

BELGIUM

Introduction

The main research institutes that are currently involved in ozone/UV and ozone related observations and research include:

- the Royal Meteorological Institute (KMI-IRM)
- the Belgian Institute for Space Aeronomy (BIRA-IASB)
- the Université de Liège (ULg) - Institute of Astrophysics and Geophysics
- the Université Libre de Bruxelles (ULB)

The laboratory of Plant Ecology of the University of Antwerp has been involved in UV-B research from 1992 to 2000.

The Belgian Federal Office for Scientific, Technical and Cultural Affairs (DWTC-SSTC) is presently funding the ESAC II (Experimental Studies of Atmospheric Changes) project in the framework of the Federal Multi-annual Scientific Support Plan for a Sustainable Development Policy (2001-2005) partim Global Change, Ecosystems and Biodiversity.

This project represents a national effort to continue the existing Belgian contribution to the long-term surveillance of the Earth's atmosphere.

Its main objectives are the following:

- Extend and improve the important existing Belgian contribution in atmospheric research that was started in the 1950s, and that is internationally recognised.
- Investigate the composition of the atmosphere, to detect and understand its evolution, mainly through field observations. Special attention is being paid to the evolution of the ozone layer and chemical species and processes with an impact on climate changes; this research is specifically conducted within the frame of the European contribution to the Network for the Detection of Stratospheric Change (NDSC; for details, visit the home page <http://www.ndsc.ws>).
- Support the Belgian policies and decisions regarding the Amendments to the Montreal and Kyoto Protocols.

The ESAC project is co-ordinated by the Belgian Institute for Space Aeronomy and involves the Royal Meteorological Institute, the Institute of Astrophysics and Geophysics (ULg) and the Université Libre de Bruxelles (see <http://www.oma.be/ESACII/Home.html>).

Via the budget for "Impulse for research in the Belgian federal scientific institutes" some relevant projects at the BIRA/IASB are funded:

- Measurement, understanding and climatology of stratospheric aerosols
Duration: 1/1/2000-31/12/2003
- Global distribution and variability of tropospheric and stratospheric nitrogen dioxide : enhancement and synergistic use of the multi-platform observing system
Duration: 1/1/2001-31/12/2002
- Study of vertically resolved ground-based FTIR measurements at the Jungfrauoch for investigating dynamical and chemical processes at northern mid-latitude

Belgium participates in the optional ESA programmes that manage the ERS (European Remote Sensing) and ENVISAT (ENVIronmental SATellite) satellite missions. Concerning the study of the atmosphere, GOME (Global Ozone Monitoring Experiment) on ERS-2 and GOMOS (Global Ozone Monitoring by Occultation of Stars), MIPAS (Michelson Interferometer for Passive Atmospheric Sounding) and SCHIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CHartography) on ENVISAT are the main atmospheric sounding instruments that measure trace gases and ozone in the atmosphere and detect their timely concentration changes.

Belgium further participates substantially in the PRODEX optional programme of ESA since 1988. PRODEX finances proposals addressing the development of new instruments for ESA satellites,

their calibration and validation, as well as their data processing including the development of algorithms, the implementation of specific applications and the general scientific data exploitation. Belgian relevant projects financed by this programme are: the Ozone validation campaigns in the context of the EUMETSAT SAF Ozone and Atmospheric Chemistry validation for the ERS and ENVISAT satellites (GOME exploitation, CINAMOM, ENVISAT-UV, SADE, ACHIWE,

Belgium is one of the four participating states in the optional Data User Programme (DUP) of ESA (1996-2003). Relevant Belgian DUP projects are: global aerosol mapping and ozone monitoring. After 2003, this programme will be integrated into the optional Earth Observation Envelope Programme (EOEP) of ESA, in which Belgium is involved since 1999.

Belgium also supports strongly the GMES (Global Monitoring for Environment and Security) initiative of the EC and ESA and participates actively in the 'GMES Services', which is part of the optional ESA Earth Watch programme.

