

# SPACE RESEARCH IN BELGIUM

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## **Preface**

This report has been prepared on behalf of the Belgian National Committee on Space Research of the "Académie Royale de Belgique" and the "Koninklijke Academie van België", for presentation at the 31st Scientific Assembly of the Scientific Committee on Space Research (COSPAR), Birmingham, United Kingdom, 14-21 July 1996.

It summarizes basic and applied space research undertaken by Belgian teams in various research institutes and universities. The names and addresses of these institutions are listed in Appendix of this report.

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# I. External Geophysics

## A. Belgian Institute for Space Aeronomy

### 1. The Grille spectrometer experiment onboard the ATLAS-1 mission

The Grille spectrometer has been developed and operated as a joint French-Belgian experiment (ONERA/LPMA and BISA)<sup>1</sup>. First deployed from stratospheric balloons in the seventies, it participated to the Spacelab-1 mission in December 1983 and the first ATLAS mission (Atmospheric Laboratory for Applications and Science) in 1992. Its objectives are the study of the vertical composition of the earth's lower stratosphere up to lower thermosphere via infrared solar occultation absorption spectroscopy, with focus on measurements of the following 10 molecules, in the 2.5 to 10  $\mu\text{m}$  spectral range: CO, CO<sub>2</sub>, NO, NO<sub>2</sub>, N<sub>2</sub>O, H<sub>2</sub>O, CH<sub>4</sub>, O<sub>3</sub>, HCl, and HF.

The retrieval of the Grille/ATLAS1 data has been performed independently by at least two different inversion algorithms, one being a least-squares global fit method, the other one an optimized Mill's inversion algorithm: as such, the quality of the results has been assessed reliably. Whenever possible, the results have been compared to correlative data from ATMOS onboard the same mission or from HALOE onboard UARS, or else to model data. The optimization of the inversion algorithm also included the development of appropriate graphical interfaces for facilitating the different processes that make up the data retrieval procedure; at BISA the retrieval is done on the Unix systems.

During the ATLAS1 flight, the earth lower stratosphere was heavily loaded with volcanic aerosols injected by the Pinatubo eruption in 1991. A careful analysis of measured spectra and corresponding auxiliary data, together with appropriate simulations, led to the conclusion that the sun-seeker has been perturbed by these aerosols during the observations through the combined effect of extra diffused light and attenuated direct solar irradiance. As a consequence, the vertical profile retrieval had to be limited at the lower altitudes to about 30 to 35 km.

A presentation of the instrument and the occultation technique can be found in Girard et al., (Planet. Space Sci., **36**, 291, 1988). During the ATLAS1 mission (March 24 to April 2, 1992), occultation measurements have been performed in the latitudinal belt ranging from the equator down to 55°S. The data-analysis went on in 1994-1995, especially for HCl, H<sub>2</sub>O, CH<sub>4</sub>, CO and NO. The NO<sub>2</sub> data could not be retrieved successfully due to a bad signal-to-noise ratio.

A most important conclusion could be drawn as to the long-term trend of the stratospheric chlorine content, from a comparison of the vertical profiles of HCl measured by Grille in 1992, shown in Fig. 1, with those determined by ATMOS onboard Spacelab-3 in 1985. The HCl mixing ratio above 50 km is a prime measurement of the effective stratospheric chlorine loading.

<sup>1</sup> ONERA : Office National d'Etudes et de Recherches Aérospatiales, Paris; LPMA : Laboratoire de Physique Moléculaire et Applications, Univ. P&M Curie, Paris; BISA: Belgian Institute for Space Aeronomy, Brussels).

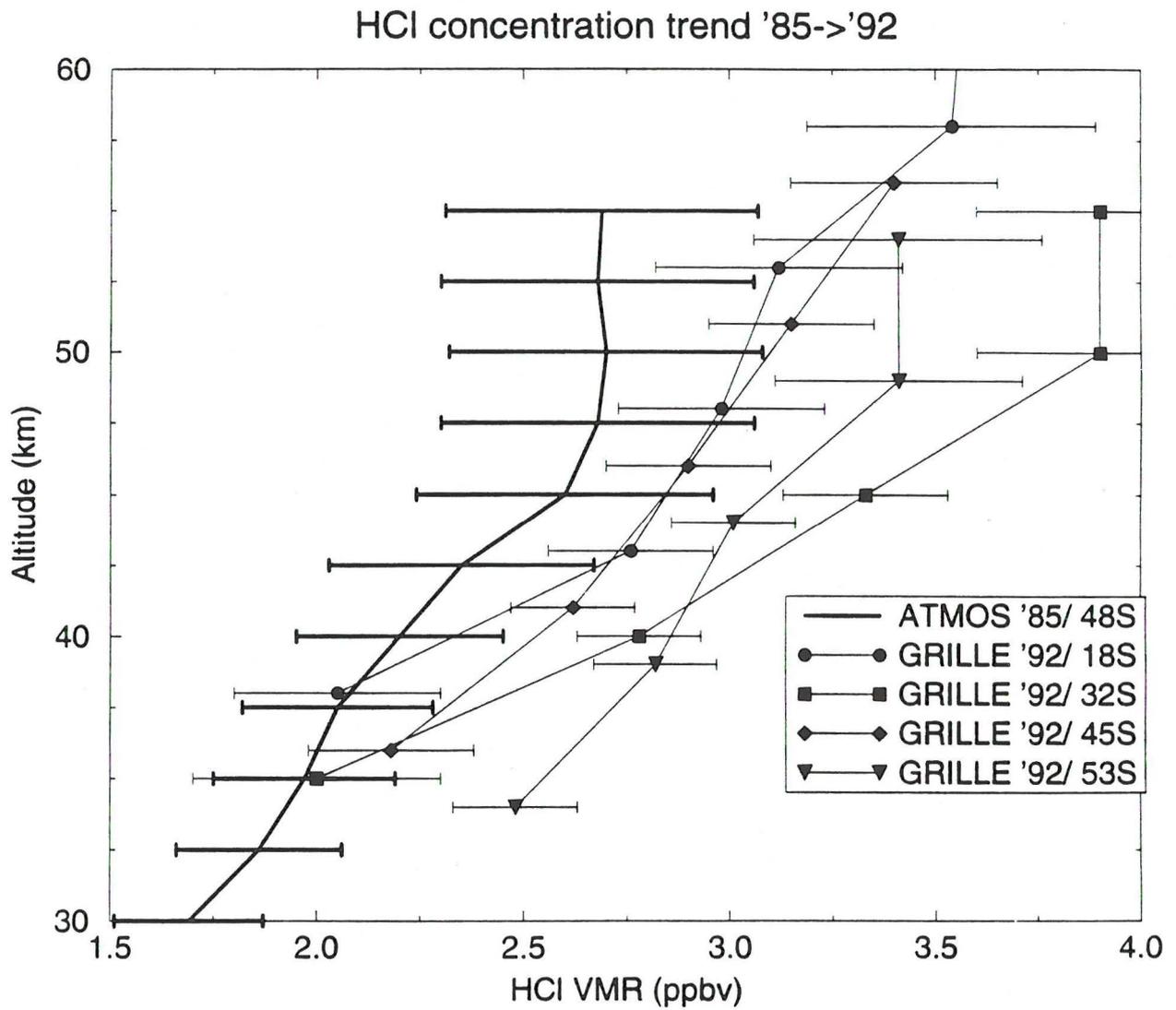


Fig. 1.- The ensemble of vertical profiles of HCl determined by the Grille experiment during the ATLAS1 mission, in comparison with a profile observed by ATMOS in May 1985 at 48°S.

According to the Grille spectrometer observations at 55 km, it amounts to  $(3.6 \pm 0.2)$  ppbv, in good agreement with the mean asymptotic value of  $(3.4 \pm 0.3)$  ppbv estimated from averaged HCl spectra from ATMOS on board the same mission (Gunson et al., *Geophys. Res. Lett.*, **21**, 2223, 1994). In comparison with the mean 1985 HCl volume mixing ratio above 50 km of  $(2.55 \pm 0.28)$  ppbv, measured by ATMOS during the Spacelab-3 mission (Zander et al., *J. Geophys. Res.*, **95**, 20519, 1990), the present value demonstrates an increase of  $(0.15 \pm 0.05)$  ppbv/yr ( alias somewhat less than 6%/yr), only slightly higher than model-predictions that evaluate to 0.11 to 0.13 ppbv/yr (WMO, Global Ozone Research and Monitoring project, Report No 37, chap. 2, 1995, and references therein). The dataset presented here is too limited to derive any significant latitudinal variations.

## **2. "MIRAS" onboard the Russian space station MIR**

"MIRAS" stands for Mid-InfraRed Atmospheric Spectrometer. It is an adapted version of the previously flown Grille spectrometer onboard the NASA Shuttles (see above), now for operation from the outer side of the Russian space station MIR. As for Grille, the responsibility for the experiment lies with the Office National d'Etudes et de Recherches Aérospatiale, Paris (ONERA), the Laboratoire de Physique Moléculaire et Applications, Univ. P&M Curie, Paris (LPMA), the Belgian Institute for Space Aeronomy (BISA) an the Russian Space Agency (IKI) with industrial partners in Belgium and Russia.

In 1994-1995, the final choice of optical filters and target molecules for observation has been made. The scientific program, in particular the microwindows to be scanned in each occultation, has been prepared in collaboration with M. Blečka of the Space Research Institute of the Polish Academy of Science in Warsaw. Correlative measurements with a Fourier-Transform IR spectrometer of comparable spectral resolution ( $\approx 0.01$  cm<sup>-1</sup>) developed by the latter team that will be installed in the Polish Tatra mountains have been planned.

A quasi-automatic program for the retrieval of the scientific data (trace gases vertical profiles) has been developed (using C and IDL languages under HP-UX). The algorithm is based on the one used for the Grille data retrieval, but it has been re-written on the purpose of an enhanced modularity, automatization of the retrieval procedure, and easy interfacing with the users; the new code is compatible with the 'old' Grille data, as well as with the new MIRAS data. Additional graphical/mathematical software tools have been developed for some preliminary inspection of the data.

During two stays at BISA in 1995 of Russian specialists from IKI and the flight control center (TSUP), a detailed observation program has been established and a protocol has been written concerning the exchange of operational, telemetry and scientific data, including exact agreements about formats.

Regarding the technical aspects, the MIRAS Flight and Qualification Models have been tested and verified in ETCA (Charleroi) in close collaboration with scientists from BISA and ONERA before delivery to Russia. There they have undergone the final qualification tests, with success. All necessary operational software was developed and delivered to Russia also.

In May 1995, the instrument has been launched onboard the Spektr module. It has been assembled in space, and on July 21, during a 5-hours Extra Vehicular Activity, it was installed on its support rails on the outer side of the module that is docked to the MIR Space Station. Thereafter, the various functionalities of the instrument have been tested in space. However in October 1995, a defect has occurred, before the first scientific operation could be performed. Up to now, no decision for repair has yet been taken.

### 3. The ORA experiment : Measurement of atmospheric minor constituents with a satellite borne radiometer

The Occultation Radiometer (ORA) project is a collaboration between the Belgian Institute of Space Aeronomy and the Department for Atmospheric, Oceanic and Planetary Physics of the University of Oxford. It has a twofold objective. The first one is a simultaneous measurement of aerosols, ozone and NO<sub>2</sub> in the middle atmosphere in order to contribute to our understanding of the role of aerosols in atmospheric chemistry which became obvious since the discovery of the Antarctic ozone hole. The second objective of the ORA experiment is to measure the water vapour concentration in the mesosphere with the aim of investigating the detailed balance of upper atmospheric water vapour, which is still not fully understood.

The ORA, which has been developed for the EURECA (EUropean RETrievable CArrier) contains two major parts. The infrared unit, designed to measure water vapor and carbon dioxide (which was used for total density determinations) was delivered by the Oxford team.

The UV-visible unit, delivered by BISA was designed to measure ozone, NO<sub>2</sub>, water vapour and aerosols, through absorption measurements in discrete wavelengths in the region from 250 to 1020 nm of the solar spectrum. It consists of 8 modules of similar design, each containing: a quartz window, an interference filter to isolate the appropriate wavelength domain, a simple optics to limit the field of view to  $\pm 2^\circ$  and a detector (either a Silicon photodiode or a Gallium-Phosphide diode, depending on the wavelength). The wavelength of the different UV-visible channels together with the major light absorbers is given in table 1.

**Table 1** : Wavelength of the different UV-vis channels and major light absorbers

$\lambda$ (nm)	259	340	385	435	442	600	943	1013
predominant constituents	O <sub>3</sub> neutrals	neutrals aerosol	aerosol NO <sub>2</sub>	aerosol NO <sub>2</sub>	aerosol NO <sub>2</sub>	O <sub>3</sub> aerosol	aerosol H <sub>2</sub> O	aerosol

BISA was also responsible for the mechanical structure, electronics hard- and software, qualification of the instrument and management with ESA.

The ORA instrument, was flown on the EURECA mission (31 July 1992 - 1 July 1993) and performed its measurements through the occultation technique or limb tomography method, which allows to derive an absolute quantity, namely the slant path optical thickness from a relative

transmission measurement. From the EURECA carrier, which had an orbit of 508 km altitude and 28° inclination, and which was a sunpointing satellite, measurements with the UV-Vis unit of the attenuation of solar radiation through the atmospheres over a period of about 9 months were obtained. The infrared unit of ORA has collected data for about 4 months. The data of the infrared unit being analyzed by the Oxford group, we will limit ourselves here to the results obtained with the UV-visible unit.

During the 9 months (from August 1992 until May 1993) of continuous operations more than 6000 sunsets and sunrises were recorded in the wavelength channels shown in table 1. The raw data as obtained from the instrument are curves representing the light intensity as a function of time, which can be converted into curves of signal versus grazing height. These signals, which result from an integration over the optical path across the atmosphere and another integration over the apparant solar disc are highly non linear functions of the local extinction profiles.

To retrieve total absorption profiles at the used wavelengths from these signals a new method referred to as NOPE (Natural Orthogonal Profile Expansion) has been developed. This technique consists of expressing the solution profile with respect to a truncated basis of orthogonal polynomials using as measure for the scalar product a generic standard profile. The coefficients defining the monic polynomials have been computed in a Stieltjes recurrence for each channel. Finally, the optimal solution profile is determined by a Levenberg-Marquardt minimization for a  $\chi^2$  merit function, as given by :

$$\chi^2 = \sum_{i=1}^n \left( \frac{y_i - S(\beta(z))}{\sigma_i} \right)^2$$

where  $y_i$  stands for the observed signal at  $n$  independent measurements,  $S$  is the best fit signal computed from the best fit profile  $\beta(z)$  and  $\sigma_i$  is the estimated error on  $y_i$ .

The results obtained for the inversion for 7 channels demonstrate the validity of the method, which generated naturally smooth profiles, with a preserved information content over a large dynamic range.

For the time being special attention has been given to the analysis of the extinction profiles at 1013 nm, which are mainly due to aerosols. The present data set clearly shows important differences between the retrieved total extinctions and the ones for standard atmosphere conditions, which are due to the presence of volcanics injected into the stratosphere by the Pinatubo eruption.

Before analysing global fields of total absorptions due to aerosols as obtained with our data between about 40°N and 40°S a validation of the data set should be performed. This validation, which consists in comparing the ORA results with the geo-synchronous results of SAGE II (Stratospheric Aerosol and Gas Experiment) is now in process and shows a good agreement between the data of both satellite experiments.

## **4. European Space Agency Polar Platform**

In 1988, at the first announcement of opportunity for the ESA polar platform, the Belgian Institute for Space Aeronomy participated in four proposals : SCIAMACHY, GOMOS, MIPAS and AMAS. The first three instruments are now accepted for flight on the future ENVISAT payload, whereas AMAS is considered for being integrated on a METEOR 3 satellite after 2000.

### **4.1. SCIAMACHY**

SCIAMACHY is an ozone, aerosols and atmospheric trace gas monitor operating in both nadir and limb mode. It is now the most sophisticated project of its kind and a reduced version, the ESA GOME instrument flying since April 1995 aboard ERS-2, proves already to be a highly successful ozone and NO<sub>2</sub> monitor. The project started as a German-Dutch venture, with Belgian scientists participating in the science team. In 1994, the Belgian Federal Services of Scientific, Cultural and Technical affairs proposed to finance and build by the Belgian industry the SCIAMACHY Polarisation Measuring Device (PMD), a six channels scientific instrument which add the polarisation spectral observation to the back-scattered and reflected light observations. This observation will not only refine the quality of the ozone retrievals but will yield original atmospheric aerosol data. BISA fully participates in the science groups of SCIAMACHY and supervises the Belgian industrial contribution to this project.

### **4.2. GOMOS**

As part of the payload of the first European Polar Platform, the Global Ozone Monitoring by Occultation of Stars (GOMOS) instrument proposed by a large group of institutions including the Belgian Institute for Space Aeronomy is now an ESA funded instrument. It consists of a telescope, feeding two spectrographs, mounted on a dedicated steerable platform. The transmittance of the atmosphere between 250 and 675 nm will be measured by comparing the spectrum of a star outside the atmosphere, and through it. The ozone vertical abundances are determined from the UV and visible absorption bands. This self-calibrated method is particularly well suited for the study of ozone long-term trend. About 25 stellar occultations per orbit and 350 per day, spread over all latitudes, can be performed from 70 km down to 15 km altitude. Ozone, NO<sub>2</sub>, NO<sub>3</sub>, H<sub>2</sub>O, aerosols and temperature vertical profiles will be simultaneously determined. The phase C/D is now in progress. The Institute is represented at the Science Advisory Group appointed by ESA and participates in the algorithm development for the aerosols retrieval. In addition, absorption cross-section data were carefully studied for GOMOS retrieval methodology and new laboratory measurements were performed in collaboration with the "Université Libre de Bruxelles" and the "Université de Reims" to improve the accuracy of the available data. A data base is currently being defined for GOMOS. These studies are made in collaboration with French (CNRS) and Finnish (FMI) institutions.

## **5. GOME**

The Global Ozone Monitoring Experiment (GOME) on board of the Earth Remote Sensing (ERS-2) satellite was launched by ESA on 21 April 1995 into an heliosynchronous polar orbit. Its main scientific objective is the study of trace constituents in the stratosphere and the troposphere.

