmospheric sensor instruments GOME and SCIMACHY
Jean Verdebout	Development of satellite-derived information on trop. actinic flux and aerosol particulate matter
Thomas Wagner	Case Studies for the Investigation of Cloud Sensitive Parameters as Measured by GOME
Mark Weber	Ozone profile retrieval from broadband nadir UV/VIS satellite spectra: How accurate is the trop. profile?

Task group 2: Use of satellite data for understanding atmospheric processes. M. Dameris and C. Granier

Demonstrate how satellite data can be combined with model results and data from terrestrial measurement to improve our understanding of dynamic and chemical processes in the troposphere.

Satellite data are ideal for initialisation, boundary conditions, and test data for chemical transport models (regional and global CTM's).

By inverse modelling satellite data allow to identify and quantify emission and sink processes of pollutants; (e.g. lightning as NO_x source).

Because of their global and long-term availability, satellite data can support two further types of studies:

1) Provide wide-ranging supplementary data to support field studies, intensive measurement campaigns and observations at individual and groups of stations.
2) they are also suitable for long-term observations over periods of years, and thus can e.g. contribute to improving our understanding of the budgets of many trace substances.

In TROPOSAT activities include:

a) Case studies with chemical transport models including inversion of transport processes, *e.g.* with a Lagrangian tracer models;
b) Validation of chemistry-climate models;
c) Comparison and interpretation of model results and individual observations with satellite data.

The studies will address the following scientific problems:

- Identification of sources and sinks of pollutants;
- Export of pollutants out of Europe into the free troposphere and to the East;
- Assessment of the role of tropospheric-stratospheric exchange in the tropospheric ozone budget;
- study of the NO_x emissions from aircraft (in the upper troposphere) and from lightning;
- accurate characterisation of the atmosphere and its change in composition in time employing data assimilation analysis.

Task group 2: Use of satellite data to understand atmospheric processes.

M. Dameris and C. Granier

Peter J.H. Builtjes	Data Assimilation of Aerosol Satellite Observations
Claire Granier	Quantification of surface emissions of ozone precursors
Franz Rohrer	Use of ENVISAT Measurements for the Examination of the Nitrogen Oxide Budget in the Upper Troposphere
Martin Dameris	Validation of a fully coupled chemistry-climate model
Jann Forrer	The use of space-borne and ground-based measurements within the Swiss Air Pollution Monitoring System to determine a spatial distribution of air pollutants by combining space-borne and ground-based observations
Rainer Friedrich	Comparison of NO_2 emissions derived from satellite measurements with bottom up calculated emissions in Europe
Garry Hayman	Feasibility of Using ENVISAT Earth Observation Data as a Component of Air Quality Management (ENVIAQM)
Jean-C. Lambert	Global and regional climatologies of stratospheric and tropospheric NO_2 and BrO based on the integrated exploitation of satellite, ground-based, balloon and 3D model data
Mark G. Lawrence	Global Photochemical Model Evaluation using GOME Tropospheric Column Data
Ulrich Platt	Construction and Analysis of Image Sequences of Atmospheric Trace Gases
Hans Schlager	Export of pollutants over Europe
Andreas Stohl	Determination of sources of tropospheric trace gases by combining satellite measurements with inverse transport modelling
Andrea K. Weiss	Tracing Atmospheric Pollution with Satellite Measurements

Task group 3: Synergistic use of different instrumentation and platforms for tropospheric measurements **H. Smit and P. Monks**

Scientific challenge: To understand the atmosphere and to follow the atmospheric changes taking place in detail. Satellites with their frequent, global coverage will be of great assistance, but clearly cannot do everything.

Therefore terrestrial measurements will be continued to be needed, atmospheric measurements made with balloons and aircraft, and the chemical transport models required to encompass and understand the results. Thus use of multiple observations and models provide a synergistic improvement to the measurements from any one technique.

Task group 3 will address the following issues.