The research institutes in Belgium: observation and research activities

The Royal Meteorological Institute (KMI-IRM)

Observations

- Daily monitoring of the total ozone amount using a Dobson spectrophotometer (Serial nr. 40) and an automated Brewer spectrophotometer (Serial nr. 16). Both direct sun (if possible) and zenith sky measurements are performed several times per day. A new Brewer double monochromator (Serial nr. 178) was installed in September 2001. All instruments are calibrated with respect to standard spectrophotometers. Their calibrations are kept completely independent, which allows mutual quality control of the data.
- Daily monitoring of UV-B radiation using the Brewer spectrophotometers. The calibration is checked on a regular basis by means of certified calibration lamps.
- Vertical ozone distribution measured three times per week by means of balloon soundings. Brewer-Mast ozone sondes were used up to March 1997, and ECC ozone sondes onwards. By applying appropriate correction procedures based on previous comparative studies and research, the mean difference between ozone profiles from both types of sondes was reduced to less than 3% at all altitudes.

Remarks: All routine observations (ozone and UV-B) are performed at Uccle (50°48'N, 4°21'E, 100 m asl) which is now accepted as an NDSC complementary site for ozone column and profile measurements. In the near future all measurements (including the historical data going back to 1969) will be archived in the Network's Data Host Facility at NOAA (Washington, DC).

Research

- Over the last years considerable effort was put in homogenising the long time series of total ozone amount and vertical ozone distribution at Uccle. Monitoring the quality of the observations is a permanent activity.
- Comparison of ozone profiles from ozone soundings at Uccle and profiles obtained from the SAGE II satellite instrument has confirmed the homogenisation consistency of the Uccle data sets.
- The trends of both total ozone amounts and vertical O₃ distributions are studied regularly. The relation between tropospheric ozone and meteorological parameters is currently under investigation.
- A UV Index forecasting procedure has been developed. During the summer months forecasted values of the UV Index are made available to the media in Belgium. An effort is being made to improve the understanding of the relation between measured and modelled UV intensities to derive optical depths in the UV from the Brewer observations.

Participation

- In the Belgian ESAC-II project.
- In ongoing international projects dealing with tropospheric ozone:
TOR-2 (Tropospheric Ozone Research) in the framework of EUROTRAC-2;
- In programmes for validation of ozone data from satellite instruments:
 - Geophysical validation campaign of GOME aboard ERS-2;
 - Validation of ozone measurements from SCIAMACHY, MIPAS and GOMOS aboard Envisat;
 - Ozone SAF (Satellite Application Facility) of EUMETSAT.

(d) Representation in international organisations

- EUMETSAT
- O₃ SAF
- COST 713 on UV-B forecast (terminated in 2001)
- ASOPOS (Assessment of Operating Procedures for Ozone Sondes), in co-operation with WMO/GAW
- NDSC
- Brewer and Dobson ad hoc committees of WMO/GAW

University of Liège (ULg)

(a) Observations

- Infrared solar observations performed regularly at the International Scientific Station of the Jungfrauoch (ISSJ, Swiss Alps, 3580 m asl) which became part of the northern mid-latitude “Primary NDSC Station” in 1989.
- Time period of observations: limited historic data in 1950-51, then increasing number of routine observations since 1976; after mid-1980s, monitoring of over 20 species, with some fifteen of direct relevance to the Vienna (1985) and the Climate (1992) Conventions.
- Type of instruments: initially grating spectrometers then wide-band, very high spectral resolution Fourier transform Infra-Red (FTIR) instruments allowing to study multiple species, simultaneously; geophysical parameters consist in total- and partial column abundances above the site.
- Archiving: series of NDSC-relevant molecules (e.g., HCl, ClONO₂, HF, COF₂, HNO₃, NO₂, NO, O₃, CFC-12, HCFC-22) measured from 1989 to present, archived at the NOAA Data Host Facility and at NILU (Norway); pre-1989 data to be archived as time permits, but available upon request; specific databases archived at NILU in support of European campaigns such as ESMOS, SESAME and THESEO, and for validating the GOME satellite experiment