GOME is a combination of four grating spectrometers observing the solar radiation scattered from the atmosphere or from the Earth's surface, covering the spectral range 240-790 nm. The instrument is operated in the nadir-viewing geometry and the current 960 km swath width is divided into three 80 x 40 km pixels. Because the input solar radiation is absorbed along its path through the atmosphere, the returned spectra recorded by GOME contain detailed information of the atmosphere's content of ozone, nitrogen dioxide, water vapor, as well as other trace gases. Knowledge of the solar radiation input is also usually required to establish the amount of absorption. Atmospheric constituents are detected by means of the Differential Optical Absorption Spectroscopy technique (DOAS). In particular, the GOME ozone total amounts retrieved during the commissioning phase were obtained by using the DOAS method in the Huggins bands.

The geophysical validation campaign of the GOME ozone and nitrogen dioxide total amount measurements was initiated in the 2nd half of 1995 in collaboration with a dozen of European institutes involved in the ground-based observations performed at the NDSC (Network for the Detection of Stratospheric Changes) Alpine and complementary stations, and in the UV-Visible DOAS network.

In order to extract reliable quantitative information on the atmospheric constituents, precise knowledge of the sensitivity of the GOME instrument is required. In addition in order to detect changes in time of these atmospheric constituents, an additional precise understanding of how the GOME instrument sensitivity is evolving and varying in time is needed.

The GOME instrument can directly measure the Earth's radiance scattered into its spectrometer, or in an alternate mode, using a slightly different optical paths, it can measure the solar irradiance arriving at the instrument. In both configurations, the optics of the spectrometer are the same, only a scanning mirror and diffuser are inserted for the direct solar measurement. In order to extract the desired geophysical unit of observed radiance, the efficiency of the instrument must be established to transfer and convert the incoming radiation to a recorded instrument signal. This efficiency is determined in the pre-launch calibration, but then it needs to be validated once the GOME is operating in orbit, and furthermore, it must be continually monitored as the mission proceeds. From a long history of space observations, there is every reason to believe that in time the GOME efficiency will change and, in fact, the efficiency will usually decrease with time. This ageing process is likely a complicated combination of contamination of optical elements coupled with the exposure to radiation, especially very energetic ultraviolet radiation of the Sun. By limiting exposure and taking every precaution to avoid contamination, both in the preparation and testing of the instrument prior to launch and in the outgassing environment of the satellite on orbit, the instrument's degradation can be minimized to perhaps only a few percent per year of operation.

The ultraviolet irradiance measurements of the SOLSTICE instrument, one of two UV irradiance instruments on the Upper Atmosphere Research Satellite (UARS) were used to validate the GOME instrument response and to evaluate how in-flight efficiency compares with the pre-launch calibration of the instrument. The SOLSTICE measurements extend back to the launch of UARS late in 1991 and are expected to continue for at least another three to five years. Therefore SOLSTICE will provide a continuous data set for the cross-calibration of the GOME instrument. SOLSTICE is also a spectrometer with spectral coverage overlapping the GOME UV channel 1 and 2, with comparable spectral resolution. The SOLSTICE measurements have their own inherent uncertainties with respect to both absolute calibration and with respect to drifts in the instrument response over time, and these factors are taken into account. We rely on the independence of the

two observations to gain an important insight into the validity of the measurements and our confidence in the respective calibration techniques, with special emphasis on an improved understanding of the GOME performance.

This validation work was initiated in July 1995 in collaboration with NCAR/HAO in Boulder, Colorado (PI : G.J. Rottman).

## **6. Stratospheric balloon borne measurements**

Two new balloon-borne instruments have been developed by the Laboratoire d'Optique Atmosphérique (LOA) with the collaboration of BISA to perform measurements of the radiance and of the polarised radiance of the Earth's limb, with the BALLAD (Balloon Limb Aerosol Detection) instrument, and measurements of atmospheric transmissions by solar occultation, with the BOCCAD (Balloon Occultation Aerosol Detection) instrument. BALLAD is observing at three wavelengths (450, 600 and 850 nm) with polarization measurements at 850 nm. BOCCAD is working at four wavelengths, the three of BALLAD plus one channel at 780 nm.

Both instruments are integrated on the same gondola and operate at the balloon float altitude. For limb measurements, made at large zenith angles, the payload is scanning the entire azimuth range by rotation. Then, before sunset, the payload is pointed toward the Sun for occultation measurements.

One flight was performed in October 1994 in the frame of the Second European Stratospheric Arctic and Mid-Latitude Experiment (SESAME) for characterisation of the aerosols at mid-latitude and for the validation of the POAM satellite.

Two other flights were performed in the frame of the phase III of SESAME from Sweden in the winter 1995. One flight occurred at the edge of the vortex, the other outside the vortex. The aerosol extinction profiles are obtained at three wavelengths, as well as the ozone number density profile. The altitude variations of the aerosol size are estimated from the angular dependence of the BALLAD measurements and from the spectral variations of the aerosol extinction deduced from BOCCAD experiment. They are found to be different for the two flights. The data analysis is still in progress.

## **7. Ground-based measurements**

The need for a complementary approach between high-quality ground-based observations, aircraft and balloon measurements, combined with satellite data and model calculations has been recognised since the 1980's and demonstrated for the ozone trend studies from satellite observations for satellite validations (e.g., GOME and UARS), and during the Arctic campaigns co-ordinated by the European Commission (EC).

Since 1990, the Belgian Institute for Space Aeronomy (BISA) has been collaborating with the "Institut d'Astrophysique" of the "Université de Liège" for the observations of tropospheric and stratospheric constituents from the International Scientific Station of the Jungfraujoch (ISSJ) with the high-resolution ( $\approx 0.0025 \text{ cm}^{-1}$ ) FTIR instruments, and for the

interpretation of these measurements. Additionally, it has been operating a SAOZ instrument at ISSJ, performing daily measurements of O<sub>3</sub> and NO<sub>2</sub> column abundances at twilight, based on the DOAS technique (Differential Optical Absorption Spectroscopy) in the 300-600 nm spectral range.

BISA up to now focused on the development of its own algorithm for inversion of the FTIR spectral data, called SFSP (SynthSpec & FitSpec). This code consists of two main modules, a first one for the calculation of synthetic spectra with high precision, a second one for the retrieval of atmospheric constituent total column abundances from the experimental spectra, based on a non-linear least-squares fit between experimental and calculated spectra. SFSP has been validated in the ESMOS II/NDSC Infrared fitting algorithms exercise (1993-1994) and has been optimised since then.

BISA also addresses the interpretation of the ozone and nitrogen dioxide data:

Progress has been made in the validation of the existing O<sub>3</sub> and NO<sub>2</sub> databases at ISSJ, from an intercomparison of the results coming from both FTIR and DOAS UV-visible techniques (SAOZ instrument). As to NO<sub>2</sub>, it has been found that the FTIR technique yields columns that are systematically higher than those from SAOZ by about 10%, if one excludes the period up to the end of 1992 for which some problems could be identified. For O<sub>3</sub>, the intercomparison combined with spectroscopic studies done by A. Barbe of the University of Reims permitted to identify the 3ν<sub>3</sub> absorption band around 3040 cm<sup>-1</sup> as being the most suitable one for the retrieval of ozone from atmospheric FTIR spectra: differences between both data sets could be reduced to about ±5%. This work is still in progress.

The available time series of ground-based measurements of NO<sub>2</sub> abundance shows a significant reduction of NO<sub>2</sub> starting in winter 1991/1992, after the eruption of the Mt. Pinatubo volcano, with a maximum decrease of about 35% in January 1992. The continued time series shows the recovery of the NO<sub>2</sub> column until August 1994. These results are compared with 2-D chemical model calculations including the effect of heterogeneous reactions using Mt. Pinatubo aerosol parameters as observed by lidar in the Alps. In general the modelled NO<sub>2</sub> columns agree qualitatively with the observations although the amplitude of the seasonal variation is underestimated, possibly due to internal limitations of the model which e.g. does not include diurnal changes. The observed and calculated NO<sub>2</sub> percent changes are in good agreement which confirms quantitatively the impact of the heterogeneous chemistry on stratospheric NO<sub>2</sub>.

In the frame of the Second European Stratospheric Arctic and Mid-Latitude Experiment (SESAME) it was decided to expand the ground-based measurements for stratospheric monitoring around 60°N to fill in the geographical gap between the observing sites situated beyond the Arctic circle and the mid-latitude Alpine stations situated around 45°N and that contribute to the Network for the Detection of Stratospheric Changes (NDSC).

BISA performed UV-visible measurements of OClO, BrO, NO<sub>2</sub> and O<sub>3</sub> column amounts at Harestua, 60° N, during the winters 1993/1994 and 1994/1995. In addition, a mobile Fourier transform spectrometer was used by the "Université Libre de Bruxelles" with the collaboration of BISA for the first time for similar measurements in the visible range during the 1995 winter.

The OCIO contents inside the polar vortex during January 1995 are quite large as compared to January 1994 indicating larger chlorine activation in January 1995. Most OCIO observations are obtained inside or at the edge of the polar vortex which indicates that the activation is essentially limited to the vortex region.

Low O<sub>3</sub> column amounts (as compared to the long term climatology derived from TOMS data) were measured in March 1994 and 1995 when the polar vortex was moving above Harestua. These measurements are consistent with episodes of O<sub>3</sub> chemical destruction inside the polar vortex in March 1994 and 1995, reported from other SESAME observations.

## **8. Measurement of the penetration of the solar UV-Visible radiation at the Earth's surface**

### ***8.1. UV-B, UV-A and Visible irradiance monitoring at the site of Uccle***

Since March 1993, a full automatic station (SUVIM) for the monitoring of the solar irradiances in the UV-B (280-315 nm), UV-A (315-400 nm) and visible (400-600 nm), is operational at the site of the Belgian Institute for Space Aeronomy .

#### ***a. Instrumentation***

In addition to the spectral measurements performed every 15 minutes for solar zenith angles lower than 100°, integrated measurements of solar irradiances in the UV-B, UV-A and total (300 nm to 3 µm) are taken every second by means of three pyranometers. The station will be completed in 1996 by a filters radiometer equipped with 10 channels of measurements to determine the total columns of ozone and aerosol.

#### ***b. Calibration and quality control of the data***

Special care is taken of the quality control of the provided data. Periodic absolute calibration (every 2-3 months), together with verifications of the relative stability of the instruments, allow to estimate the uncertainty on the absolute irradiance measurements to ± 5%. This value is confirmed by the results obtained during the last European Intercomparison Campaign (Ispra - Italy, 1995).

#### ***c. Data processing and final products***

A summary of the data obtained in Uccle is given in table 2. It is a data base completed by ancillary measurements such as the total column amount and the vertical profile of ozone density (measured by the Royal Meteorological Institute of Belgium), the detailed meteorological conditions (19 parameters every 3 hours for 21 stations in Belgium), twice daily meteorological soundings providing temperature profiles and relative humidity profiles.

Moreover, all the software for a global interpretation of the data in terms of the different atmospheric parameters (contents and concentration profiles of ozone, meteorological parameters...) have been developed and a first physical interpretation of the spectral measurements has been realised. A detailed study of the influence of the type of cloud cover (type of cloud, lower

altitude, depth, single or multiple layer) is under realisation by a double approach. A "parameteric" study based on a statistical analysis of the spectral measurements and a "theoretical" approach based on the conclusions of the "exact" atmospheric radiation transfer models.

**d. National and international collaborations**

Some specific collaborations are established with the Royal Meteorological Institute of Belgium for the measurements of the UV-Visible solar irradiance, and the utilisation of the ozone measurements. A collaboration has also been established with the "Unité de Biologie Végétale of the Faculté Agronomique de Gembloux". Finally, a close collaboration was established between our group and the team of Prof. J. Lenoble from the "Université des Sciences et Technologies de Lille" (France). The small distance between the two sites of measurements allows a relatively easy comparison of the solar irradiances measured at Lille and Brussels.

**Table 2** : Summary of the UV data produced in Uccle.

<b>UV-B MEASUREMENTS IN UCCLE</b> (Lat. 50° 48'N, Long. 4°21' E, Alt. 120 m)			
<b>SPECTRAL MEASUREMENTS :</b>			
Beginning : 26/03/1993			
Data : <b>1993</b>	13166	scans	→ 227 days
<b>1994</b>	20340	scans	→ 343 days
<b>1995</b>	21988	scans	→ 365 days
<b>1996</b>	3712	scans	→ 75 days (15/03/96)
<b>Total</b>	<b>59206</b>	<b>scans</b>	<b>1010 days</b>
<b>INTEGRATED MEASUREMENTS :</b>			
<b>UV-B</b>	starting date : 03/02/1995		
<b>UV-A</b>	starting date : 11/08/1995		
<b>TOT.</b>	starting date : 25/07/1995		
	<b>UV-B</b>	<b>UV-A</b>	<b>TOTAL</b>
<b>1995</b>	324 days	224 days	157 days
<b>1996</b>	73 days	73 days	73 days (15/03/96)
<b>Total</b>	<b>397 days</b>	<b>297 days</b>	<b>330 days</b>

## **8.2. The European Program : "Calibration and maintenance of Standards for Spectral UV Measurements" (CAMSUM)**

Within the frame of the CAMSUM program, a fifth intercomparison campaign has been organised in Ispra (Italy) in May-June 1995. This campaign which followed three field intercomparison campaigns (Thessaloniki 1991 and 1992, Garmisch-Partenkirchen 1993) and a calibration intercomparison campaign in the laboratory (Brussels, 1994), permits to test some complex procedures to compare spectral data, and to precise the influence of different parameters as the precision of absolute calibration, the discrepancies between the ideal "cosine" response and the actual angular response, the precision and the reproducibility of the wavelength scale,... on the quality of the experimental data and the coherency of the instruments used presently in Europe.

## **9. Absorption in the Schumann-Runge bands**

The extensive use of two and three dimensional models of the terrestrial atmosphere becomes more and more time consuming even on large computers. Physical parameters must be known, with high accuracy. As an example, the penetration of solar radiation in the wavelength region between 175 nm and 205 nm requires 16000 spectral points for the cross section at each altitude.

A new approximation has been developed for those cross sections, such that only 16 intervals are required to make the computations. This approximation is valid over the whole altitude range and never leads to spurious effects.

## **10. Measurement of atmospheric constituents by active chemical ionization mass spectrometry**

This research is a cooperation between the Belgian Institute for Space Aeronomy, the "Laboratoire de Physique et Chimie de l'Environnement du CNRS" (Orléans, France) and the "Physikalisches Institut" of the University of Bern (Switzerland), which aims the development of a method for the simultaneous in-situ measurement of nitric acid and dinitrogen pentoxide (and in future chlorine nitrate) in the stratosphere, by means of active chemical ionization (ACIMS). The collaboration is performed within the MACSIMS projects financed by the European Commission in the Environment programme (contract nrs. EV5V-CT92-0062 and ENV4-CT95-0042) and by the FKFO-MI (Fundamental Research Fund on Ministerial Initiative).

The ACIMS technique relies upon the formation of specific product ions from reactions of atmospheric trace gases with precursor ions produced by an external ion source mounted in front of a mass spectrometer. From the analysis of the relative abundance of precursor and product ions in spectra, obtained with the ion source, the mixing ratio of reactive trace gases can be obtained. The innovation of the method proposed in the MACSIMS project, was the development of an ion source producing alternately  $\text{Cl}^-$  and  $\text{I}^-$  ions. Such an ion source would allow the derivation of the concentration of both  $\text{HNO}_3$  and  $\text{N}_2\text{O}_5$  in the stratosphere. Ion sources were developed producing mainly  $\text{Cl}_n^-$  or  $\text{I}_n^-$  ions ( $n = 1, 2, 3$ ).

The  $\text{HNO}_3$  concentrations can be derived from the abundance ratio of the specific product ions  $\text{NO}_3\cdot\text{HCl}$  (resulting from the reaction of  $\text{Cl}_3^-$  with nitric acid) and of the source ions  $\text{Cl}_3^-$ . Whereas it was originally believed that the  $\text{N}_2\text{O}_5$  concentration could be derived from abundance ratio  $[\text{NO}_3^-]/[\text{I}^-]$ , measured with the ion mass spectrometer and the known rate coefficient of the ion-molecule reactions involved, recent laboratory measurements have shown that this measurement results in the sum of the concentrations of  $\text{N}_2\text{O}_5$  and  $\text{ClONO}_2$ . A third ion will have to be introduced to separately determine the  $\text{ClONO}_2$  mixing ratio. This new development is proposed within a new project MACSIMS 2.

The main results obtained within this reporting period can be summarized as follows : The balloon borne instrument with a simple ion source, producing only  $\text{Cl}_n^-$  was finalized in the Spring 1994 and was flown in May 1994 from the CNES balloon launching base in Aire sur l'Adour. In spite of some technical problems in flight (erasing of some part of the memory of the on board computer, prohibiting working in the automatic mode) good results were obtained in flight and a nitric acid profile between 20 and 30 km altitude could be derived from the spectra. For the analysis of these data the results of measurements of ion-molecule reactions concerning polyhalide ions with nitric acid obtained in parallel in the laboratory were used.

The instrument with the switching ion source, producing alternately  $\text{Cl}_n^-$  and  $\text{I}_n^-$ , was finalized in October 1994 and was flown in November from the INTA base in Leon (Spain) during a balloon launching campaign organised by CNES. Due to a problem with a high voltage power supply the instrument could not work in the ACIMS mode, but a large number of spectra of the major natural negative ions was obtained.

In 1995 a new design for the high voltage supply, which had been defective in the November 1994 flight, was completed and a method for time of flight was included in the instrument. The new ACIMS instrument was launched in November 1995 from the Leon base in Spain. This flight was a complete success. A preliminary of the results indicates that a nitric acid profile can be derived which is in good agreement with previously measured ones. The analysis concerning the iodine ion source is still in progress.