- Different satellite data sets will be combined to explore large scale NO_x sources and assess the contributions from lightning (derived from e.g. ATSR and non-satellites) and biomass burning.
- The comprehensive record of O_3 and water vapour measurements with quasi-global coverage made since 1994 from commercial aircraft within the European MOZAIC program will be used together with satellite data from different O_3 and H_2O profiling instruments (*e.g.* GOME, ENVISAT, CRISTA, MLS, METEOSAT, TOMS, TOVS) to explore the processes governing the global tropospheric O_3 and H_2O budgets [Helten *et al.*, 1998, Marenco *et al.*, 1998].
- Exploration of the possibility of including space-borne measurements (e.g. CO from ENVISAT) as an operational part in national air pollution monitoring networks.
- Improved FTIR-retrieval strategies from ground-based techniques will be exploited for synergistic use with satellite data.

Important aspect: The different contributions are covering a broad scale of integrated use of satellite and non-satellite data to study tropospheric processes on different spatial and temporal scales. The experience and the know-how achieved during the project are the first steps towards the establishment of an “Integrated Observation System” (cf IGOS) as part of an integrated research approach to explore the troposphere.

Task group 3: Synergistic use of different instrumentation

H. Smit and P. Monks

C.A.M. Brenninkmeijer	Comparing CARIBIC and Satellite Data (COCASAT)
John P. Burrows	Synergistic Use of Ground based, GOME and SCIAMACHY Tropospheric Retrievals
A. R. MacKenzie	Scientific applications of ENVISAT atmospheric data within the APE Research Community.
Valérie Thouret	Comparison between various satellite sensors and MOZAIC data
Martine De Mazière	Retrieval of tropospheric information from ground-based FTIR observations, supported by synergistic exploitation of various ground-based and space-borne measurement techniques and data.
Paul S. Monks	The development of multi-platform methods for derivation of tropospheric composition from space
Herman G.J. Smit	Control Mechanisms of Water Vapour in the UT
Ralf Sussmann	Satellite plus Ground-Based FTIR Measurements for Tropospheric Studies: Towards an Integrated Global Measurement System (IGMS) and an Improved Validation Strategy

Task Group 4: Development of Validation Strategies for Tropospheric Satellite Data Products. H. Kelder

The novel algorithms allowing the observation of tropospheric composition from space require thorough testing and verification.

Thus strategies for the geophysical validation of tropospheric satellite data products need to be developed and applied:

- collection of comparative measurements (ground-based, aircraft, and other satellite measurements);
- intercomparison of these measurements with the satellite data; comparison of the satellite data with model results;
- analysis of different retrieval methods; analysis of different measuring techniques; use of data assimilation methods.

Among the validation activities envisaged are the following.

Validation of the tropospheric output from the ENVISAT instruments, SCIAMACHY, MIPAS and GOMOS.

Improved strategies for validation envisaged for comparison of satellite data must take into account the different vertical resolution, averaging kernels and viewing geometries of the technique used for validation and the satellite instrument.

Ground-based data to be used for validation will include the ozone sonde data available from the NILU/NADIR data base, the long term NO_2, ozone, SO_2, and aerosol measurements in the EMEP data base. This will be combined with inverse modelling activities. Comparisons are involving, FTIR measurements, with a focus on the tropospheric O_3, CO, CH_4, N_2O, and H_2O.

The *validation comparisons with aircraft measurement*s will include those produced from the EC project, CARIBIC, data from the high-altitude aircraft M-55 Geophysica, and the MOZAIC data. Other comparisons will deal with radiation budgets and albedo estimates, aerosols, scattering coefficients, and concentration profiles of HCHO and CO.

Attempts at *validation using model results* include comparing the SCIAMACHY CO and CH_4 tropospheric columns with results from the 3D chemistry transport model, TM3. The MOPITT CO and CH_4 data will be compared with GCM models.