(b) Research

- Through its participation in the reanalysis of quasi-global observations by the American shuttle-based FTIR instrument ATMOS (Atmospheric Trace MOlecule Spercetroscopy), members of ULg have contributed to the automatic retrieval of some 30 atmospheric constituents between about 70 and 5 km altitude, thus demonstrating the possibility to sound both the stratosphere and the free troposphere from space (for details, visit <http://remus.jpl.nasa.gov/atmosversion3/atmosversion3.html>).
- Participation to the Belgian ESAC–1 and -2 projects. The main objective is to contribute inputs in support of the Montreal and Kyoto Protocols, thus contributing to sustainable development policies.

- Participation in EC projects: COSE, SOGE, THESEO-2000+, also in the EUROTRAC-2/TROPOSAT subproject.
- Contributions to ESA-co-ordinated calibration/validation projects in support of the ENVISAT mission.
- Participation in the definition of the Canadian ACE space mission and the European IASI/EUMETSAT experiment, and preparation to support their validation.

(c) *International involvements*

- Scientific contributions to international assessments issued regularly by the WMO and by the EC.
- Representations in the EC-Ozone Panel, the SAG of ENVISAT-MIPAS, the NDSC-GAW, the IOC.

Belgian Institute for Space Aeronomy (BIRA-IASB)

(b) *Observations*

(a1) *Ground based observations*

- Monitoring of O₃ and interacting species (halogens, NO_y, BrO, HCFC, CFC,...) for budget and long-term trend studies: continued since eighties
- Monitoring of UV-B
- Campaign measurements for related process studies, e.g., in the frame of THESEO, SESAME, EASOE (EC)
- Some focus on tropospheric O₃ in LS/UT and free troposphere - inversion methods for ground-based data to derive information about vertical distributions of atmospheric species, in particular distinct tropospheric and stratospheric abundances (O₃ sondes at Uccle/Ukkel, see RMI section 2.1; differential campaign in Jungfraujoch area in summer 1998; long-path measurements at ULB campus)
- Observatories and instruments involved:
 - Jungfraujoch: FTIR and SAOZ instruments. SAOZ measures O₃ and NO₂ columns in the UV-Vis spectral range, since 1990. The time series of FTIR data starts in the early eighties (see ULg section 2.2)
 - Uccle/Ukkel (see section 2.1 for Dobson, Brewer and O₃ sondes): UV-B instruments (spectral UV-B measurements), since 1993
 - Harestua, Norway, 60°N, 11°E: UV-VIS DOAS instruments, since 1994 (O₃, NO₂, OCIO, BrO)
 - Observatoire de Haute Provence (OHP), France, 44°N, 8°E: UV-VIS DOAS instrument (O₃, NO₂, BrO columns), since summer 1998. The UV-VIS DOAS instrument has been upgraded with an off-axis capability in 2000 and since then provides also tropospheric abundances of O₃, NO₂, BrO, and H₂CO.
 - Ile de la Réunion (22°S, 55°E) : UV-Vis DOAS off-axis instrument (O₃, NO₂, BrO, H₂CO columns and tropospheric abundances), starting in summer 2002.
 - Mobile Fourier-transform instrument for campaign measurements; the first one will be held in Ile de la Réunion (22°S, 55°E), in Sept-Oct. 2002

Remarks: All sites are NDSC-affiliated. Data concerning the chemical species are submitted to NADIR/NILU and NDSC/NOAA databases; UV-B data are in the SUVDAMA (EC) database.

(a2) *Balloon measurements*

- Stratospheric balloon measurements of species relevant to the O₃ issue, in particular HNO₃ vertical profiles between 15 and 35 km, possibly ClONO₂ and HCl in the future. The technique used is chemical ionisation mass spectrometry.