In parallel with the balloon measurements the ion-molecule reactions of  $\text{HNO}_3$  with  $\text{Cl}_n^-$  and  $\text{I}_n^-$  ( $n = 2,3$ ) have been studied at room temperature by means of a flow tube coupled to a quadrupole mass spectrometer. The reaction rates for  $\text{Cl}_n^- + \text{HNO}_3$  for  $n = 2$  and 3 have been determined relative to the known reaction rate for  $n = 1$ . Nitric acid reacts with  $\text{Cl}_n^-$ , resulting mainly in the product ion  $\text{NO}_3\cdot\text{HCl}$  for  $n = 3$ . The product ions of the slower two body reaction of  $\text{Cl}_2^-$  could not be determined unambiguously, but most probably  $\text{NO}_3^-$  as well as  $\text{NO}_3\cdot\text{HCl}$  are formed. For the study of  $\text{I}_n^- + \text{HNO}_3$ , the known reaction  $\text{CO}_3^- + \text{HNO}_3$  was used as a reference. No reaction has been observed for  $\text{HNO}_3$  with  $\text{I}_n^-$  ions ( $n = 2,3$ ).

Additionally rate constants have been determined for the reactions of nitric acid with  $\text{CO}_4^-$ ,  $\text{O}^- \cdot \text{HNO}_3$ ,  $\text{O}_2^- \cdot \text{HNO}_3$  and  $\text{NO}_3^- \cdot \text{HCl}$ .

The data concerning the reactions of  $\text{Cl}_3^-$  and  $\text{NO}_3\cdot\text{HCl}$  with nitric acid have been used for the analysis of the balloon measurements.

## 11. Study of Space Plasmas

### *11.1 The Magnetosphere and Ionosphere*

A comprehensive theoretical and data analysis effort is made at the Belgian Institute for Space Aeronomy to study the structure and dynamics of space boundary layers and for modeling the Radiation Belts. Theoretical results have been applied to a number of projects. Our strategy is a balanced mix of analytical modeling, and numerical and data analysis using various spacecraft database.

#### *11.1.1. Structure and stability of the magnetopause*

Simple models of magnetopause current layers (MCLs) of finite thickness (with a minimum number of free parameters) can be used to illustrate the effects of asymmetrical boundary conditions on the internal structure of the current layer. One-dimensional current layers are thermodynamical nonequilibrium systems which have an excess of free energy that allows excitation of drift tearing modes which result in destruction of magnetic surfaces. The stochastic wandering of magnetic field lines between the destroyed surfaces can result in the formation of percolated magnetic filaments topologically connecting magnetosheath and magnetospheric field lines. The stochastic percolation model by Galeev, Kuznetsova and Zelenyi, based on the symmetrical charge-neutral Harris equilibrium, was generalized for asymmetrical MCLs. Asymmetry in the B field profile strongly modifies the dependence of the marginal MCL thickness (below which the MCL is subjected to percolation) on the angle of magnetic field rotation  $\theta_0$ . The maximum thickness of MCLs which still could be subjected to percolation is achieved for  $\theta_0 > 90^\circ$ , that is, for southward IMF. Realistic asymmetrical MCLs are likely to be thinner for a northward IMF than for a southward IMF. For northward IMF the MCLs are likely to be thinner for larger values of plasma  $\beta$  in the magnetosheath.

#### *11.1.2. Impulsive transport of solar wind into the magnetosphere*

According to the theory of "impulsive penetration" (IP) proposed by Lemaire and Roth, magnetosheath plasma irregularities with an excess momentum density enter the geomagnetic field by means of an  $\mathbf{E} \times \mathbf{B}$  drift resulting from their self electric polarization. Collective polarization, thermo-electric charge separation, and non-adiabatic braking are important non-ideal MHD processes. The dipole-dipole interaction force between the Earth's dipole field and the current system of a penetrating 3-dimensional diamagnetic plasmoid can increase or decrease the entry velocity, depending on the orientation of the IMF. Laboratory experiments as well as significant geophysical observations are consistent with this impulsive penetration model. A comparison between the mechanism of IP proposed by Lemaire and Roth and that advocated by Heikkila has been undertaken.

#### *11.1.3. EMF driver of subauroral ion drifts*

The polarization charges induced by thermoelectric effects at the front of a hot plasma cloud drifting down the magnetotail into the colder and low density plasmatrough region produce a charge separation electric field which has been calculated with the kinetic model of Tangential Discontinuities (TD) developed at the Institute for Space Aeronomy in Brussels. The electric field

distribution determined by the difference of the gyroradii of the warm and cold ions is mapped down from the magnetosphere to the altitude of 400-500 km along magnetic field lines. It is shown that this thermoelectric field is large enough to drive strongly peaked westward ion drifts sometimes observed in the topside subauroral ionosphere. The latitudinal width and peak amplitude of the resulting ion drift are comparable to those observed in SAID events.

#### ***11.1.4. Radiation Belt modelling***

It has been shown that the atmospheric density averaged over a drift shell (B,L) is a useful coordinate to organise the field aligned distribution of the omnidirectional fluxes of trapped energetic protons at low altitudes for  $L < 1.7$ . It is in this respect better than the magnetic field intensity B generally used to map these fluxes in empirical radiation belt models like AP-8.

#### ***11.1.5. Plasmaspheric temperatures***

In the topside ionosphere the temperature of the ions increases with the altitude. It has been shown that such a positive temperature gradient can be a consequence of the non maxwellian character of the ion velocity distribution function (VDF) i.e. an excess of suprathermal particles in the tail of the VDF. This is the case when the VDF is approximated by a Kappa function. With such a VDF at a low altitude reference level the high temperatures observed in the plasmasphere can be explained without heating of ions by ad-hoc wave-particle interactions.

#### ***11.1.6. Field aligned current - potential characteristics***

It has been shown that the current-potential characteristics of auroral flux tubes that Lemaire and Scherer have determined in the 70's for maxwellian ion and electron velocity distribution functions (VDF) is a sensitive function of the distribution of suprathermal particles forming the tail of the VDF. New current potential characteristics have been obtained for VDF approximated by Kappa functions.

It has been found that the field aligned potential for which the net field aligned current density is null increases significantly when the index Kappa of the VDF is reduced from infinity (maxwellian case) to values of 3 or 4.

#### ***11.1.7. Plasmasphere***

The mechanism of formation of the plasmopause has been revised. A more comprehensive scenario based on field aligned plasma flow driven unstable by the sudden unbalance of the inertial, centrifugal, pressure and gravitational forces along geomagnetic field lines has been shown to be at the origin of the peeling-off of the plasmasphere in the nightside sector when westward magnetospheric convection is enhanced. This mechanism shades also new on the mechanism of formation of the Light Ion Trough (LIT); it sets also the stage for the subsequent plasmaspheric refilling process.

### ***11.2. The Solar wind***

The overall multi-layer structure of the magnetic field profile observed by ULYSSES across a broad solar wind tangential discontinuity can be reproduced fairly well by means of a kinetic model. Such a simulation provides complementary information about the velocity distribution

functions, which are not always available from the plasma experiment due to the low time resolution inherent in plasma measurements. The success of such a simulation proves that the kinetic model can be used as a realistic basis for further studies of the structure and stability of solar wind tangential discontinuities.

Some tangential discontinuities (TDs) observed in the solar wind by ULYSSES interface plasma regions that only differ in their bulk velocity and the orientation of the magnetic field; solar wind composition, density, temperature and plasma beta in both regions are essentially the same. The influence of a plasma velocity jump across the TD on the magnetic field is investigated through the analysis and simulation of equilibrium plane TD configurations. The theoretical results are compared with ULYSSES observations. It is concluded that (a) the magnetic field rotation angle is related to the kinetic pressure enhancement within the transition zone, (b) the velocity jump inferred from the plasma experiment lies -- within limits set by accuracy and time resolution - inside the domain where the kinetic model allows an equilibrium solution to exist, and (c) the morphology of the magnetic field variations observed in the transition agrees very well with the theoretically predicted profile.

## **12. Study of the Planet MARS**

The Russian Space Research Institute IKI has the intention to launch on November 16, 1996, an interplanetary spacecraft in the direction of the planet Mars. It will consist of an orbiter and of a number of autonomous stations and penetrators. After about 315 days and about 300 million kilometers of flight the autonomous stations and penetrators will separate from the orbiter part which will be brought into an orbit around the Red Planet.

The goal of the MARS-96 mission is to make scientific investigations in a wide range of fields, such as: interplanetary plasma; astrophysics; the surface of Mars; the internal structure of Mars; the atmosphere and climate of Mars; and the magnetosphere of Mars.

The Belgian Institute for Space Aeronomy (BISA) is member of an international consortium of scientific research institutions that participate in the MARS-96 project by means of the experiment MAREMF and the experiment SPICAM.

### **12.1. MAREMF**

The experiment MAREMF (MARS Electrons and Magnetic Field) is a magneto-electro probe that will perform combined measurements of the magnetic field components by means of magnetometers and of the 3-dimensional distribution of the electron flux in the solar wind as well as in orbit around Mars by means of two Electron Spectrometers. The main contribution of BISA is the production and programming of the Data Processing Unit (DPU) associated with the Electron Spectrometers. This construction phase was terminated in the period 1994-1995.

The principal members of the MAREMF scientific consortium are :

- IKI, Russian Space Research Institute, Moscow, Russia
- IWF, Institut für Weltraum Forschung, Graz, Austria
- MPE, Max-Planck-Institute für Extraterrestrische Physik, Berlin, Germany
- MPAE, Max Planck Institute für Aeronomy, Katlenburg-Lindau, Germany
- KFKI, Research Institute for Particle and Nuclear Physics, Budapest, Hungary
- BISA, Belgian Institute for Space Aeronomy, Brussels, Belgium

The MAREMF Data Processing Unit, which is dedicated to the control of the 3-D Electron Spectrometers and to the handling of data collected by these instruments is composed of 4 modules:

- The processor module containing the Transputer Processor with its floating-point unit, 96 Kilobyte of ROM memory, 256 Kilobytes of RAM memory, 32 Megabytes of EEPROM memory, reset and watchdog circuits and serial communication circuitry for inter-DPU message handling.
- A module containing interfaces with the telemetry, telecommand and on-board time systems of the spacecraft.
- A module containing the serial interfaces to the Electron Spectrometers and the control circuitry for their power supply voltages.
- The power supply module which is connected to the 27 V bus and to the relay commands of the spacecraft. This module delivers stabilized +5 and +9 V voltages to the other modules and protects the DPU-E against overcurrent and overvoltage conditions.

The total mass allocated to the complete MAREMF instrument is 10.5 kg whereof 1.9 kg is reserved for the DPU-E.

The total power available for MAREMF is 10 Watt. The DPU-E, without Electron Spectrometers connected, consumes about 2.3 Watt which is less than the 3 Watt allocated.

## ***12.2. SPICAM-S***

The SPICAM experiment (SPectroscopie pour l'Investigation des Caractéristiques de l'Atmosphère de Mars) is a Belgian-French-Russian collaboration consisting of several instruments. The one that is developed and manufactured under the responsibility of the Belgian Institute for Space Aeronomy is called SPICAM-S.

The main goal of SPICAM-S is to characterize the Martian atmosphere, principally by measuring the vertical distribution of the main constituents (CO<sub>2</sub>, H<sub>2</sub>O, O<sub>3</sub>, O<sub>2</sub>, CO, dust and aerosols) and their variations in time and place, by monitoring the temperature and density, but also by observing the structure of the ionosphere and its interaction with the solar wind, by determining the exospheric temperature, by studying the atmospheric transport processes and by searching for undetected components.

SPICAM-S is a 20 kg weighing, box shaped instrument. The 478 mm x 445 mm x 215 mm measuring aluminium instrument (baseplate plus removable cover) interfaces mechanically with the satellite's main body through four especially conceived titanium bolts.

The thermal interface of SPICAM-S consists of several elements. The heat exchange with the satellite through the fixation bolts is limited by construction to 10 K/W. SPICAM-S is protected from thermal influences from far space and neighboring instruments by a fiberglass-Kapton layered thermal blanket. Finally a radiator drains superfluous heat from a thermally critical part of the instrument.

The indispensable optical interface is a 60 mm diameter opening in the top plane of the instrument. It is shut off while the instrument does not function, and opens for every observation period. SPICAM-S has six external connectors : two of them towards a central electronics block (the power and the communication interface), an other directly towards the satellite (emergency opening of the shutter). The three remaining connectors allow temporary autonomous functioning or disconnection of certain subsystems of the instrument. The overall power consumption of the experiment is approximately 52 W.

SPICAM-S is an optical spectrometer which is sensible in the ultraviolet, visible and infrared parts of the solar spectrum. It consists of two spectrometer channels, one ultraviolet and visible channel (250 to 750 nm) and one infrared channel (1.8 to 5  $\mu\text{m}$ ). Each channel contains a spectrometer, preceded by a light focussing optical system and followed by a cooled detection system. Since SPICAM-S uses the Sun as a light source, it has to point towards the Sun and has to track it. The satellite guarantees the opening of the SPICAM-S instrument to be directed roughly ( $\pm 1^\circ$ ) towards the Sun. Therefore, only small modifications to the satellite's tracking system have to be performed by the instrument's suntracker itself. The SPICAM-S suntracker consists of a motor driven mirror situated underneath the instrument's inlet hole, reflecting the incoming light towards the spectrometer channels, and a Position Sensitive Device (PSD) that gives the necessary feedback about the solar position in order to steer the mirror motors. As a supplementary feature a controlling camera is installed in order to make a low resolution image of the observed solar disk (shape and point towards which the instrument is pointing). The four blocks (two spectrometer channels, suntracker/shutter and controlling camera) are driven by four completely independent electronic units, each containing their own microprocessor or microcontroller system.

#### *12.2.1. The qualification model*

In 1994 the qualification model has been developed and delivered to IKI. In January 94 thermal-vacuum test were done in ESTEC (Noordwijk - The Netherlands) and in March 94 qualification tests were performed in INTESPACE (Toulouse - France). These tests consisted of thermal-vacuum tests, vibration tests for each of the three axes, electromagnetic compatibility tests (EMI/EMC) and structural verification. All tests were performed in a complete flight configuration. Due to problems during vibration tests on the IR-channel, new vibration tests (for one axis only) were performed again in May 94 in INTESPACE. In June 94, a final acceptance was performed (external verification and reduced EMI/EMC-tests). In July 94, the model was finally delivered to IKI and accepted during integration tests.

In September 95, connection tests were done between the qualification model and the sounder in Babakin Center (Moscou - Russia). In December 95, the qualification model was recuperated after delivery of the flight model. The qualification model was verified and its hardware was refurbished.

### ***12.2.2. The electrical model***

The electrical model had been delivered to IKI in 1993. In December 94, integration tests of this model were performed on the sounder in Babakin Center. In April 95, simulations of the flight cyclograms were performed on the sounder. In order to fulfil contractual agreements, the engineering model was delivered to IKI in April 94 as a "simplified flight model" after integration and acceptance in Paris and Moscou. The engineering model was recuperated in September 94 after delivery of the qualification model.

The engineering model was used to perform tests on the real Sun from equatorial tables in Brussels and Saint-Michel (Observatoire de Haute-Provence, France). From these tests realistic spectra from the Earth's atmosphere were obtained and showed the technological quality of the instrument.

### ***12.2.3. The flight model***

The flight model was assembled, tested and integrated during the last half of 95. In July 95 the suntracker, the UV/Vis-channel, the camera- and the IR-channel were integrated in Brussels. At the end of August 95, tests were performed with the flight model on the equatorial tabel in the Observatoire de Haute-Provence, France. During these tests a set of absorption measurements was taken from the Earth's atmosphere.

In September 95, integration tests were performed with the Electronic Block in Paris, followed by acceptance tests (EMI/EMC, vibration, thermal-vacuum, thermal, structural control, mechanical interfaces) in Toulouse. In November 95, the flight model was accepted in IKI during controlling tests.

### ***12.2.4. Preparation of a balloon flight***

A stabilizing platform was developed in order to allow sun pointing of the SPICAM-S instrument during a balloon flight planned in 1996. An adaptation scheme was pointed out for modification of the instrument to the ballooning infrastructure.

## ***12.3. ISO TOO proposal on observation of global dust storms on Mars***

The Belgian Institute for Space Aeronomy proposed the observation of global dust storms on Mars with the ISO payload, this proposal made jointly with the SRON (Groningen) and IKI (Moscow) was accepted as a target of opportunity proposal. It intends to measure the changes in chemistry of the Martian atmosphere in relation with the increase in temperature, dust and water vapour expected from the dust-storms, and interpret them in terms of the two dimensional model developed at the Belgian Institute for Space Aeronomy. The launch of ISO was performed in November 1995 and by the end of the year, the payload had already received astronomical signals. At the end of 1995 appeared the beginning of a global dust-storm which was missed by ISO due to the directions of the Sun and Mars. It is hoped that ISO will still be fully operational in the middle of 1997 when the next Mars storm season will occur.

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## B. Institute of Astrophysics of the University of Liège

### 1. The role of hot atoms in the structure and photochemistry of the Earth's upper atmosphere

Ground state  $N(^4S)$  nitrogen atoms are produced with excess kinetic energy by direct  $N_2$  dissociation as well as exothermic chemical reactions. A stochastic model was used to calculate their steady state energy distribution function in the thermosphere. Inelastic collisions with  $O_2$  produce nitric oxide with a much higher efficiency than thermal nitrogen atoms. Numerical simulations for the low latitude thermosphere at solar maximum activity conditions show that  $N_2$  dissociation and ionization by fast photoelectrons produced by solar soft X rays are a significant source of  $N(^2D)$  and fast  $N(^4S)$  atoms which are precursors of NO in the lower thermosphere. A twofold increase of the solar soft X rays irradiance was shown to double the NO peak density as observed with a 27-day period during high solar activity phases.