Task Group 4: Validation of tropospheric satellite data

H. Kelder

Ilse Aben	Validation of Methane and Carbon Monoxide Data from SCIAMACHY
D.W. Arlander	Validation from long term tropospheric measurements for use and usability of satellite data
D.W. Arlander	Validation assistance from the NILU/NADIR data base
Cornelis Blom	Validation of tropospheric satellite data products using *in-situ* and remote-sensing observations from the high-altitude platform Geophysica
Hendrik Elbern	Validation of Variational Satellite Data Assimilation Analyses by in-situ Observations
Bo Galle	Satellite validation using groundbased spectroscopical techniques.
Rodolfo Guzzi	Retrieval of Aerosol Load and Profile from Space
Wolfgang Junkermann	Radiation Budgets and Trace Gas Distributions in Planetary Boundary Layer and Free Troposphere from Airborne *in-situ* Measurements
Hennie Kelder	Co-ordination of the validation activities for SCIAMACHY
Alexander Meister	Validation of a spaceborne sensor for the investigation of dust storms over the Mediterranean and the Atlantic ocean using an airborne LIDAR system
Rudi Zander	Monitoring of the variability and long-term evolution of tropospheric constituents by infrared solar absorption spectrometry at the Jungfraujoch, Switzerland

UNDERPINNING AND DERIVED ACTIVITIES

The main task group activities will require supporting research, also we expect to undertake some derived activities.

- **Development of appropriate data assimilation techniques.**

Satellites can observe the Earth with nearly complete global and good temporal coverage. They also offer the only practical method of obtaining data over certain areas of the world, especially the oceans and remote land areas.

The aim of data assimilation is the combination of our theoretical understanding encapsulated in a model, with measurements (which may be sparse), and any *a priori* information that we might already have (*e.g.*, climatologies) to analyse and/or forecast the state of the atmosphere at any given time or place. [*e.g.* Lary 1999].

Data assimilation techniques enable us to exploit information elegantly that is simply not available by using models or observations independently.

Software already available includes Optimum interpolation, 4D-Var, and the Kalman filter data assimilation tools.

- **Specification of requirements for new satellite instruments.**

Measuring chemical species in the **troposphere** from space is at the forefront of current science and technology and clearly needs **development of new observing techniques, concepts, and strategies.**

Within the next years there will be opportunities to propose new satellite missions addressing the requirements of measuring the troposphere from space.

Understand the fundamental science, policy, and also the technological limitations.

As questions arise about the changing nature of the troposphere, it is essential to develop and to take advantage of these new methods and techniques and to integrate them with scientific requirements

TROPOSAT will provide a European forum for development of concepts for instruments and platforms aimed at observing tropospheric parameters from space (new concepts such as GEO-SCIA, observing the troposphere from a geostationary orbit),

New options are likely to be available for space borne instrumentation with the growing commercial use of space and the use of small satellites as in the IRIDIUM and GLOBALSTAR networks, which will require smaller and lighter instrumentation developed over shorter time scales.

Industry and the scientific community should be encouraged to participate at an early stage in the definition of and priority for new satellite instrumentation for measuring the troposphere and so be allowed to influence the future prospects for future tropospheric measurements and science. Within EUROTRAC-2, TROPOSAT will develop an European wide approach for specifying the requirements for new instrumentation and techniques.

TROPSAT - A forum for exchange of expertise

The exchange of knowledge, expertise, and ideas between scientists throughout the tropospheric community is a primary goal of this proposal. Therefore a good fraction of the effort in this project will be devoted to the exchange of information, view of the problems, and education of the scientists in the areas of research, which are important for the successful use of satellite data.

Equally important is to ensure that the “satellite instrument community” (i.e. the scientists and groups working on the design of satellite instruments and the development of evaluation methods) are fully aware of the needs and requirements of the atmospheric scientists.

Besides the organisation of workshops open to the general scientific community there will be special workshops on selected subjects (like image processing or the properties of the satellite instruments of interest to the atmospheric research).

Obviously this project is rather an open forum for ideas than pursuing a defined set of scientific tasks. However it can be assumed that research might be needed in the following areas:

SATELLITE INSTRUMENTS FOR TROPOSPHERIC RESEARCH, SPECIES MEASURED AND THE SATELLITE PLATFORM.