Research

(b1) Satellite experiments, in particular GOME/ERS-2 (current) and ENVISAT

- Validation and maturation of level 2 products, including O₃, NO₂, BrO, and aerosol, based on ground-network correlative observations
- Development of climatologies of some stratospheric species like NO₂, ...
- Scientific studies concerning O₃ related dynamical and chemical processes are ongoing, in preparation of the exploitation of the ENVISAT data
- Chemical 4D variational data assimilation, in particular of O₃ (see also modelling)
- Extra-terrestrial solar UV irradiance calibration, UV proxies, and mapping of UV at the surface, UV-index mapping
- Analysis of stratospheric aerosol data: characterisation, climatology, etc., based on exploitation of ORA/EURECA radiometer and SAGE II data; in future, extension towards ENVISAT data
 - Spectral inversion of satellite data (BrO from GOME, aerosol from ORA and GOMOS (prototype algorithm)).

(b2) Modelling studies

- Complete 3D modelling of the stratosphere, including transport, chemistry, aerosol micro-physics and a heterogeneous chemistry module
- Chemical 4D variational data assimilation, in particular of O₃
- 1D box model for process studies, and for interpretation of UV-Vis DOAS observations
- Studies based on 3D model IMAGES for the troposphere and UT/LS boundary region
- Development of inverse tropospheric modelling methods, to identify emissions

(b3) Laboratory measurements (in co-operation with ULB; see section 2.4)

- Spectroscopic studies in support of remote sensing experiments (optical spectroscopy, ion chemistry for mass spectrometry applications,...)
- Spectroscopic studies in support of investigations concerning global warming issue
- Radiometric calibration for UV monitoring instruments

(c) Representation in international organisations

- WMO: UV-SAG (GAW)
- SPARC/WCRP
- NDSC (GAW/WMO)
- SAG of GOME and GOME-2, GOMOS, SCIAMACHY, OMI
- O₃ Panel (EC), Vintersol Core Group (EORCU)
- ESA council
- Member of the Science Team of the Canadian ACE/SciSAT mission

(d) Participation

- to International assessment studies: the EC Scientific Assessment 'European research in the stratosphere 1996-2000, Advances in our understanding of the ozone layer during THESEO', EUR19867, 2001
- in many EC projects; ongoing projects are: QUILT, UFTIR (+ co-ordination), MAPSCORE
- in TROPOSAT, subproject of EUROTRAC-2
- in the project 'Chemistry and climate related studies using the IASI remote sensor' for preparing the scientific research aspects of the IASI mission onboard METOP-1 (launch nominally 2005).

Universite Libre de Bruxelles (ULB)

(a) Observations

- Infrared and UV-Visible solar observations performed at the Brussels (ULB campus) site.
- Campaign solar observations facilities are being installed on Ile de la Réunion

Type of instrument: very high spectral resolution Fourier transform spectrometer operating in the IR, Vis and UV regions, allowing to study multiple species simultaneously and yielding total- and partial column abundances above the sites.

(b) Research

- Laboratory spectroscopic studies in support of remote sensing experiments (absorption cross-sections and absolute intensities).
- Laboratory spectroscopic studies in support of global warming issues.

(c) Participation

- in the Belgian ESAC (Experimental Studies of Atmospheric Changes), the main objective of which is to contribute inputs in support of the Montreal and Kyoto Protocols (collaboration with IASB, IRM and ULg)
- in the ACE (Atmospheric Chemistry Experiment) project of the Canadian SCISAT-1 satellite mission and co-ordination of the Belgian contributions.
- in the IASI project of the European EUMETSAT mission on board the future METOP satellite

The Laboratory of Plant Ecology of the University of Antwerp

(a) Observations

During the past years regular, but not continuous measurements of UV-B were made at the University (Wilrijk/Antwerpen) using an Optronic OL754 spectro-radiometer, last calibrated in 1998. Due to technical problems with these measurements, they have not been included in any data-network. The measurements have been discontinued and it is as yet unclear whether they will resume.