A model of the hot oxygen geocorona in the transition region near the exobase has been developed, based on a Monte Carlo solution of the nonlinear Boltzmann equation for hot oxygen atoms produced by chemical processes usually considered as a source of hot oxygen (photodissociation of  $O_2$  and dissociative recombination of  $O_2^+$  and  $NO^+$  ions). The energy distribution function of the thermal and non-thermal  $O(^3P)$  atoms and of the nonthermal  $O(^1D)$  atoms was calculated from the thermospheric collision-dominated region to the exosphere where the gas flow is virtually collisionless. The model was first applied to equatorial latitudes for conditions of low solar and geomagnetic activity. Numerical simulations showed that the distribution function of thermal oxygen is increasingly perturbed by collisions with the hot oxygen population at high altitudes and departs significantly from a Maxwellian distribution at all altitudes. The number density and temperature of the nonthermal oxygen atoms were derived from their microscopic distribution function and found to be in qualitative agreement with previous theoretical and experimental estimates. This model was also used to calculate the distribution of the hot oxygen atoms during geomagnetically disturbed nighttime conditions. The precipitation of energetic  $O^+$  ions and the subsequent enhancement of the hot O corona at high latitudes was simulated for the September 17, 1971 storm conditions. It was found that, in such circumstances, the  $O^+$  precipitation is a significant source of superthermal O atoms leading to important perturbations of the velocity distribution of the bulk oxygen population. The effective gas temperature near the exobase is similar to that in the undisturbed atmosphere by the hot O density rises considerably over the quiet condition values.

Exothermic reactions involving metastable neutrals and ions were proposed as sources of hot oxygen atoms in addition to the classical  $O_2^+$  and  $NO^+$  dissociative recombination. The Boltzmann equations were solved with a Monte Carlo stochastic simulation method to calculate the nonthermal populations of hot O atoms at steady state in the transition region. It was found that the calculated density of the nonthermalized fraction of superthermal O atoms (produced in chemical reactions) is significantly enhanced when the new sources are included. The variation of the vertical distribution of hot O between solar maximum and minimum conditions was also evaluated and showed good agreement with the available experimental evidence.

## 2. Ultraviolet observations of giants planets with the Hubble Space Telescope

### 2.1. Morphology of the Jovian UV aurora

A series of six images covering a complete rotation of the north polar region of Jupiter was obtained in February 1993 with the Faint Object Camera (FOC) onboard the Hubble Space Telescope (HST). These images provided the first global picture of the morphology of the Jovian ultra-violet aurora observed from Earth orbit. It was found that the auroral emissions do not exactly follow the footprint of a constant L-shell although the size of the oval and its location agree best with the footprints of the  $\approx 30 R_J$  field line in the GSFC  $O_6$  model of the Jovian magnetic field. Small scale features with characteristic sizes of  $\sim 1000$  km were observed along the auroral oval. The change of morphology observed as a function of the System III longitude appears as a persistent characteristic of the morphology of the north polar aurora.

In July 1993, two sets of ultraviolet images of the Jovian north aurora were obtained with the FOC. The first series showed an intense discrete arc in near corotation with the planet. The maximum apparent molecular hydrogen emission rate corresponds to an electron precipitation of  $\sim 1$  Watt per sq. meter, which is about 30000 times larger than the solar EUV heating. Such particle heating rate of the auroral upper atmosphere of Jupiter should cause a large transient temperature increase and generate strong thermospheric winds. Twenty hours later, the discrete arc had decreased in brightness by more than one order of magnitude. The timescale and magnitude of the change in the UV aurora lead us to suggest that the discrete Jovian auroral precipitation is related to large-scale current system variations, as is the case for Earth's discrete aurorae. Multi-spectral observations of the far ultraviolet Jovian aurora with the FOC were used to describe and compare the morphology and the mean brightness of the  $H_2$  Lyman and Werner bands observed at 153, 125, and 130 nm. It was shown that most of the emissions are confined inside the  $6 R_J O_6$  - GSFC auroral oval and fill a large fraction of the polar cap. During the  $\sim 50$  hours time span of the observations following a very strong aurora, no bright arc was observed along the oval mapping the  $30 R_J O_6$  oval. Hydrogen emissions at 125 and 130 nm were observed down to  $50^\circ N$  and somewhat below, a region not accessible to previous FOC observations at longer wavelengths. Temporal variations are also observed on timescales of hours to days.

In support to the HST observation models of the volume excitation rate had been previously developed for low energy electrons and oxygen ions. However, the energy range of the study has to be extended towards higher energy in view of recent results on the penetration depth of the primary particles. We used an existing electron code of degradation of energy (Gérard and Singh, J. Geophys. Res. **87**, 4525, 1982) which has been improved, updated and adapted to the case of precipitating protons. The altitude distribution of the volume excitation rate was compared for electrons and protons, for various initial energies in the range 10-50 eV and 50 keV to 1 MeV, respectively. Previous data collected with the International Ultraviolet Explorer satellite provided evidence of a longitudinal dependence of the absorption of the Jovian auroral  $H_2$  Werner bands by the hydrocarbons along the auroral oval. This had been interpreted as a longitudinal modulation, either of the atmospheric composition and dynamics, or of the penetration depth of the primary auroral particles. However, the angular distribution of the precipitating particles is basically unknown. The influence of the choice of the angular distribution on the energy determination has been studied. The interpretation of the longitudinal modulation of the color ratio in terms of energy

variations was discussed in view of the large energy derived at the brightness peak, and in the context of the Hubble Space Telescope images.

## **2.2. Far ultraviolet spectroscopy**

The first spectroscopic observations of planetary aurora with the HST/GHRS were made in 1993. These included two spectral regions centered on the H<sub>2</sub> Lyman and Werner bands of a region of Jupiter's northern aurora. A rotational-vibrational temperature for H<sub>2</sub> of  $530 \pm 100$  K was derived, a value significantly less than the 850-110 K reported for Jovian H<sub>3</sub><sup>+</sup> in the near-infrared but consistent with the temperature reported for fundamental-band quadrupole H<sub>2</sub> emission. The results were interpreted in terms of electron impact excitation of H<sub>2</sub> from secondary particles generated by primaries precipitating into Jupiter's atmosphere from the magnetosphere. In the region of the observed aurora, the homopause level was found to be significantly hotter but not necessarily higher than observed at nonauroral latitudes.

A second series of observations of the emission spectrum from Jupiter's north auroral atmosphere were made with 0.57 Å spectral resolution over 1204-1421 Å. Bright emissions have been detected from 50 to 60 latitude at locations consistent with 6 to 30 R<sub>J</sub> auroral ovals, with much fainter emissions away from the auroral ovals. The observed Ly-α emission wings extend more than 1 Å from line center and appear correlated in strength with the H<sub>2</sub> brightness. Individual rotational lines in the H<sub>2</sub> Werner band system were resolved, allowing a determination of the H<sub>2</sub> rotational temperature at the altitude of the emission. Best-fit temperatures from 400-500 to 700-750 K were derived, with the auroral emission layer temperature changing either across the auroral oval or over several days' time.

## **2.3. Saturn's auroral UV emission and polar haze**

Near simultaneous observations of the Saturnian H<sub>2</sub> north ultraviolet aurora and the polar haze were made at 153 nm and 210 nm respectively with the FOC on board the post-COSTAR Hubble Space Telescope. The auroral observations covered a complete rotation of the planet and, when co-added, they revealed the presence of an auroral emission near 80°N with a brightness of about 150 kR of total H<sub>2</sub> emission. The maximum vertical optical depth at 210 nm was found to be located ~ 5° equatorward of the auroral emission zone. The haze particles are presumably formed by hydrocarbon aerosols whose production is initiated by H<sub>2</sub><sup>+</sup> auroral production. In this case, the  $3 \times 10^{10}$  W of H<sub>2</sub> emission observed with the FOC, combined with the deduced haze optical depth required an efficiency of aerosol formation of about 7%. This result indicated that auroral production of hydro-carbon aerosols is a viable source of high-latitude haze.

## **3. ATMOS-related investigations**

Jointly with the NASA - Jet Propulsion Laboratory (JPL), Pasadena, California, and the NASA - Langley Research Center (LaRC), Hampton, Virginia, the Institute of Astrophysics of the University of Liège has pursued its co-investigation of the chemical composition and physical structure of the Earth's middle atmosphere between about 10 and 150 km altitude. This investigation is based on the analysis of infrared solar observations made in the occultation mode from aboard Space Shuttles with the ATMOS (Atmospheric Trace MOlecule Spectroscopy) fast and high-resolution (0.01 cm<sup>-1</sup>) Fourier transform spectrometer developed and managed at JPL,

and whose spectral coverage (2 to 16  $\mu\text{m}$ ) allows to study some 30 telluric gases quasi simultaneously.

Following excellent missions in 1985, 1992 and 1993 (reported about in previous COSPAR issues), ATMOS performed its 4th space flight from 3 to 14 November 1994 aboard the american shuttle ATLANTIS as part of the ATLAS (ATmospheric Laboratory for Applications and Science)-3 mission to planet Earth. Over 100 sunset occultations and almost as many sunrises were observed successfully, respectively between 3 and 49°N and 65 to 73°S, the latter events encompassing in- and out-of-vortex investigations over Antarctica.

Key findings which have been established thus far from analyses of series of typical occultations or zonal averagings concern :

- increase in all chlorinated and fluorinated anthropogenic constituents throughout the stratosphere, and conservation of the budgets of total chlorine (Cl) and fluorine (F), sources, sinks and reservoirs combined. When accounting for a 4 to 6 years time delay for boundary air to mix in the stratosphere, these budgets are consistent with the tropospheric loading of Cl and F found near the ground.
- comparison of the stratospheric budgets of Cl and F measured by ATMOS in 1985 and 1994 indicates increases of 38 and 67% respectively; these increases mirror precisely the trends measured in the tropospheric loadings caused by anthropogenic Cl- and F-bearing sources at the ground, in particular the most used CFCs -11 and -12, and the HCFC-22. No volcanic contribution needs to be invoked to explain both the loadings and trends of Cl and F throughout the stratosphere.
- strong upwelling in the tropics, where tropospheric air with weak horizontal mixing is lofted vertically then transported to mid-latitudes; this is corroborated through studies of long-lived tracers such as  $\text{N}_2\text{O}$ ,  $\text{CH}_4$ ,  $\text{CCl}_2\text{F}_2$ ,  $\text{CHClF}_2$ ,...; these same tracers reveal substantial meridional mixing of air at mid-latitudes, throughout the stratosphere.
- the evolution of the hydrogen budget (i.e.,  $\text{H}_2\text{O} + 2 \times \text{CH}_4$ ) at northern midlatitudes reflects the vertical propagation rate and the seasonal variation of water vapor entering the stratosphere; it has allowed to estimate the vertical velocity of transport in the tropics and its change with season.
- the evaluation of heterogeneous processes occurring on sulfate aerosols, such as the hydrolysis of  $\text{N}_2\text{O}_5$  to  $\text{HNO}_3$ , and the re-partitioning of reactive nitrogen (NO and  $\text{NO}_2$ ) and chlorine (Cl and ClO); notice that ATMOS measures the following nitrogenated gases : NO,  $\text{NO}_2$ ,  $\text{HNO}_3$ ,  $\text{HNO}_4$ ,  $\text{N}_2\text{O}_5$  and  $\text{ClONO}_2$ .
- simultaneous denitrification and dehydration associated with sedimentation of stratospheric clouds was observed to be confined to air in the Antarctic vortex, with the containment of processed air inside it being better defined and maintained than in Arctic-related vortex situations.
- the quantification of the rates of subsidence of large-scale air masses in the 1994 Antarctic vortex, in satisfactory agreement with the subsidence measured over the Arctic in 1993.
- the anomalously high concentration of  $\text{N}_2\text{O}_5$  observed for the first time at the edge of the 1994 Antarctic vortex.

Various of the above mentioned findings are discussed in papers accepted for publication in a special issue of Geophysical Research Letters to appear in 1996.

#### 4. Stratospheric balloon observations

Results from two balloon flights performed in 1992 and 1993 from the National Scientific Balloon Facility of Fort Sumner, New Mexico, have been compared with correlative HALOE (Halogen Absorption Limb Occultation Experiment) measurements for HCl. While the balloon results are well in line with expectations based on the ATMOS observations of 1992, 1993 and 1994, they are higher than the HALOE measurements by some 7 to 10% above about 6 mbar (~ 34 km). Similar differences found for other molecules (i.e. HF, CH<sub>4</sub> and H<sub>2</sub>O) have been assigned by the HALOE investigators to a beta angle (the angle between the orbit plane and the Earth-Sun line) dependence of spectral parameters such as Doppler shifts and uncertainties in the assumed Voigt line shape above the 10 mbar level.

Comparison of the HCl profile derived during a "Balloon Intercomparison Campaign" in 1983 and those obtained from our 1992 and 1993 flights indicates a mean rate of HCl loading in the middle and lower stratosphere equal to  $(3.5 \pm 0.4 \text{ %/yr})$ , which mirrors well the change in anthropogenic chlorine-bearing source gases at the ground.

#### 5. Ground-based versus space observations

Monitoring activities of some 20 telluric gaseous constituents have been pursued at the International Scientific Station of the Jungfrauoch (ISSJ) located at 3580 m altitude in the Swiss Alps. They are based on infrared solar observations performed with two very high resolution Fourier transform spectrometers. During the last decade, the stratospheric molecules HCl, HF, ClONO<sub>2</sub>, COF<sub>2</sub>, NO, NO<sub>2</sub>, HNO<sub>3</sub>, HNO<sub>4</sub> and O<sub>3</sub> have been measured specifically within the frame of the global "Network for the Detection of Stratospheric Change" (NDSC) and its European component "ESMOS" (European Stratospheric Monitoring Stations). Source gases such as CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>, CO, C<sub>2</sub>H<sub>2</sub>, C<sub>2</sub>H<sub>6</sub>, HCN, OCS, CCl<sub>2</sub>F<sub>2</sub>, CCl<sub>3</sub>F, CHClF<sub>2</sub>, SF<sub>6</sub>, H<sub>2</sub>CO, ..., were investigated as our contribution to the EUROTRAC-TOR (Tropospheric Ozone Research) and the Belgian "Global Change" programs. Both short, seasonal-, and long-term changes in the vertical column abundances above ISSJ have been quantified for most of the molecules enumerated above. In particular, column increases were observed for all chlorinated and fluorinated compounds (sources, sinks and reservoirs combined) as well as for CO<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub>; decreases were confirmed for the CO and C<sub>2</sub>H<sub>6</sub> burdens.

Numerous ISSJ campaign-like activities were coordinated to provide correlative/validation data for various Space programs. Among these are the HALOE (Halogen Absorption Limb Occultation Experiment; HCl, HF, CH<sub>4</sub>, ...) and CLAES (Cryogenic Limb Array Etalon Spectrometer; ClONO<sub>2</sub>, CFC-12...) experiments aboard UARS (Upper Atmospheric Research Satellite); the MAPS (Measurement of Air Pollution from the Shuttle; CO) flights in April and October 1994; the ATMOS/ATLAS-3 mission of November 1994; the GOME (Global Ozone Monitoring Experiment) remote soundings during the second half of 1995. Some of these correlative supports are described in papers given in the publications list; others are still in progress.

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## **C. Royal Meteorological Institute of Belgium**

### **1. Ionospheric studies**

Monitoring of the bottom ionosphere by teledetection of the electronic density distribution is one of the tasks of the Dourbes ionospheric station. Hourly ionograms are produced and special campaigns are made with more frequent ionograms.

During the years 1994 and 1995, the effort was pursued to reduce the long delay between the actual sounding and the validation and preparation of the data to build the ionospheric data base. This delay is reduced by 60 percents.

Beside this, most of the time was devoted to a major European collaboration on Prediction and Retrospective Ionospheric Modelling over Europe (PRIME) COST 238 Project with emphasis on oblique soundings. This action COST terminated in 1995. A campaign of oblique soundings was organised between the Dourbes station and the Observatori de l'Ebre (Spain) using a special technique based on phase measurements of the echoes and which improves the accuracy of the virtual height up to one or two kilometers. In the theoretical domain, the problem of the inversion of oblique soundings was investigated in collaboration with the Institute of Terrestrial Magnetism, Ionosphere and Radio wave propagation (Izmiran) of the Russian Academy of Sciences, Moscow.

Two special campaigns were undertaken to produce ionospheric electron content (IEC) values every ten minutes in order to compare with the total electron content (TEC) values deduced from the GPS system of the Royal Observatory of Belgium.

### **2. External Geomagnetism**

An absolute observatory magnetometer now provides data on the LAN at the Centre de Physique du Globe at Dourbes (Belgium). These data are available on near real time on this LAN.

The transmitter to the Intermagnet network on satellite (Meteosat) is ready and will work as soon as administrative questions are solved.

The work on a Potassium hyperfine structure magnetometer has led to an absolute accuracy better than 0.1 nT for all the Geophysical range. The works on the automatic Diflux and on the tandem Cs-K magnetometer were pursued.

On the theoretical ground, a dipolar model for the Earth magnetic field over Belgium has been constructed. It determines the thickness and the magnetisation variation of the crust over Belgium.

The VIth Workshop on Magnetic Observatory Instruments, Data Acquisition and Processing was organized at the Centre de Physique du Globe at Dourbes from the 18 to 24 September 1994. More than 70 scientists from all over the World were present.

### 3. Solar Constant and Earth's radiation budget

#### 3.1. NASA-ATLAS program

The experiment SOLCON (Solar Constant) of the Royal Meteorological Institute of Belgium flew on ATLAS 3, launched on November 3, 1994. The Solar constant was measured again with high accuracy, its value decreasing slowly as expected. During the flight of ATLAS 3 an unplanned experiment to measure the density of air was performed successfully with SOLCON. Advantage was taken of the results of ATLAS 2 to reduce the different available sets of observations since 1978 to one set base on the Space Absolute Radiometric Reference.

#### 3.2. EUROMIR mission

The Belgian Space Remote Operation Center (BSROC) together with ESA and the European Space tele-operation as well as the Russian Space Agency (IKA) has prepared and started in 1995 the EUROMIR mission for two Belgian experimenters : Prof. L. Froyen of the "Katholieke Universiteit Leuven" and Prof. M. Paiva of the "Université Libre de Bruxelles/Hôpital Erasme".

BSROC has established the connection with the German Space Operation Center (GSOC) and has transferred data video images, sound in real and near real time. An operational support is given to the experimenters during the weekly cycles of their operations.