(NOT INTENDED TO BE COMPLETE)

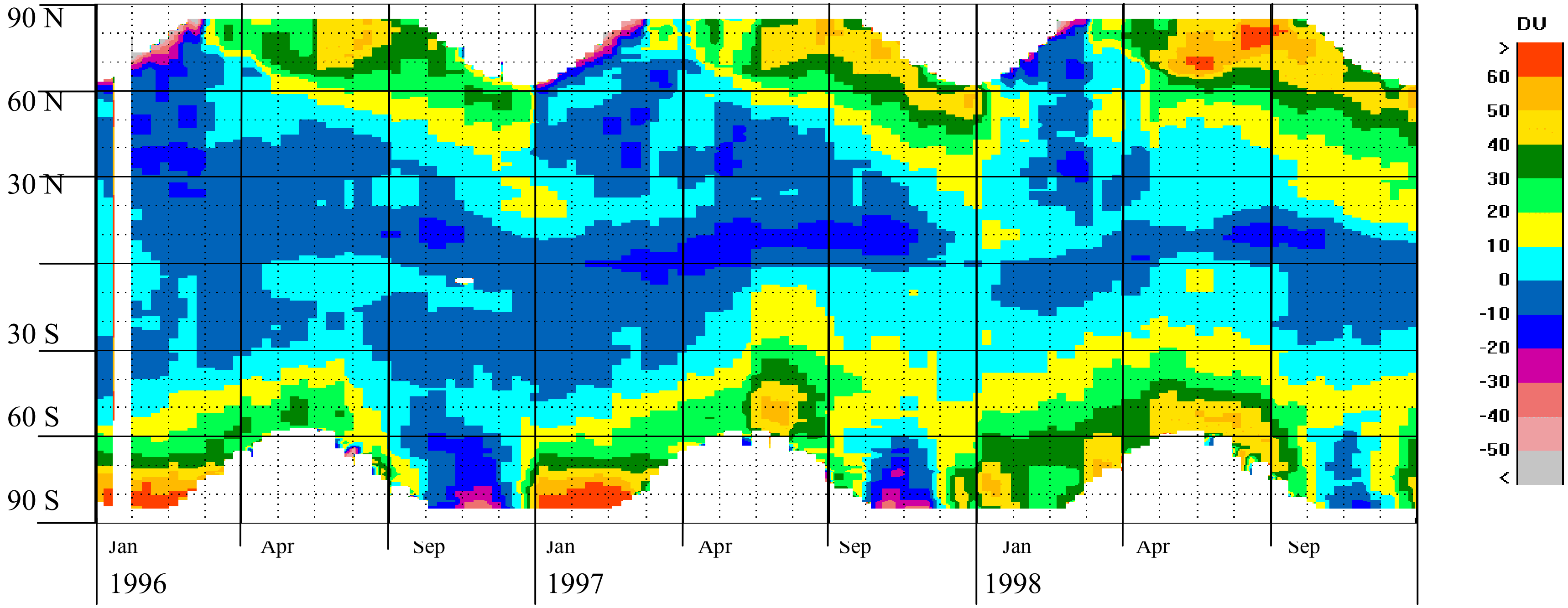
Instru-ment	Name	Height of measure-ment[a]	Target Species	Platform
ATMOS	Atmospheric Trace Molecule Spectroscopy	ST and **upper Tr**	O_3, NO_x, N_2O_5 $ClONO_2$, HCl, HF, CH_4, CFCs, etc.	Space Shuttle Spacelab-3 (1985), ATLAS-1,2 and 3 (1992,1993 and 1994)
ATSR	Along Track Scanning Radiometer	**TR**, sea surface	Aerosols, clouds, sea surface temperature	ESA-ERS1,2 (1991-present)
AVHRR	Advanced Very High Resolution Radiometer. Four channels on the first 4 platforms listed, five channels on the last 5 platforms	**TR**	Smoke, fire, clouds aerosols, vegetation	TIROS-N, NOAA-6, -8, - 10; -7, -9, -11, -12, -13 (1978- present)
BUV	Backscatter Ultraviolet Ozone Experiment	ST, **TR**, profiles	O_3	Nimbus-4 (1970-1974)
GOME	Global Ozone Monitoring Experiment	**TR** and ST	O_3, NO_2, H_2O BrO, OClO, SO_2, HCHO, clouds and aerosols	ESA-ERS-1 (1995-present)
GOMOS	Global Ozone Monitoring by Occultation of Stars	**Upper TR**, ST and ME	O_3, NO_2 NO_3	ESA ENVISAT (2000)
IMG	Interferometric Monitor for Greenhouse Gases	ST and **TR**	O_3, N_2O, H_2O, CH_4, CO and CO_2	ADEOS (1996-97)
MAPS	Measurement of Air Pollution from satellites	**TR**	CO	STS-2 (1981); Space Shuttle (1984 and 1994)
MERIS	Medium Resolution Imaging Spectrometer for Passive Atmospheric Sounding	**TR**	H_2O, clouds and aerosol	ESA-ENVISAT (2000)