(b) Research

The laboratory of Plant Ecology of the University of Antwerp has been involved in UV-B research from 1992 to 2000. The main objectives were to describe and model the impact of increased UV-B levels on the growth, physiology and productivity of crop plants. During the first years bean and rye were studied both in growth chambers using artificial light and in greenhouses of different UV-transmitting Plexiglas. In these studies differences of 10-20% in UV-B were used. Since 1997 the attention focused on grassland species. The sensitivity of 6 economically important grass species has been screened in a greenhouse study. The results indicate huge differences between the species. Some are seriously damaged by ambient UV-B doses while others are positively affected by these same doses. Both total growth and plant morphology are influenced by UV-B, but not always at the same time indicating the existence of a photo-morphological response to UV-B. In 1999-2000 the interactive effects of different UV-B levels with enhanced CO₂ were studied. Ambient UV-B increased the positive effect of CO₂ on growth of different grass species and of white clover. Furthermore the effects of UV-B on competitive interactions between grass and white clover were investigated. The results showed that current UV-B levels have only photomorphogenic effects on both species, but the resulting changes in biomass allocation can nonetheless influence competitiveness and thus result in reduced growth of some species.

Original key results

The evolution of Ozone at Uccle

Over Uccle the total ozone content has decreased by 1.2 +/- 0.6 % per decade during the period August 1971 - December 2001. This negative trend is mainly due to decreasing ozone concentrations in the stratosphere during the winter/spring period, as observed from the results of the ozone soundings since 1969. The troposphere shows an increase in ozone concentrations.

Jungfraujoch long-term observations

- Since 1986, monitoring of the vertical column abundances of HCl and ClONO₂, which are the main **inorganic Cl_y reservoirs** in the stratosphere; their sum shows that the rate of increase of Cl_y has progressively slowed down during the mid-1990s, and has stabilised since about 1997, in response to the production regulations on O₃-depleting substances outlined in the Montreal Protocol and its Amendments and Adjustments. Ongoing measurements should provide indications regarding a statistically significant rate of decrease of Cl_y following this stabilisation.
- Monitoring of the evolution of anthropogenic **chlorine-bearing source gases** such as CFC-12 and HCFC-22 demonstrates the efficiency of the amended Montreal Protocol upon regulated versus unregulated ozone-depleting compounds.
- The **O₃ column** monitoring above ISSJ from 1984 to 2001 shows an average decrease of (-0.25 ± 0.12) % per year; the large uncertainty results from the strong perturbation that resulted from the Mt. Pinatubo eruption in 1991 and affected the stratospheric ozone layer during 3 to 5 years.
- The vertical column monitoring of the most abundant **NO_y compounds** (HNO₃, NO₂, NO, ClONO₂) shows no statistically significant change in their total stratospheric loading. However, NO₂ reveals a statistically significant rate of increase of (0.6 ± 0.2)%/yr which is commensurate with similar studies at southern mid-latitudes.
- The continued, although slowing rise of the **inorganic fluorine concentration** HF + COF₂ in the stratosphere, contrary to the decrease of chlorine. At present, the observed rate of change is in poor agreement with model predictions and correlative observations.
- Determination, from the mid-1980s to present, of the rates of increase of the major **radiatively active gases** that are to be regulated by the Kyoto Protocol: CO₂ (mean 0.41%±0.01% / year), CH₄ (slowing down from 0.74%/year in 1987 to 0.1%/year in 2000), N₂O (mean 0.30%/year), SF₆ (slowing down from 14%/year in 1987 to 5%/year in 2000).
- **Tropopause heights** appear to have risen during the eighties, and lowered in the nineties. This may correlate with changes in the radiative balance in the atmosphere. The tropopause changes may also explain observed differences in the rates of change of N₂O concentrations at sea-level versus total column trends; they may also correlate with the slowing in the nineties of the negative total ozone trend that was observed in the eighties. Has a recovery of ozone been observed after 1994 ? The question whether this signature is due to inter-annual variability or to a steady trend will be answered by extending the times series in the future.