#### 3.3. SOHO mission

BSROC supports the transfer of the SOHO (Solar and Heliospheric Observatory) mission of two Belgian experimenters : Dr. D. Crommelynck (Royal Meteorological Institute) for its participation to the VIRGO (Variability of Solar Irradiance and Gravity Oscillations) experiment with its DIARAD (Differential Absolute Radiometer) and Dr. P. Cugnon for its participation to EIT (Royal Observatory of Belgium).

DIARAD has been launched on December 2, 1995. Preliminary data treatment shows that the radiometer behaves as expected.

### 4. Publications

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## **II. Space Astronomy**

### **A. Royal Observatory of Belgium**

#### **1. Infrared Astronomical Satellite (IRAS) and Infrared Space Observatory (ISO)**

The stellar wind of early-type stars (spectral type OB) was studied through the infrared and radio continuum. The observations at 12, 25 and 60  $\mu\text{m}$  were collected from the Infrared Astronomical Satellite (IRAS), and supplemented by data from ground-based observatories and radio-telescopes. Comparison of time-independent hydrodynamical models with the observations indicate that at least some of the stars show additional flux. We therefore introduced clumping in the wind and found that the discrepancies in the flux could be explained under the assumption that the parameters for the clumping are of the same order as those predicted by sophisticated time-dependent hydrodynamical models. This work will be extended to Wolf-Rayet stars.

The present observations allow us to derive information about clumping close to the surface of the star. To extend our coverage we have an observational programme for the Infrared Space Observatory (ISO) where a few B-stars and Wolf-Rayet stars will be observed at 60, 90 and 160  $\mu\text{m}$ .

#### **2. International Ultraviolet Explorer (IUE) and Hubble Space Telescope (HST)**

The Uniform Low Dispersion Archive (ULDA) of the ESA IUE Observatory can be consulted by means of the user-friendly software package USSP. In Belgium it is installed on the  $\mu\text{Vax}$  of the Royal Observatory, which acts as National Host. The archive can be consulted directly at the Observatory or by remote access. The format of the extracted spectra is compatible with MIDAS (Munich Image Data Analysis System). Version 4.0 of the Archive, which contains all low-resolution spectra up to Jan. 1, 1992, has been installed and is used regularly by Belgian astronomers.

Archive data of high-resolution spectra were used to study the P Cygni profiles caused by the stellar wind of early-type stars. To construct theoretical models for the wind we started from a code developed by Lamers, Cerruti-Sola and Perinotto. This code was extended to include non-isotropic and distance-dependent turbulence in the wind material. The fitting of the theoretical models to the observations has also been automated.

Preliminary tests show that obtaining a good fit for the profiles is difficult due to the blends by photospheric lines. Therefore archive spectra of the Hubble Space Telescope for stars with a similar spectral type in the Magellanic Clouds, where the metal abundances are lower, have been

consulted. This will allow us to judge better the influence of photospheric lines on our sample of stars.

### **3. Atmospheric Trace Molecule Spectroscopy (ATMOS)**

ATMOS (Atmospheric Trace Molecule Spectroscopy) is an experiment of JPL (Jet Propulsion Laboratory)/NASA. High resolution absorption spectra of the earth atmosphere were taken from the Space Shuttle in 1985, 1992, 1993 and 1994, using a very performant Fourier transform spectrometer, mainly to study the vertical distribution of molecular constituents of our atmosphere.

The solar team of the Royal Observatory of Belgium, in collaboration with solar spectroscopists of the University of Liège, is interested in the pure solar spectra, obtained with the sun high above the horizon, from 2 to 16  $\mu\text{m}$ , free from any telluric absorption. The work consisted of measuring and interpreting the ATMOS solar spectra.

The main results based on these pure solar spectra can be divided into three different domains: solar physics, atomic and molecular spectroscopy:

- Solar physics: new determinations of the solar abundance of C, N, O and Fe; a refined photospheric model based on atomic and molecular lines;
- Atomic spectroscopy: identification of new infrared lines of Fe I based on laboratory and theoretical spectra, determination of term energies and of solar-derived  $g_f$  values for all relevant lines (in collaboration with two spectroscopic groups: at Lund and at Amherst);
- Molecular spectroscopy: determination of a new refined set of spectroscopic constants for the ground state of OH.

## **4. Hipparcos astrometry mission and double star astronomy**

### ***4.1. Input catalogue consortium***

The Hipparcos Input Catalogue (HIC) already published in 1992 has been edited on CD in 1994 by the European Space Agency with softwares for Macintosh and PC including the data on double and multiple systems collected in a specific Annex (vol. 6) established on the basis of the CCDM.

A systematic search of new identifications of double and multiple stars in this catalogue has been pursued (see 4.2). This had led to the discovery of some errors due to source-catalogues. Identifications and errors have been published in the Bulletin of the CDS at Strasbourg.

### ***4.2. Catalogue of the components of double and multiple systems (CCDM)***

A first edition of this catalogue has been presented during the XXII<sup>d</sup> IAU General Assembly at The Hague in 1994 at a poster-session of the Symposium n° 166 "Astronomical and Astrophysical objectives of Sub-milliarcsecond optical Astrometry" and has been published. It has also been deposited at the Centre de Données Astronomiques at Strasbourg (CDS) under ref. I.211 and a summary of its introduction has been published in the Bulletin of this Centre.

It contains 34.031 systems of which 14.700 have been observed by Hipparcos.

Since the publication, 833 more known double and multiple systems have been identified in the Hipparcos Input Catalogue and have been added to the definitely identified systems in the CCDM. This was made possible by the use of newly available data and of a copy of the INDEX-WDS (December 1994) kindly put at the disposal of the HST Double Star Working Group in advance of publication by C.E. WORLEY of the USNO, Washington. The use of the Guide Star Catalogue (GSC) has also been predominant.

Simultaneously, by realising the CCDM, errors have been found in the INDEX CATALOGUE OF VISUAL DOUBLE STARS (1961.0) by H.M. JEFFERS and W.H. Van den BOS. The list of these errors has been published in the Bulletin of the CDS at Strasbourg.

The CCDM is now being pursued independently of the Hipparcos mission, in view of future double star researches and especially in view of future space astrometry projects such as GAIA, to which the Royal Observatory of Belgium is also participating.

#### ***4.3. Final Hipparcos Catalogue***

The manuscript of the final Hipparcos Catalogue is in preparation. To assist the two Data Reduction Consortia (NDAC and FAST), a Double Star Working Group has been set up in 1993 by the Hipparcos Science Team (HST). Members are : M. PERRYMAN (Great-Britain), J. KOVALEVSKY (France), F. MIGNARD (France), J. DOMMANGET (Belgium), P. LAMPENS (Belgium), L. LINDEGREN (Sweden), S. SÖDERHJELM (Sweden), R. PANNUNZIO (Italy).

For practical reasons, all double stars in the Hipparcos programme have a CCDM identifier. Such identifiers have thus been created for all new systems discovered by the satellite, that means for 6.900 new systems and for 9.100 stars suspected of duplicity. They have been introduced in the CCDM on a provisional basis.

After the merging of the data was achieved by the two Reduction Consortia, a list of results on double and multiple stars was sent in order to undertake at Brussels the identification of the components for each system observed. Based on this merged list and on a subset of the CCDM, a procedure has been developed that verifies the concordance in relative astrometry and photometry between the (sometimes old) ground-based and the satellite data. As a result, 8735 known components (some 90%) have been automatically identified. For the remaining 10%, it has been necessary to check the identifications on a star-to-star base. New components have been found in 2% of the systems while it has not been possible to give the exact component identification for another 3%.

#### ***4.4 Double Star Astronomy***

Hipparcos results will be of great profit for all fields in astronomy. But as usual, results by new techniques should be considered with great care. In that respect it has been shown that Hipparcos measurements of double stars should be treated cautiously when computing new orbits.

First results of a complementary ground-based photometric programme that aims to provide astrophysically significant colour indices for the Hipparcos double and multiple systems have been presented.

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## B. Space Center of Liège

### 1. SOHO-EIT

A global optical survey of the solar corona will be accomplished by observations made with the EIT (Extreme ultraviolet Imaging Telescope) on-board the SOHO spacecraft (Solar Heliospheric Observatory).

EIT is a high resolution multi-bandpasses Ritchey-Chretien telescope with normal incidence multilayered mirrors. Various aluminium filters are used to reject visible light. The images are recorded with an EUV enhanced camera with a backside thinned CCD (1024 x 1024 pixels) cooled down to - 70°C. The four channels of EIT are 171 Å (Fe IX), 195 Å (Fe XII), 284 Å (Fe XV) and 304 Å (He II), all with the same field of view of 45 x 45 arcmin centered on the sun.

In the frame of an international consortium (B, F, USA), the Space Center of Liège (CSL) ensured the technical management of the overall program, and was in charge of all the AIV activities at instrument level.

The laboratories involved in the EIT consortium are :

IAS - Orsay, F (Institut d'Astrophysique Spatiale)  
CSL - Liège, B (Centre Spatial de Liège)  
ROB - Bruxelles, B (Royal Observatory of Belgium)  
NRL - Washington DC, USA (Naval Research Laboratory)  
LAS - Marseille, F (Laboratoire d'Astronomie Spatiale)  
IOTA - Orsay, F (Institut d'Optique Théorique Appliquée)  
LPARL - Palo Alto, Ca, USA (Lockeed Palo Alto Research Laboratory)  
GSFC - Greenbelt, Md, USA (Goddard Space Flight Centre)

Since 1989, the EIT team at CSL was responsible for

- the technical management of the instrument
- the interfaces with ESA
- the instrument specifications
- the qualification of the instrument (vibrations, thermal tests, ...)
- the assembly, integration and verification activities with high level cleanliness requirements
- the follow up of the S/C mechanical and thermal verifications
- the launch preparation

In 1994 and 1995, among all the CSL activities related to the EIT program we can list the following :

- leak tests on the vacuum seal housing of the instrument
- stray-light tests
- acceptance vibration tests on the flight sensor
- a new thermal analysis of the instrument with correlations after tests at S/C levels and final trimming before flight
- a completely new aperture door design, qualification and manufacturing at a very late stage in the program (single point failure)
- full functional tests of the instrument (camera, thermal system and all the mechanisms)
- alignment verification
- a verification of the vibrations recorded during S/C acceptance and jitter tests
- vacuum operations in the leak tight instrument, during all the S/C AIV and just before launch

The flight sensor was delivered to ESA in April 94 for integration on the spacecraft. After the spacecraft thermal tests at Intespace (Toulouse), a new door system has been delivered and integrated by CSL on the instrument in January 95. These operations were followed by the mounting of the spare camera with a new CCD chip. CSL ensured the periodic pumping of the sensor, for cleanliness and safety purposes during all the spacecraft AIV.

In August 95, SOHO was transferred to Kennedy Space Centre, where CSL followed the last tests and performed the final preparation for flight. A very late pumping verification was performed on the ATLAS launch tower just before flight.

SOHO has been successfully launched on 02-Dec-95 by an Atlas Centaur IIAS rocket. During the first commissioning operations, the door system was unlocked and successfully open by mid Dec 95.

EIT took its first EUV images of the sun's corona on 02-Jan-96. They demonstrated all the capability of the instrument to fulfil the high level scientific objectives of the mission.

## 2. XMM-OM

The Space Center of Liège participates to one of the programs of the XMM payload : the optical monitor (<sup>XMM</sup>OM).

The <sup>XMM</sup>OM is the instrument that enables XMM to provide simultaneous images in the waveband of 150 nm to 650 nm. The scientific consortium supporting <sup>XMM</sup>OM activities is made of the :

- Mullard Space Science Laboratory of University College London (UK)
- Department of Astronomy of the Pennsylvania State University (USA)
- Space Centre of Liège of the University of Liège (B)
- Astrophysical Institute of the University of Liège (B)

The main characteristics of <sup>XMM</sup>OM are :

- Cassegrain telescope with primary mirror diameter of 300 mm
- Diagonal field of view of 24 arcmin
- Resolution of 1 arcsec
- Two redundant detection paths constituted of a filterwheel (with U, B, V, UV, interference filters and grisms) followed by a MCP detector
- Magnitude limit in 1000s : 24.5
- Magnitude of brightest star : 14.5

CSL contributes to the delivery of the Telescope Module Power Supply Unit (TMPSU). It is basically a DC/DC that converts the 28 V DC spacecraft power into lower voltages for the electrical units inside the instrument. The TMPSU contains digital logic that receives operational commands from the ground and consequently switches on or off electrical devices. It also receives information from sensors and encoders and it sends it back to the ground. The TMPSU controls the electrical status of <sup>XMM</sup>OM.

CSL is responsible for the space qualification and acceptance tests of <sup>XMM</sup>OM. It will provide the facilities for vibration, thermal vacuum and thermal balance tests. From the scientific side and to an end-to-end optical verification campaign is foreseen. In thermal vacuum image quality, distortion and point source throughput measurements will be performed.

The image quality for large field of view will be checked with artificial stars. These artificial stars are simulated by pinholes located in the focal plane of a collimator. The simulated star points will serve for point source calibration purposes. A system level flat field test and straylight test are also foreseen.

CSL started in 1994 with the TMPSU activities. The TMPSU breadboard model is in a terminal phase. The qualification and flight model will be delivered respectively in September 1996 and in June 1997.

Meanwhile the system calibration plan has been issued by Mullard Space Science Laboratory in 1995. This document describes the scientific test requirements and it is the input that allows CSL to define the specific tests and optical ground support equipment to be build. The test campaigns of three months will start in December 1996 for the qualification model and December 1997 for the flight model.

### **3. Integral-OMC**

An optical monitoring camera (OMC) will be mounted on the INTEGRAL platform, to be launched in 2001 in the frame of the ESA long term scientific plan Horizon 2000. The OMC will provide observations of long duration in the optical band simultaneously with those at X-rays and  $\gamma$ -rays obtained with the other INTEGRAL instruments. Images with a 5° x 5° field of view will be focused on a CCD camera (1024 x 1024 imaging pixels).

CSL is part of the OMC international consortium (Spain, Belgium, Ireland and UK), and is in charge of the study and delivery of the complete optical system, the optical baffle and the aperture cover. All the assembly, integration and verification activities related to overall instruments are planned to be performed at CSL.

The OMC program started in 1995 at CSL. A first optical design has been developed and optimised for the wavelengths of interest. This design has been updated several times according to the new CCD chip which was still to be selected. The stray-light is an important parameter for OMC. A reduction of  $10^{15}$  of the sun light is needed to achieve the scientific objectives. Studies are on progress to design and evaluate the remaining unwanted light arriving on the detector. An optimisation will be performed once all the parameters related to the OMC accommodation on INTEGRAL will be known.

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## C. Astronomical Institute of the "Katholieke Universiteit Leuven"

The main topic of research of the institute is the study of circumstellar matter surrounding young, old, and binary stars. It is based on optical observations and on observations with the IRAS and IUE satellites.

From a study of IRAS sources with bright optical counterparts, several new young stars of the Herbig Ae/Be class were found. Our research focusses on objects which have left their parent star formation cloud, and which are surrounded by a dusty disk. An interesting result is that the spectral energy distribution of several sources is characterized by a dip at about 5 A.U. from the star, i.e. at the distance of Jupiter. A tantalizing possibility is that the process of planet formation is well developed in these disks.

From IRAS and optical data several post-AGB stars, i.e. low-mass stars in a terminal evolutionary phase, were found. A special group of objects displays marked abundance peculiarities, which are ascribed to gas accretion on the star. It was found that all these objects are binaries, with orbital periods of the order of one year. Clearly, then, the stable circumsystem disks are responsible for the peculiar processes taking place.

In two objects, HR4049 and HD213985, the circumstellar matter can be observed both in emission (IRAS) and in absorption (IUE); the circumstellar absorption is variable in both cases. Multiwavelength studies of these objects allowed us to find correlations with the behavior of the circumstellar 220 nm bump (HD213985) and the far-UV extinction rise (HR4049) with the grain characteristics as revealed from the infrared observations.

The supergiant 3 Puppis is characterized by a huge infrared excess. Combining optical and space data, it was possible to show that this object is a massive supergiant and not a post-AGB star. The peculiarity of 3 Puppis appears to be linked to its presence in a binary with an extreme mass ratio.

The institute is intensively involved in the data analysis and calibration processes of the Infrared Space Observatory (ISO), which was successfully launched on November 16, 1995. This involvement has resulted in scientific contributions to both the central and open observing programmes with the satellite.

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## **D. Astronomical Observatory of the University of Ghent**

### **1. Magnetic Field Turbulence in Cometary Beam-Plasma Systems**

The highly successful missions to comets P/Giacobini-Zinner, P/Halley and very recently P/Grigg-Skjellerup, with their splendid in situ measurements of a wealth of plasma phenomena, have confirmed some of the theoretical foundations, but at the same time called for a drastic refinement of those. Complete assimilation of cometary ions into the solar wind can only occur through collective effects which generate low-frequency turbulence. Why these low-frequency electromagnetic fluctuations should dominate is not yet clear from a theoretical point of view. The mass-loading of the solar wind is also responsible for the cometary bow shock.

Theoretical developments and numerical simulations of plasma modes and instabilities involve not only the linear but also the quasilinear and nonlinear aspects needed to determine the ultimate levels of low-frequency turbulence. Good agreement has been reached in this stimulating interplay between theoretical concepts and observational evidence.

There are many applications of similar theories to linear and nonlinear plasma modes outside the cometary context. Some relevant examples include certain types of solar flares, magnetospheric and auroral plasmas and dusty plasmas in the solar system. The nonlinear framework can even be used to model nonlinear mode coupling in stellar pulsations.

In particular, low-frequency electromagnetic turbulence near the proton gyrofrequency observed far upstream of comet P/Halley can be excited by a beam instability driven by relative streaming between cometary protons, solar wind protons, and water group ions. For a given solar wind velocity, the growth rates peak at a certain optimum frequency shift (from the exact proton gyrofrequency), and the wavelengths involved can be deduced in a selfconsistent way from the dispersion law. Only under ideal conditions when all parameters remain constant would the mode corresponding to the optimum frequency shift grow fastest and might it be possible to observe a nearly constant frequency mode. However, if the solar wind parameters were not constant, then a mode which was earlier in resonance would no longer remain so, and some other mode with a slightly different frequency shift may start to grow fastest, leading to a mixing of many modes. Thus, only rarely would one be able to observe a single mode near the proton gyrofrequency, exactly as what happens in the observations. Our selfconsistent approach yields resonant instabilities with left-handed polarizations in the spacecraft frame.