Table continued

MIPAS	Michelson Interferometer for Passive Atmospheric Sounding	Upper **TR**	O_3, NO_x, N_2O_5 $ClONO_2$, CH_4, CFCs, etc., T	ESA ENVISAT (2002)
MOPITT	Measurement of Pollution in the Troposphere	**TR**, profiles	Total column of CO, CH_4 + CO profiles	NASA AM-1 (1999)
OMI	Ozone Monitoring Instrument	**TR**	O_3, SO_2, NO_2,	EOS-CHEM (2004)
POLDER	Polarisation and Directionality of the Earth's Radiance	**TR**	Polarisation, aerosols, clouds	ADEOS-1 (1996-97)
SAGE I	Stratospheric Aerosol and Gas Experiment I	**Upper TR** and ST profiles	O_3, NO_2, aerosols	NASA Atmospheric Explorer Mission (1979-81)
SAGE II	Stratospheric Aerosol and Gas Experiment II		O_3, NO_2, H_2O, aerosols	NASA Earth Radiation Budget Sat. (1984 – pres.)
SAGE III	Stratospheric Aerosol and Gas Experiment III		O_3, OClO, BrO, NO_2, NO_3 aerosols	Meteor 3M (1999); Space Stat. (2002)
SBUV	Solar Backscatter Ultraviolet Ozone Experiment	ST, **TR**, profiles	O_3	Nimbus-7 (1979-90)
SBUV-2	Solar Backscatter Ultraviolet Ozone Experiment 2	ST, **TR**, profiles	O_3	NOAA –9 (1985-present) –11(1989-95)-14 (1995-pres.)
SCIA-MACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography	**TR**, ST, and ME total columns and profiles	O_3, O_2, $O_2(^1\Delta)$, O_4, NO, NO_2, N_2O, BrO, OClO, H_2O, SO_2, HCHO, CO, CO_2, CH_4, cloud, aerosol, p, T.	ESA-ENVISAT (2002)
TES	Tropospheric Emission Spectrometer	**TR** total columns and profiles	Various incl. HNO_3, O_3, NO, H_2O	NASA-EOS-CHEM (2003)
TOMS	Total Ozone Monitoring Spectrometer	ST, **TR**, profiles	O_3	Nimbus 7 (1979-92) ADEOS (1996-97) Earth Probe (1996-) Meteor (1992-94)

[a] TR: troposphere, ST: stratosphere

Temporal distribution of differences between the ozone columns retrieved from GOME and from TOVS.



Positive values refer to points where TOVS columns are higher than GOME, negative values to where GOME columns are higher than TOVS. (Dameris et al. 2002)

Seasonal variation of tropospheric NO_2 vertical column over Europe derived from GOME measurements.

(Wenig, University of Heidelberg, 2001)