UV spectral irradiance measurements at Uccle

Having acquired now about 11 years of UV spectral irradiance data, a UV climatology has been developed. The key factors that influence the UV dose at ground level are the occurrence of clouds and the amount of ozone: their impact has been studied. Because of the large variability of these factors, the available time series of UV data appears to be too short to detect a possible UV trend in a reliable way.

An operational **UV index forecasting procedure** has been developed and implemented: UV Index forecasts are now disseminated daily to the public in the late spring and summer months.

Laboratory data

The molecules for which new or more accurate spectroscopic data (absorption cross-sections, line positions and intensities) have been obtained are: O₂ and its collision complexes O₂-X with X=N₂, Ar, or O₂ itself), NO₂ and its dimer N₂O₄, H₂O and its isotopomers HOD and D₂O, C₂H₂, OCS, HOCl, and HCFC-22 and HFC-152a.

Progress in instruments, data analysis and interpretation

New climatological models have been developed for particular purposes, e.g., for O₃, based on the Uccle soundings and local tropopause altitudes, for NO₂, based on the synergy between satellite and ground-based data and models, and for HF, HCl and CH₄, based on HALOE satellite data.

The development and quality assessment of the GOME BrO product

The development of a correlative data base for ENVISAT

Co-ordinates of Belgian institutes involved with ozone related observations and research

Royal Meteorological Institute
Dr. D. DE MUER (ozone observations)
Dr. H. DE BACKER
Avenue Circulaire 3
B-1180 Brussels
Tel: +32-2-373 06 11
Fax: +32-2-375 50 62
Hugo.DeBacker@kmi-irm.be
ddm@oma.be
<http://www.kmi-irm.be/>

Université Libre de Bruxelles
Labo. de Chimie Physique Moléculaire
Prof. R. COLIN (laboratory studies)
CP50, Ave. F.D. Roosevelt
B-1050 Brussels
Tel: +32-2-650 24 20
Fax: +32-2-650 42 32
rcolin@ulb.ac.be

Belgian Institute for Space Aeronomie
Dr. P.C. SIMON, Director
Dr. M. DE MAZIÈRE (Satellite borne remote measurements of the composition of the atmosphere, implementation and testing of retrieval algorithms to invert observations into geophysical data)
Dr. J.-F. MULLER (Global tropospheric ozone modelling)
Dr. D. GILLOTAY (Ground based measurements of solar radiation: UVB)
Avenue Circulaire 3
B-1180 Brussels
Tel: +32-2-373 04 11
Fax: +32-2-374 84 23

Martine.DeMaziere@mailserv.oma.be
pauls@aero.oma.be
jfm@oma.be
<http://www.oma.be/BIRA-IASB/>

Institute of Astrophysics and Geophysics
University of Liège
Prof. R. ZANDER and Dr. E. MAHIEU
(ATMOS, ISSJ observations; R.Z., NDSC co-chairman)
Institute of Astrophysics and Geophysics
17, Allée du 20 Août
B-4000 LIEGE
Tel.: 32 4 3669756
Fax: 32 4 3669747
r.zander@ulg.ac.be
emmanuel.mahieu@ulg.ac.be

University of Antwerp (UIA)
Department Biologie
Laboratory of Plant Ecology
Dr. G. Deckmyn
Universiteitsplein 1
B-2610 Wilrijk
Tel+32-3-8202257
Fax: +32-3-8202271
gaby.deckmyn@uia.ua.ac.be

Federal Office for Scientific, Technical and Cultural Affairs
Mrs. M. VANDERSTRAETEN (Advisor for scientific affairs)
Wetenschapsstraat 8 Rue de la Science
B-1000 Brussels
Tel: +32-2-23 83 610
Fax: +32-2-33 05 912
[E-mail: vdst@belspo.be](mailto:vdst@belspo.be)
<http://www.belspo.b>