### **2. Dusty Space Plasmas**

Dusty plasmas contain charged dust grains which are much more massive than protons and usually carry high negative charges due to preferential capture of electrons. Linear and nonlinear modes have been investigated in magnetized such plasmas, where the dust dynamics is modelled by a number of cold, highly negatively charged and very massive fluids, besides ordinary electrons and protons. Several low-frequency motions occur which are typical for the dust components, some of

them described by model equations such as the derivative nonlinear Schrödinger equation for electromagnetic waves.

One can include equilibrium drifts and even fluctuations in the grain charges. The latter occur because the dust grains do not have a fixed charge, and perturbations in the plasma potentials induce fluctuations in the grain charges due to liberation or capture of additional electrons and protons. Such sources or sinks for electrons and protons translate as mass and momentum losses or gains. For the dust fluids it is mostly fluctuations in charge that is a new phenomenon. As a result several modes become unstable.

For electromagnetic modes the instability is due to the momentum loss or gain. If we assume the dust to be quasi-immobile, due to their heavy masses, a whistler-like wave has been derived and its stability discussed. When streaming effects are also taken into account, the modes can be stabilized for specific values of the different parameters controlling the momentum transfer and the streaming. On the other hand, for moving dust, nonresonant electromagnetic fluctuations are studied in a multibeam plasma with anisotropic pressures, by taking the momentum and pressure changes in the dust charges into account. Equilibrium drifts are included, leading to a dispersion law for Alfvén modes in the firehose-like limit. Possible instabilities are discussed, including their quasilinear evolution.

Many of the above analyses are relevant to different kinds of astrophysical and heliospheric plasmas.

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## E. Astrophysical Institute of the "Vrije Universiteit Brussel"

A part of the work was devoted to the investigation of a number of OB-runaways. More precise data on position and space velocity of stars are becoming more and more available from the astrometric satellite Hipparcos. From the position and space velocity of these runaways we traced back their birth place and birth date. Using massive binary evolutionary computations, leading to theoretical values of the atmospheric abundances, masses, ages, radii, and comparing those with observed values of these quantities allowed us to discriminate among various possible evolutionary scenarios, and to model a number of runaways. Indeed, the position in space and the space velocity derived from ground based and space observations allows to determine the time elapsed since the supernova event. Using this parameter to make comparisons with the evolutionary sequences permits to retrace the history of the investigated associations and runaway objects.

Evolutionary computations with the new OPAL opacities were performed for massive close binaries with mass ratio 0.6 and 0.9, primary masses between  $3 M_{\odot}$  and  $40 M_{\odot}$ , with chemical abundances holding for the Galaxy and the Magellanic Clouds.

These extended library of binary models allows to derive analytic expressions among the various stellar parameters, and provides in this way an excellent tool for observers, as well users of optical telescopes as space telescopes to interpret their results.

The stellar mass-losses (ranging up to several  $10^{-5} M_{\odot}/y$ ) influence stellar evolution radically and have been considered in our computations the evolution of massive close binaries. The mass losses have been determined from the P-Cygni profiles of the spectral lines of massive OB-stars and WR-stars. The profiles have been collected from observations in the Ultraviolet with IUE.

The evolution of the secondary after the mass transfer phase was continued till the end of its core hydrogen burning phase. Conclusions after critical comparison between the results of the Galaxy and the MC's were presented. Especially rather far evolved massive systems, Wolf-Rayet stars and massive X-ray binaries were investigated, comparing the obtained theoretical results with observations e.g. as made in the X-region by UHURU, ROSAT and the EINSTEIN X-ray observatory.

In order to explain a number of features of the well observed supernova SN1987a, more explicitly the explosion in the blue region of the HRD, the binary hypothesis for this object was proposed and examined. A special recipe for the behaviour of the mass receiving star during mass transfer, i.e. complete mixing of the infalling material with the existing material was suggested; the procedure was inserted in the evolution code, tested and used to calculate evolutionary sequences for massive stars. It turns out that this assumption leads to a good agreement with the observations.

Since January 1995, a new research topic was started : the effect of close binary evolution on number statistics and on spectral synthesis of large groups of stars. We focussed on the number of Be stars formed through intermediate close binary evolution, the number of OB and WR stars with a compact companion, the effect of binary evolution on the evolution of the number of WR

stars and O-type stars in starburst regions, with emphasis on the so called WR galaxies. We conclude :

- The number of Be stars formed through binary evolution is small, may be less than 10% of the total number.
- The number of WR type stars with a compact companion may be as low as 2% of the total WR sample, i.e. if Cyg X-3 is a WR+CC, it may be unique.
- The effect of binary evolution on the evolution of the number ratio WR/O in starbursts is very large, contrary to previous investigations which were however very qualitative as far as binaries are concerned.

Mass-loss is also a fundamental parameter which influences the evolution of Be stars. The mass losses have been determined from the profiles of the spectral lines which have been collected from observations in the Ultraviolet with IUE.

The observations looking for long-term variability of Be stars, collected at Calar Alto and Observatoire Haute-Provence have been reduced. One high-light on long-term variations are the V = R transitions in HR 1961 and in the extreme pole-on Be star 11 Cam, monitored in different emission lines. The detection of an asymmetric He I absorption line, which has recently be found to be variable is first evidence for the binary nature of 11 Cam. One high-light on short-term variations is the binary Be star  $\phi$  er. A new model has been proposed to explain the origin of the He I 5875 Å line without the requirement of a current mass-transfer. First model calculations of a rotating disk, excited by the companion star supports this new idea.

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## III. Space Geodesy

### A. Royal Observatory of Belgium

#### 1. Geodesy

The Royal Observatory of Belgium (ROB) has a long tradition of collaboration in astronomical and geodetic international campaigns. The ROB participated to the BIH observations for time and latitude determinations and to the first European geodetic network (WEST) developed for satellite observations from 1966 to 1971. It conducted latitude measurements from TRANSIT satellite tracking (1972-1987) by the DMAHTC Doppler network. GPS measurements were carried out in the frame of the international EUREF89, EUREF-NORTH, GIG'91, EPOCH92, EUREF-L-D-B94 campaigns and different national GPS campaigns.

A TurboRogue receiver, permanently operating at the ROB in Brussels, is included in the IGS network since November 1993. The data are processed by the CODE processing centre.

Due to the growing interest of the Belgian GPS user-community, 3 more permanent TurboRogue receivers have been installed in Belgium during 1994. All 4 receivers are now operating permanently and the data are processed daily at the ROB with the Bernese software and self-developed programs. The principal goal is the study of the effect of the ionospheric refraction on GPS computations and the determination of precise station coordinates in an international reference frame, allowing to study correlations between the coordinate variations and geophysical phenomena. The 4 stations were the reference points during the deployment of the first "zero order" GPS network (30 stations) in Belgium by the National Geographic Institute.

The IGS station in Brussels is very interesting from a geophysical point of view because of the collocation with other geophysical instruments. A TRANET station was operating on the same site from 1972 to October 1993.

A superconducting gravimeter is continuously recording at the ROB and until now absolute gravity measurements were carried out twice a year. In 1996 an absolute gravimeter is expected to be operating more often. Ground water level variations are monitored and seismic measurements are continuously made on site.

Precise frequency is made available to the GPS receiver by a H-maser.

The GPS station at the ROB combines the national and international aspect of GPS and offers collocation with a variety of other geophysical instrumentation.

Scientific research is concentrated on different topics :

### ***Study of the effect of the ionospheric refraction on GPS measurements.***

The Total Electron Content (TEC) is the main parameter to determine the effect of the ionospheric refraction on GPS measurements. Irregularities in the TEC, such as Travelling Ionospheric Disturbances (TID's) or scintillations can result in important positioning errors. For this reason, statistics about the occurrence of these irregularities are computed.

These phenomena are studied using 3 independent measurement types : Transit, GPS and ionosonde observations are used to compute the total Electron Content. A very good agreement has been found between these different measurements.

### ***Modelling an methodologies used for processing GPS observation campaigns.***

Theoretical studies concerning the processing of static GPS measurements resulted in a software capable of calculating small GPS networks. This software was successfully tested on a GPS network observed on the Mount Etna Volcano.

A GPS network on the Mount Etna volcano (Italy) was observed during 3 campaigns from 1992 to 1994. The goal was to detect ground displacements on the volcano. It was shown that the presence of extreme tropospheric conditions and different micro-climates at the volcano (as for most volcanoes) caused systematic errors of about 10 cm in the estimated heights, if only an a priori tropospheric modelling was used. However, if evaluated with extreme care, valuable information could still be extracted from the height measurements.

The comparison of the horizontal positions from the two first campaigns showed a horizontal displacement of a few cm of the volcano towards the East. This movement was reobserved with the third campaign, validating the results the previous ones.

## **2. Earth rotation and time**

The Earth rotation amplitude variations have been studied by spectral analyses, wavelet analyses, and correlations with other parameters with a particular attention on the 50-day, 120-day, 2,5 years (QBO) and 5,5 years. The amplitudes of the fluctuations observed at all or part of these periods, were estimated, in the Earth rotation as well as in the observations of the atmospheric angular momentum, the solar wind, the interplanetary magnetic field and the geomagnetic indices; their mutual correlations and coherencies have been also estimated.

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## **B. Royal Military Academy**

### **1. Determination of the belgian geoid at the cm-level**

The modern era is characterised by an ever growing impact of satellite systems on almost every domain of our daily existence, such as telecommunication, agricultural and forestial exploitation aided by teledetection satellite services, worldwide transport through global navigation satellite systems, ... . To integrate the spatial information obtained by these new technologies into the historical grown cartographic representations, such as the Belgian Lambert projection and the ortometric height determination, one needs to be able to convert the three-dimensional data related to a universal or global reference to the national or local projection system.

The classic approach for defining the spatial position of a point consisted of two independent procedures. The planimetric position was determined under the assumption that the nationally chosen reference ellipsoid (Hayford 1924) and the national geoid are tangent in an arbitrary chosen point, situated at Lommel for Belgium. Initiated by an astronomical point-positioning and astronomical azimuth, a national triangulation net of first order, densified into a second and third order planimetric net, was established by the National Geographic Institute (NGI), formerly known as the Military Geographic Institute. The ortometric height component results from a classic levelling originating at the reference point at Ostend indicating the mean sea level. Its reference level is formed by the national geoid, representing the local physical model for the Earth.

The approach used in the field of satellite systems finds its origin in the description of the theory of the gravimetric potential of the earths attraction. This development starts with the specification of the earths mathematical model, namely a revolution ellipsoid. The orbital position of the satellite, and the derived geometrical information, therefore refers to this reference ellipsoid.

In order to be able to transform the geometric data derived from satellite systems, one needs to exactly locate its national geoid with regard to the international reference ellipsoid of the global satellite datum and determine the transformation formulas between the heterogeneous national coordinate system and the homogene satellite datum. The determination of the Belgian geoid at the cm-level is based on satellite observations using highly accurate differential positioning with the Global Positioning System and gravimetric measurements. A new net of order zero will be made up of about 36 points parcelled throughout Belgium. This net, known as BREF, will be densified in the future by the NGI to obtain a national coverage of approximately 1 GPS point each 8 km<sup>2</sup>.

The determination of the Belgian geoid is performed in collaboration with the Royal Observatory of Belgium, the Catholic University of Leuven and the National Geographic Institute of Belgium. Cooperation extends to the surrounding countries in order to realise a smooth transition to their national geoids.

## **2. Differential navigation using the global positioning system**

The Global Positioning System GPS-NavSTAR offers worldwide users the possibility to position themselves in real-time. At the department a least-square solution and a Kalman filter approach, based on the L1-phase filtered SPS pseudo-range measurements and the observed Doppler frequency on the L1-carrier wave, is being developed. The eight state Kalman vector models the geodetic position and velocity of the kinematic vector and determines the offset and drift component of the local oscillator compared to the master GPS time. This modelling allows to update the position of the kinematic vehicle even when less than four satellites are present.

Practical testing has been performed near Vilvoorde. Static differential positioning enabled to establish a local reference receiver at the installations off As.I.A.T. This geodetic positioning was based on the determination of the baseline between the Turbo Rogue reference receiver positioned at the Royal Observatory of Belgium (Uccle) and the local Ashtech reference receiver at As.I.A.T. Several kinematic tests were executed and a comparison between absolute and differential navigation of an army jeep has been performed. Since a navigator references himself on a chart of graphical representation of the obtained trajectory based on an electronic chart has been programmed. The electronic charts implemented are in the popular DXF-format. A transformation between the satellite datum WGS84 and the national cartographic projection Lambert 72 and the UTM projection are performed for specific regions.

LtZ de Coppieters de Gibson performed a differential kinematic test on board of the minehunter Aster. He examined and compared different positioning strategies based on the GPS system and compared these results with the well known hyperbolic Syledis navigation system used on board of the Aster. The marine community is preparing itself to use electronic charts. Different implementation techniques for these electronic charts, their minimal requirements and the necessity of integrating these charts with the Global Positioning System were investigated by LtZ de Coppieters.

## **3. Publications**

- MULS, A., Symposium 14th AFCEA Europe Brussels symposium and exposition : "Interoperability through open systems - The technological challenge", Brussel, October 1993.
- MULS, A. and BRUYNINX, C., The necessity of integrating the global positioning system for navigational purposes, ACEA Conference, Pyramid Brussels, 27-29 Oct. 93, invited presentation.

## IV. Material Sciences

### A. Microgravity Research Center of the "Université Libre de Bruxelles"

#### 1. Experiments in microgravity conditions

##### 1.1. *Capillary convection in a three layers system (Mini-Texus 2, Spacelab IML 2, Maxus 2- LMS 1)*

The Mini-Texus 2 sounding rocket was launched in Spring 1994 to allow the study of the best way to create a large flat liquid/gas interface. During the IML 2 mission of Spacelab in July 1994, the Microgravity Research Center (MRC) team performed very successful experiments on hydrodynamic instabilities in a three layer system heated perpendicularly to the liquid/liquid interfaces. The analysis of the data acquired during the Spacelab flight, started in June 95 and is not yet finished. Many interesting data have been accumulated and there is a qualitative agreement between theory and numerics. Preparation of the Spacelab LMS 1 mission is now progressing, the launch is foreseen in July 1996. The physical characteristics of the fluids to be used in this second experiment will allow to study oscillatory behaviour (including travelling waves) beyond critical temperature difference.

The MRC performed also parabolic flights to verify the stability of the n-octane - methanol - n-octane system. Preparatory work included also tracers selection and time-line definition. Unfortunately, the experiment on the Maxus 2 sounding rocket failed for payload technical reasons and a refligh has been requested.

##### 1.2. *Soret coefficient (EuReCa)*

The results of the Soret coefficient measurements performed during the EuReCa 1 mission in 1993 have been analyzed and published. The MRC is now preparing the measurement of Soret coefficients in crude oil mixtures under microgravity conditions. The design of the new instrument as well as the definition of the best carrier is progressing. It is planned to perform this experiment in a Get Away Special can (GAS) on board a US shuttle. This study has been supported by theoretical work to define the Soret coefficients in such complex mixtures.

Very interesting results have been obtained in the study of the influence of Soret effect on the velocity of solidification and on morphological stability of growing crystals (collaboration with NIST - Washington, USA, and CENG - Grenoble, France).

### ***1.3. Bifurcation anomalies in Marangoni instabilities (BAMBI) - Foton 1997***

The MRC is preparing the BAMBI experiment to be performed in a Russian retrievable capsule Foton. The flight is planned for 1997. This experiment will be performed in the "Fluidpac" facility. MRC takes part in the development of this instrument, particularly with respect to the definition of the optical diagnostics in the framework of an industrial consortium led by Verhaert Design and Development. In parallel with the experimental work, very intensive theoretical investigations are conducted in collaboration with the team of Prof. Lebon of the University of Liège.

Instationary Marangoni-Bénard convection is investigated experimentally in a silicone oil layer 5 millimeters thick while heated from below with a constant power. The investigations reflect on the influence of the transient behaviour on the flow and temperature fields occurring due to the instationary conditions.

Extension of the work performed earlier on slow spatial modulations of two-dimensional rolls to the interaction of several roll patterns with arbitrary orientations. In particular, the interaction of resonant triads of wavevectors on the critical circle allows to study modulations of hexagonal Rayleigh-Marangoni-Bénard patterns, including defect formation and motion, effect of lateral walls and wavelength selection.

### ***1.4. Image processing of liquid/gas interface displacemen in a porous media***

Experiments were performed during ESA parabolic flights in order to measure the velocity of a liquid/gas interface inside a porous media. These experiments were video recorded. The design of a software able to localize the liquid/gas interface as a function of time is completed. This information can be stored in a compact and usable form.

The comparison of the experimental results with the theoretical model developed in collaboration with Prof. N.N. Smirnov, from the Moscow State University, is very good.

### ***1.5. Analytical and numerical investigation of thermocapillary flow in corner region***

Thermocapillary driven flow is numerically investigated for an asymmetric cylindrical liquid bridge. In the absence of gravity deviations from a cylindrical shape may be due to thermocapillary flow or a volume  $V \neq \pi R^2 d$ , where  $R$  is the radius and  $d$  is the length of the liquid bridge. The influence of the volume constraint on the thermocapillary flow, driven by a linear variation of the surface tension  $\sigma = \sigma_0 - \gamma(T - T_0)$ , was considered.

The previous work was extended and focused on the thermocapillary flow in the corners, where the free surface and the rigid wall meet at a contact angle  $\alpha$ . It is found analytically that for the Stokes flow near the corner exist the critical contact angle  $\alpha_c = 128.7$  where the stream function changes its sign. For  $\alpha > \alpha_c$  the local flow reversal is predicted. Special numerical efforts were used to prove it. The design of the hardware is progressing in order to select the best carrier on board of which the experiment could be performed.

## 2. Theoretical work to prepare future experiments

### 2.1. *Amplitude equations study of Marangoni-Bénard instability in two-layer systems with non-deformable interface*

This work consists in an amplitude equation analysis of the interactions between waves with wavenumber  $k_1$  (and phase speed  $\omega/k_1$ ) and stationary convection with wavenumber  $k_2$ . These two modes may bifurcate almost simultaneously from the conductive state of a two-layer Bénard system, when the ratio of layer thicknesses is near a particular value (codimension-two singularity).

When  $k_2 \neq 2k_1$  (non-resonant case) and the first bifurcation occurs for steady convection, a second bifurcation to a spatially quasiperiodic and time periodic mixed mode is obtained when increasing the driving gradient. No stable small-amplitude solution exists when the Hopf bifurcation is the first one. The occurrence of either of these two possibilities depends on the thickness ratio. When  $k_2 = 2k_1$  (resonant case), the system presents a much wider variety of dynamical behaviours, including quasiperiodic relaxation oscillations and temporal chaos.

The analysis performed for the resonant system concentrates on a scenario of transition to chaos consisting of an infinite sequence of "period-doubling" bifurcations of stable homoclinic orbits, for which the left-right symmetry of the convective system plays an essential role. For increasing constraint, a reverse cascade is observed, for which quadratic nonlinearities in the amplitude equations are shown to entirely determine the dynamics (cubic and higher order terms may be neglected near the codimension-two point).

### 2.2. *Finite-amplitude regimes of the Marangoni-Benard instability*

The MRC studies thermocapillary instabilities in systems submitted to temperature gradients far above the threshold of instability. As the method is based on the amplitude equations formalism, which is only strictly valid near the threshold, the results are only qualitatively valid, but the comparison with a fully numerical method (Galerkin) developed during 1991 shows good agreement. In particular, the wavelength selection between fastest growing large wavenumber modes and slower small wavenumber modes is investigated, the latter of which finally determine the size of convection cells (which grow until occupying the entire periodic simulation domain). Also investigated is the heat transport increase due to convection, measured by the decrease of the bulk temperature with respect to the purely conductive solution, and replacing the Nusselt number, for systems in which the injected heat flux is kept constant.

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## **B. Space Centre of Liège**

### **1. Space Bio-Separation**

In the frame of the Space Bio-Separation project, an instrument for high value proteins separation by liquid electrophoresis has been developed. This instrument (called RAMSES) has been part of the scientific payload of the International Microgravity Laboratory II (STS 65 shuttle flight), in July 1994.

Despite some anomalies during the mission, the instrument has proved the feasibility of the process : only minor updates need to be realised for further missions. The experimental procedures have been checked and adapted to the specific environment to assess the correct behaviour of the instrument. It can be concluded that the technological objectives have been met.

The main asset of microgravity is to increase the applicable range of some operational parameters, such as electrical field or sample concentration. A noticeable stability of the fluid flow has been observed, clearly demonstrating the gravitational origin of some ground disturbances.

After landing, the collected samples have been directly sent to laboratories. The analyses show that the performances of the separation cell agree with the numerical predictions. Some comparisons have been made with identical samples purified under one-g conditions. It has been possible, namely, to purify in orbit conditions a sample of gamma Interferon from a highly concentrated protein solution (4 times the nominal concentration usable under ground conditions). The yield rate has been so significantly increased. Nevertheless, in order to definitely confirm the advantages of a microgravity production, it should be improved to some extent. Another important result is that the biological activity of the purified specimens has been maintained.

Re-flight of the instrument is presently under negociation.

### **2. Publications**

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## C. Department of Metallurgy and Materials Engineering of the "Katholieke Universiteit Leuven"

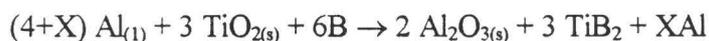
### 1. Metal Matrix Composites

#### 1.1. *In-situ composites*

The objective is the study of the feasibility of the in-situ process to cast reinforced metal matrix composites. The main problems of casted metal matrix composites are a poor interface between particle and matrix, floating or sedimentation of the particles in the melt and a drift of particles in the last part during solidification. The advantages of the in-situ system are the strong mechanical bond between the particles and the matrix, a reduction in the particle size of the reinforcement and the low production cost. With the help of our experimental results a model, for prediction of the influence of different parameters on the final composite material, is developed.

In the scope of the research about in-situ reaction of Al-Al<sub>2</sub>O<sub>3</sub> and reinforcements in a metal a study is made of the following systems : Al-Mo-B, Al-W-C and Al-B-C. The materials are analysed by the differential scanning calorimetry (DSC), to obtain information about the reaction temperatures and kinetics. All three systems give an endothermic peak at 710°C. After solidification of the Al-W-C system the following phases exist in any case : W, Al<sub>4</sub>C, W<sub>2</sub>C, WC and WO<sub>2</sub>. About the Al-Mo-B system we recognize the next phases : Al, Mo and MoO<sub>2</sub>. The other phases are difficult to identify.

An alternative material system is the production of Al-Al<sub>2</sub>O<sub>3</sub> and Al-Al<sub>2</sub>O<sub>3</sub> - TiB<sub>2</sub> composites by a in-situ reaction between TiO<sub>2</sub>, B and molten aluminium. The following reaction formula is relevant :



These processes are presently under investigation.

#### 1.2. *Solidification aspects of metal matrix composites*

To obtain a homogeneous composite material especially a good control of the solidification process is necessary. The sedimentation of the particles, the interaction of the particles with the solid-liquid interface, agglomeration, convection and the morphology of solidification influence the solidification process. Reference experiments are carried out on model systems with existing composites.

A first material is Duralcan<sup>tm</sup> (Al-Si alloy with 7% SiC particles). The Duralcan material is suited for studying the effect of gravity and convection, since the particles sink and show explicit segregation behaviour. The morphology of the matrix is dependent on thermal conditions. With slower cooling rates the size of the dendrites become larger.

This material was selected for the two experiments in the space station MIR (EUROMIR 95). Besides gravity, the influence of different cooling rates and temperature gradients is investigated. In each experiment two samples have respectively a high and a low gradient. The evaluation of the samples is in progress and will be finished after the 1g-reference tests will be completed (end 1996).

Another model material system, Al-TiB<sub>2</sub>, was selected for the EUROMIR '94 experiment at the space station MIR. Due to technical defects, this experiment could only be performed in January 1996. Samples are just returned.

Finally a dedicated furnace with the following specifications has been developed and constructed for ground based research :

- Maximum temperature > 1900°C
- Gradient of temperature > 10 K/mm
- Cooling rate > 100 K/s
- Sample velocity 0.25 mm/min -- 10 mm/s

Finally liquid metal quencher (Ga-In) is installed to obtain the high gradient and the high quenching rate.

### ***1.3. Modelling***

A model that takes into account the different phenomena during casting of MMC, like agglomeration and sedimentation, is developed. Two mechanisms for the motion of a particle in the liquid are considered : buoyant motion caused by a difference in specific mass between particle and liquid, and Brownian motion, due to random forces in the liquid. The model considers a rectangular volume, which is filled with liquid metal of uniform temperature and viscosity. The temperature of this medium remains constant. In order to simulate solidification, the viscosity of the medium can increase to infinity. This solidification proceeds with a planar interface normal to the direction of the gravitational force. The sizes of the particles are taken randomly from a normal distribution with mean and standard deviation. The simulation works with discrete timesteps. It is assumed that during such a timestep, each particle or group of particles moves with constant velocity. Once a velocity has been determined for every particle in the volume, it is checked whether particles collide with the volume walls or with each other. A collision with volume side surface is elastic, a particle sticks when it collides with the bottom and when two particles collide, they may or may not stick. All mobile particles that are in contact with the "solidified" medium are immobilised.

The simulation with different parameters leads to the following conclusions :

- As particle size increases, the sediment is denser.
- As variance in particle size increases, the time for all particles to settle increases.
- As sticking probability decreases, the suspension becomes more stable.
- An increase in temperature will be accompanied by a decrease in viscosity, and these two will increase the sedimentation rate.
- An increase in gravity will form a denser sediment.
- A solidification rate of 20 times the sedimentation rate is sufficient to retain a quite homogeneous particle distribution in the liquid.

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## V. Life Sciences

### A. Biomedical Physics Laboratory of the "Université Libre de Bruxelles"

#### 1. Spacelab mission SLS-1

Multiple-breath N<sub>2</sub> washouts (MBNW) with a N<sub>2</sub> free inspired gas mixture were used to study the inhomogeneity of ventilation in four astronauts before, during, and after 9 days of exposure to microgravity on Spacelab Life Sciences-1. Subjects performed 20-breath MBNW at tidal volumes of ~ 700 ml and 12-breath MBNW at tidal volumes of ~ 1,250 ml. Six indexes of ventilatory inhomogeneity were derived : (1) distribution of specific ventilation (SV) from mixed-expired and (2) end-tidal N<sub>2</sub>, (3) change of slope of N<sub>2</sub> washout (semilog plot) with time, (4) change of slope of normalized phase III of successive breaths, and (5) dead space. Significant ventilatory inhomogeneity was seen in the standing position at normal gravity (1G). When we compared standing 1G with microgravity, the distributions of SV became slightly narrower, but the difference was not significant. Also, there were no significant changes in the change of slope of the N<sub>2</sub> washout, change of normalized phase III slopes, or the anatomic dead spaces. By contrast, transition from the standing to supine position in 1G resulted in significantly broader distributions of SV ( $P < 0.05$ ) and significantly greater changes in the changes in slope of the N<sub>2</sub> washouts ( $P < 0.001$ ), indicating more ventilatory inhomogeneity in that posture. Thus these techniques can detect relatively small changes in ventilatory inhomogeneity. We conclude that, contrary to medical textbooks, the primary determinants of ventilatory inhomogeneity during tidal breathing in the upright posture are not gravitational in origin (Prisk et al., 1995).

#### 2. Spacelab mission SLS-2

Single breath wash-in tests for helium and sulfurhexafluoride were performed in 4 subjects exposed to 14 days of microgravity ( $\mu\text{G}$ ) during the Spacelab flight SLS-2. Subjects inspired a vital capacity breath of 5% He, 1.25% SF<sub>6</sub>, remainder oxygen, and then exhaled to residual volume at 0.5 l/sec. The tests were also performed with a 10 sec breath hold at the end of inspiration. Measurements were also made with the subjects standing and supine in 1G. Phase III slope of the single breath washout was measured after the dead space washout and prior to the onset of airway closure. In all subjects in 1G, whether standing or supine, phase III slope for SF<sub>6</sub> was significantly steeper than that for He. However in  $\mu\text{G}$ , the slopes became the same. Furthermore, following breath holding in  $\mu\text{G}$ , the SF<sub>6</sub> slopes were significantly flatter than those for He. On return to 1G, the changes were reversed, and there was no difference between preflight and postflight values. Because most of the phase III slope reflects interactions between convective and diffusive transport processes in the acinar regions of the lung, the results suggest that  $\mu\text{G}$  causes conformational changes in the acini, or changes in cardiogenic mixing in the lung periphery, but in either case the mechanism is unclear (Prisk et al., 1996).

### **3. Spacelab mission D-2**

We studied the contribution of inter-and intraregional inhomogeneity of specific ventilation or ventilation per unit of lung volume ( $\Delta V/VO$ ) from the rebreathing inert gas trace in micro-gravity ( $\mu G$ ) and on ground (1G). The rebreathing tests were carried out by four astronauts before, during and after the 9-day Spacelab D-2 mission. Starting from functional residual capacity, the rebreathing maneuver consisted of eight reinspirations from a bag filled with 1.8 to 2.2L of test gas mixtures containing approximately 5% Argon. The rate of Argon equilibration in the rebreathing bag was quantified by determining the logarithm of the actual minus equilibrated Argon concentration normalized to inspired minus equilibrated Argon concentration, termed RBeq. A compartmental model of the lung (Verbanck and Paiva, 1994) was used to validate the method for determining RBeq, and to simulate the influence of intra-and interregional  $\Delta V/VO$  inhomogeneity on the RBeq curve. The comparison between the experimental 1G and  $\mu G$  RBeq curves and model simulations shows that gravity-independent  $\Delta V/VO$  inhomogeneity is at least as large as gravity-dependent  $\Delta V/VO$  inhomogeneity (Verbanck et al., 1996).

### **4. Ground based studies**

#### ***4.1. Experiments under hypergravity***

The experiments, designed to extend to hypergravity our observations during parabolic flights, have demonstrated non linear relationships between several physiological variables and G (Estenne et al., 1995). We have shown that it is not possible to extrapolate to  $\mu g$  some of the observations made in the human centrifuge.

#### ***4.2. Measurements of the human diaphragm shape in vivo***

The interpretation of our experiments in  $\mu g$  requires the knowledge of the shape of the diaphragm in vivo. We have performed a detailed analysis using magnetic resonance imaging (Gauthier et al., 1994) and have shown that the diaphragmatic fibers may shorten more than any other skeletal muscle.

#### ***4.3. Aerosol studies***

In view of future experiments, where aerosol deposition in the lung will be studied in  $\mu G$  extensive simulations of aerosol transport were performed, both with one-dimensional (Darquenne and Paiva, 1994) and two-and-three dimensional models (Darquenne and Paiva, 1996) of the human lung.

#### ***4.4. Clinical applications***

Single breath tests with helium and sulfurhexafluoride, identical to those performed during missions SLS-2 and D-2 were performed in 22 heart-lung transplant recipients (Van Muylem et al., 1995). The results of these test on the patients who developed a rejection of the lung have shown specific characteristics. The test may be more specific than the standard pulmonary function tests to lung rejection and may allow a more rapid diagnostic.

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## **VI. Remote Sensing**

### **A. Laboratory for Geological Remote Sensing and Information Management of the Royal Museum for Central Africa**

#### **1. Exploring for base metals in Henan Province, China**

The search for new copper deposits is an important task for Chinese geologists. The increasing demand of the growing industry, now induces a shortage in some non-ferrous metals on the national market. In this scope, the China National Non-ferrous Metals Industry Corporation (CNNC) has undertaken a review of the possible sources of this basic commodity. The study is carried out as a co-operative program between the CNNC's Center of remote sensing for Geology, the Henan Research Institute of Geology for Mineral Resources, and the Belgian Royal Museum for Central Africa (RMCA).

Henan, located in Central China, South of Yellow River, is a traditional copper province; copper has been discovered and mined for many centuries and small scale extraction centres are still now in operation in the region. The study area lies in the south-western part of the province, in the median part of the QinLing mountain. Geologically, this mountain chain corresponds to an orogenic belt, developed between the North China and the YangTze blocks.

An inventory of the mining potential in a given area requires the support of modern geologic concepts and can take advantage of using the most recent techniques. The aim of the present project was to use remote sensing and GIS data integration for introducing new geologic guidelines for mineral exploration and help in defining target zones with high Cu potential.

The study consists in laboratory data processing and analysis yielding interpretation controlled in the field. Following subsidiary tasks have been performed:

- establishing a synthesis of the geologic knowledge on the area and of the principles currently used in mining exploration;
- controlling in the field, the existing regional geologic interpretations and the genetic models built for the known ore deposits;
- improving the definition of the ore controlling factors;
- processing satellite images in order to provide the most suitable base for visual interpretation and lithologic discrimination aswell as deciphering the influence of rocks and soils in the total signal;
- measuring on the field the radiometric factors of reflectance for calibrating the signal.
- gathering all possible sources of geological, geophysical, geochemical information on the area;

- analysing the whole set of image and non-image data, integrate them and interpret them in relation with the ore controlling factors;
- defining zones of converging favourable conditions and select targets for further mineral exploration.

The analysed satellite imagery comprises, in the optic range, a Landsat Thematic Mapper scene and a Spot P scene and, in the radar SAR range, an ERS-1 and a JERS-1 scene. Problems in remote sensing of geological features result, in the optic range, from the dense vegetal cover and, in the radar range, from the high and varied relief. Intensive preprocessing of imagery has thus been required. Nevertheless, the geological map has been enhanced according to novel structural and lithologic interpretations.

Multilayer analysis of geophysical data (gravimetry, magnetism, gamma-ray spectrometry) has also required intensive preprocessing due to the nature of the original data. This has in turn allowed to re-consider the geology of this part of the QinLing belt in a new geodynamic perspective.

Financial support has been provided by the China National Non-ferrous Metals Industry Corporation and by the Belgian Ministry of Science OSTC in the frame of the general protocol on scientific and technological co-operation between the Belgium-Luxembourg Economic Union and the People's Republic of China.

## **2. Mapping stony soils in Morocco for agricultural development**

The presence of calcrete at low depth limits the agricultural development of the Sahel des Doukkala, situated at the South-East of the city of El Jadida. The planification of the mechanical dislocation and the removal of the duricrust of a zone as large as 100,000 hectares requires a specific mapping of the crusts and of the stony component of the soil surface. This mapping was achieved through satellite remote sensing, using image processing of multispectral and panchromatic SPOT, Landsat Thematic Mapper and radar ERS1. The results of image processing were combined with other information (such as a digital elevation model obtained from digitized topographic maps, roads and rivers networks and field observations) in a Geographic Information System.

A field survey has been performed in April 1995 in order to define the most significant parameters of the problem: the presence of calcrete, its depth and thickness, its relationship with the distribution of stones on the surface, the geological composition of the bedrock, the nature of the soils, the topography, the agricultural landuse and the progress of stone removal. The main soils of the region developed on Quaternary dune sandstone with carbonaceous matrix consist in fersiallitic red soils in the South (complex profiles with sandy surface layer, or clayey composition of the surface layer due to erosion) and calcimagnesian soils in the North. Vertisols are found in some depressions, whereas the top of the dunes are mainly occupied by stony soils, outcrops of calcrete or eroded soils. Though rather moderate, the topographic variations control the variations of the duricrusts, the surficial stone component, and soil composition. Moreover, zones covered by sand deposits are numerous and well evidenced on SPOT imagery.

The images were processed on the basis of the conclusions of the field survey. The analysis of color composites and supervised classifications provided a map of the main types of soils and of their surficial stone content. The best classification result has been checked in the field. After improving the classification, a general accuracy of 78 % was reached.

A final guide map was obtained by aggregation of the classes of soils and stone contents. It provides the delimitation of different areas where the duricrust can be broken and removed.

The study has been carried out as an operational project of co-operation between this laboratory and the Ministry for Agriculture of Morocco, under the supervision of the Belgian administration for technical co-operation AGCD/ABOS.

### **3. Detection and modeling of the injection and dispersion of volcanic ash plumes into the atmosphere using digital satellite data**

This project is devoted to study the explosive activity of volcanoes that occurred during the last decade via satellite data. The main goals are: (1) to perform multispectral processing of satellite image data in order to detect and track volcanic ash clouds and (2) to describe and model the ascending and spreading dynamics of volcanic eruption clouds in the atmosphere.

Only about 60 volcanoes are in eruption each year and among them, 3 to 4 are sufficiently explosive to inject ash and volcanic gases into the stratosphere.

The global atmospheric impact of these explosive eruptions is not well known but has been observed in the case of the Tambora (Indonesia, 1815), El Chichon (Mexico, 1982), Mt St Helens (USA, 1982) Galunggung (Indonesia, 1983), Pinatubo (Philippines, 1991) eruptions and some others.

The atmospheric discharge of ash during volcanic eruptions is a significant hazard for civil air transport. Microscopic shards of silicate volcanic glass are highly abrasive causing severe damages to aircraft exterior surfaces and windshield, their melting properties (800-1200C) are also responsible of several engine failures. Because airborne radar aboard aircraft are unable to detect a dispersed volcanic ash cloud, numerous encounters of aircraft with volcanic plume have occurred during the past decade. These incidents were sometimes serious, as in Indonesia in 1982 when two Boeing 747s flying through the eruptive plume of Galunggung volcano at 11 km altitude suffered engine failure resulting in emergency landings or in Alaska (Redoubt) in 1990.

Some of the recent volcanic eruptions (Agung, 1963; El Chichon, 1982 and Pinatubo, 1991) have also injected huge volumes (5-20MT) of SO<sub>2</sub> gas at high altitude. In the cold, oxidizing environment of the lower stratosphere, this SO<sub>2</sub> is converted into sulfuric acid droplets that remain suspended long after the larger silicate particles have settled down from the cloud. These long-lived stratospheric clouds of sulphate aerosols can affect global climate. These volcanic clouds can also trigger heterogeneous chemical reactions leading to stratospheric ozone depletion.

In the first step, we are interested in studying the latest large explosive eruptions of the Pinatubo (Philippines, June 1991), Hudson (Chilean, August 1991) and Kamchatka volcanoes. We process existing satellite data, radio-sounding profiles and field data in order to model the behaviour of these volcanoes and their plumes. We use meteorological satellite data in both visible and infrared wavebands and enhanced detection techniques to analyse and monitor the subsequent ash clouds for any part of the earth.

Imagery from the geostationary meteorological satellites, providing global coverage between latitudes 60N and 60S using visible and thermal infrared sensors (GOES, USA; GMS, Japan; Meteosat, Europe), is acquired approximately every hour in both the visible and thermal infrared bands at a maximum resolution of 8 km. They provide information necessary to track the horizontal dispersion and long distance transport of volcanic plume.

The polar-orbiting meteorological satellites (NOAA satellite with AVHRR instrument) with visible and infrared sensors provide two daily global coverage of all volcanic areas. Measurements of infrared emission in the 10-12  $\mu\text{m}$  window can be used to detect volcanic clouds during an eruption and in the days and weeks following it. Their signature can be recognized by multispectral image processing of the T4-T5 temperature differences and it is possible to use this as an operational tool to assist in the forecast of volcanic cloud hazards.

Multispectral image processing of satellite data can be completed with field observations and conventional radiosounding data to determine the altitude of a volcanic eruption, the size, speed and position of the ash cloud and the direction the ash is spreading.

We can estimate height of the ash cloud's top from the temperature at the profile surface of the ash cloud and the air temperature around the volcano. The different plume isotherms are related to the vertical and horizontal plume morphologies.

The duration of the discharge of gas and ash into the atmosphere for individual eruptions can be estimated from the length of seismic eruption noise recorded in the seismic station nearby the volcanoes combined with the satellite image observations.

Using plume top heights on the infrared satellite image we can calculate the thermal energy released necessary to drive an eruption plume to this altitude and the intensity of the eruption in a given atmosphere.

Finally, we can calculate the mass of injected particles in the plume from the thermal energy released and the particles size distribution. We can make a rough estimate of the minimum mass concentration of particulate material contained in that eruption cloud assuming that the particulate material consisted entirely of ash with no liquid or solid hydrometeors.

In conclusion, studies of volcanic eruption plume properties into the stratosphere with satellite data are available for forecast and detection of the phenomenon and for monitoring of volcanic explosive eruption and their environmental impact.

This study is supported by a FRFC and a FRIA grant.

#### **4. Application of remote sensing and spectroradiometric measurements in the field to lithological mapping of the chuya depression in Gorno-Altai, South Siberia**

This work is part of a study of Cenozoic basins of Siberian Altai including geomorphologic and neotectonic studies and geological mapping. It is based on the assumptions that mineral objects can be identified by their spectral signature (reflectance) measured with high spectral resolution in the field and that the spectral properties of the natural surfaces can be used to discriminate lithologic bodies on the basis of medium spectral resolution satellite data.

The disclosure of Chuya depression is part of the tectono-sedimentary events related to the India-Eurasia collision. The basin is covered by two SPOT scenes both acquired on June 13, 1986. Image maps were produced on the basis of orbital parameters, referenced in the UTM projection system.

Typical sites were chosen on the image maps, where the satellite data represents spectral properties of surficial objects, and measurements of the spectral factors of reflectances were realised with a GER IRIS MARK V spectroradiometer in the range of 400 to 2500 nanometers, at a mean resolution of 3 nanometers (900 spectral bands for 2100 nm).

Raw image data were calibrated into reflectance factors by regression on targets measured in the field. Image processing included optimized colour composites, principal component analysis, ratioing, classifications. Isodata histogram clusters means are compared to field reflectances. This classification provide a good discrimination of surface deposits, and straight boundaries are the expression of Neotectonic events.

Basement lithologic units and structures are enhanced by the colour composite with high pass spatial filtering.

#### **5. Geomorphological structure of the Chuya intermontane depression (Gorny Altai)**

A new model for the neotectonic evolution of the Chuya intermontane depression in Gorny Altai is a result of detailed geomorphological studies based on field observations, the interpretation of aerial photographs and SPOT image processing and interpretations.

A regional compression along the submeridional axis is the main idea of the model. This compression sequentially causes formation of a system of ridges with a trough-like sedimentation basin between them, division of this basin into separate basins as a result of shearing displacement of the ridges, and division of the ridges into blocks, which is accompanied by sediment crumpling in the marginal parts of the Chuya sedimentation basin.

## **6. Water properties at lake Teletskoye from spectral characteristics and spot imagery: preliminary results**

Variations of the radiances in a SPOT mosaic of lake Teletskoye and their well structured spacial distribution suggest a relationship between the reflectance of the water and its composition (suspended sediment concentration SSC, chlorophyll or organic acids).

High resolution measurements of the spectral signature of water were performed in the field, together with the measurement of water transmissivity, temperature, SSC and salinity, and compared to SPOT data calibrated into reflectance factors (including atmospheric correction).

Though the field work was performed in July 1994 and SPOT scenes were acquired in June 1986, some correlation appears between the field reflectances and the SPOT data. No correlation could however be established between SSC and water reflectance, due to the lack of reliable SSC data.

This preliminary approach demonstrates that the processing of SPOT imagery supported by field measurements of reflectance can provide synthetic information on water composition on the whole area of lake Teletskoye, and could be very useful to extrapolate local measurements and map the spacial distribution of the SSC and its variations in time.

## **7. The map and database of active faults of Central and Eastern Africa**

### ***7.1. General scope***

Movement along faults, is considered the most possible source of damaging earthquakes. The characteristics of the active faults represent fundamental data in estimating the magnitude of the earthquakes they are liable to generate and the probability of such an event in a particular area. The importance of studying active faults was recognised by the creation of the Project II-2 : "World Map of Active Faults" as a part of the International Lithosphere Program. The present ongoing realisation is a contribution of the Department of Geology to this global project. The study area covers Central and Eastern Africa from Botswana to Ethiopia and from Zaire to Mozambique.

### ***7.2. Objectives***

The aim of the general project is to identify the major active faults in the World and map them at global and continental scales. An additional objective of the Department is to stimulate and contribute in neotectonic studies in that part of the African continent where the available neotectonic information remains poor and scattered, by providing a permanently updated state of the art on the topic and thematic maps on appropriate regional to local scales. Consequently, the document to be realised had to be able to evolve with the expected advance of neotectonic knowledge. Its concept evolved to the compilation of digital maps supported by a database describing the faults.

### **7.3. Progress**

A database have been constructed in connection with a SPANS G.I.S. environment and was first tested using the information collected about active faults of Tanzania. All the available data concerning faults showing evidences of recent movement were introduced into the database. Most of the information had to be collected in an indirect way through a critical analysis of general geological maps, geophysical surveys, satellite and airborne imagery interpretations or geomorphological studies. Other information liable to contribute in a neotectonic model -general fault pattern, data on lithosphere thickness, Neogene volcanic activity, location of earthquakes epicentre, hot springs, distribution of recent geologic formations...- was also gathered in separate files of the database.

### **7.4. Results**

In this preliminary compilation, the quality of the neotectonic information available lead us to extend the definition of "active fault" to fault showing evidences of movement in quaternary times. In many cases, the information concerning the type, sense, rate and periodicity of the movement, the age of last activity remains to be improved by specific field work. Nevertheless, in its present form, the database already appears a useful tool :

- For instance, the data set of Tanzania is frequently used it in the frame of the Department's research programs. Flexibility of the environment and visualisation capabilities are appreciated.
- Amongst others, the GIS allows to evaluate the existing, very heterogeneous, cartographic information in a common geographic reference. It also enables to compare different regional structural interpretations based on the same original dataset, helping us to propose a new, more valid synthesis using the whole available information.
- Thematic maps can bee quickly edited on any geographic area by integrating the results of current studies to a selection of different types of information available in the database.
- Updating the database is easy and several improvement have already been brought according users suggestions.
- A Desktop Mapping System (Spansmap for Windows) allows to link digital maps with spreadsheets. This makes possible to display on the same screen a map and datasheets with complete description of faults selected on it with a cursor.
- A preliminary version of the database is presently available for Ethiopia, Kenya, Uganda, Tanzania, Mozambique, Zimbabwe and Botswana. Compilation for Zaire, Rwanda, Burundi, Zambia have been undertaken

### **7.5. Collaborations**

At the present stage, the main contributions to the compilation were brought by V.G. Kazmin (Russian Oceanographic Institute) for Ethiopia and Kenya and by M. Wafula (Luiro) for the Kivu Province (Zaire). Contribution of regional specialists and interested persons is now requested on the basis of the existing databases for improvement of the preliminary version.

## **8. Data base of active faults in Europe and their geo-environmental effects**

### ***8.1. General scope***

The identification of the major active faults was undertaken as a part of the International lithosphere Program at a global scale. This compilation showed that an abundant neotectonic information concerning Europe is potentially available but would take advantage in being gathered in a standard format. The definition of "active fault" varies from one author to the other and is differently considered according to the neotectonic situations encountered in the different regions.

The necessity arises for providing the scientific community with a database liable to make neotectonic information available for investigations about geo-environmental effects in Europe. The set up of this database is a NATO supported project

### ***8.2. Objectives***

The project is aiming at initiating a database on active faults and their geo-environmental effects in Europe. The objectives consist in :

- unifying methods and techniques for data collection and presentation,
- developing the software for a database connected with GIS,
- starting data collection on active faults and deformation as well as their geo-environmental effects.

### ***8.3. Progress***

Three thematic workshops were organised on the following topics:

- Principles of the Data collection: Nature and possible sources of information. Constraints of data format
- Geological standards for an exhaustive definition of an "active fault" in mobile zones and platform areas
- Informatic solutions: Characteristics of the required software. Compatibility with existing "Geographic Information Systems" (GIS) and Data-management software.

Methods and principles defined during this workshops were tested and preliminary results exchanged

### ***8.4. Results***

- *Unification of methods and techniques of compilation*

A standard terminology and a list of descriptors to be used for systematic compilation of data on active fault have been defined. A standard datasheet for description of individual fault was designed and is presently available to potential users. The proposed classification

allows to describe the fault in detail, to formalise the description of objects and to prepare the data for selection, and analysis (e.g. for determination of their statistical characteristics).

*- Software development and GIS database set up*

A software was first written by Russian participants in order to facilitate recording data avoiding the problem of selection and acquisition of an expensive GIS software. This software is still currently used by Russian participants of the project allowing the capture, storage, and the processing, of information. The structure of DB files generated by this software includes both geological and geographical information. Full compatibility was established with two commercial GIS (Spans and ArcInfo) and tested on several applications.

*- Data collection on active faults*

Partial data of active faults for South Europe (Turkey, Greece, Italy, part of France) have been introduced into the database. It also already includes practically all European part of the former USSR.

*- Testing the capabilities of the database*

Some analytic applications provided interesting results particularly in improving maps of potential seismicity.

### **8.5. Evolution of the project**

Completing the Active Fault Database with the presently available information over whole Europe will only be possible with the contribution of a large panel of geoscientists. A new project have now to be defined with the aim of initiating an international network of co-operation for data collecting and analysing.

### **8.6. Collaborations**

The project have been carried out in collaboration with E. VITTORI, Nuclear Safety and Health Protection Direction (DISP-ARA) in Rome, V. TRIFONOV, D. ZYKOV, A. IOFFE, R. TRIFONOV, A. KOZHURIN the Geological Institute, Russian Academy of Sciences (GIN RAS), in Moscow.

## **9. Radar interferometry for two different geological applications :**

*The present day evolution of an active continental rift: the Tanganyika-Rukwa-Malawi rift zone (Tanzania) and the volcanic activity and the surface evolution of the Ragang and Mayon volcanoes areas (Philippines)*

The recent success of radar interferometry with the ERS1 data allowed numerous possibilities in geology. Dramatic examples have recently been offered in tectonics or in the numerical analysis of topography (DEM). Our research started on 1st March 1995 and is focused on the study of the present-day evolution of the active continental rift zone situated

between the lakes Tanganyika and Malawi: the Rukwa rift zone. Radar interferometry is used to determine the active faults, to measure the displacement along them and the direction of the movement. The technique will also be applied for the study of surface evolution around the Mayon and Ragang volcanic areas (Philippines). These regions know important surface changes and are in constant evolution.

The ERS2 launch in May 1995 could sensibly increase the quantity of available data. Because interferometry needs very strict orbital conditions, the tandem mission ERS1-ERS2 should solve this major problem. Furthermore, the temporary installation of the mobile receiving station in Libreville (Gabon) by ESA will allow data acquisitions on the zone of interest in Tanzania. Up to now, this region is still uncovered by data of any interferometric use.

The first operation has consisted in the search of suitable image pairs of the studied area in Tanzania. No such pairs have been found among archived data.

This project has been selected by ESA for the use of data released by the mobile receiving station of Libreville (Gabon), 27 images could be obtained from the moment that the station becomes operational. A field campaign focused on the measurement of surface parameters influencing the radar signal, performed at or around the moment of acquisition has been performed. Structural data have been collected as well; especially in the Mpanda region (North Rukwa) where the lack of information is important and where the seismic activity is the most pronounced.

In order to diversify the field of application, the technique will be applied in another geological context, namely the monitoring of volcanic hazards. The project is implicated in the GARS (Geological Application in Remote Sensing)-ASIA co-operation program of the geological department of MRAC and will participate to the study of two volcanic areas: the Mayon and the Ragang volcanoes in the Philippines. This latter phase of the program is coordinated and supported by UNESCO. Ten images have been ordered in both archived and special acquisitions.

## **10. Discrimination of Karoo and Pre-Karoo structures in Shaba (Eastern Zaire)**

### ***10.1. General scope***

Tabular formations are known on both side of the Kibaran belt. As well north west as south east of that axis, they generally show old red sandstones facies with several thick formations of diamictite, considered of glacial origin. In North and Western Shaba, an Upper Palaeozoic -Karoo- age is attributed to all those tabular formations, whereas in the South East they are considered as exclusively belonging to the Upper Proterozoic Kundelungu. The lithological similarity between the two groups have been a source of confusion since the beginning of the geological study of Zaire and could be, up to now, a misleading element in building a structural model of the whole region.

## **10.2. Objectives**

The objectives of the study is to define the relationship existing between Karoo and Kundelungu, to define their geographic extents and consider the consequences of local wrong stratigraphic attribution on the existing regional models.

## **10.3. Methodological approach**

The region is a well-known copper province and has been intensely surveyed for mineral resources. Nevertheless, these explorations, mainly carried out before the sixties, could rarely take advantage of aerial-photographs. On the other hand the more recent published regional geologic models, using remote sensing techniques, could only find their basic geological information on small scale interpretative synthetic maps. The present study, based on a detailed analysis of aerial photographs and satellite imageries, is supported on an accurate repositioning of the abundant original field descriptions recorded in the Museums archives.

## **10.4. Progress**

A set of preliminary maps of the whole Shaba Province. (from 5° to 13°S and 22° to 30°E) was first draw at the scale 1:200,000 on the basis of airphoto mosaics to be used as a background for field observations and remote sensing data integration. In Eastern Shaba the area of supposed tabular Kundelungu clearly appears on air photos and satellite image to be occupied by two distinct geologic entities with contrasted geomorphological characteristics. Consequently, the Kundelungu formations, showing strongly structured photo facies, have to be differentiated from the Luapula Beds, extending without morphological expression through the huge Luapula Plain from Lake Moero to the Irumi Hills. Integration of archive data shows that the latter are more likely to be equivalenced to the Karoo.

A key-problem has been the confusion made during the surveys between different conglomeratic formations of supposed glacial origin. Three key-zones were analysed in detail :

- the Kiaka region, where the Kundelungu type section have been established
- he Mwashya salt springs area, where glacial facies were first described
- the Lufukwe anticline, on the eastern border of the Kundelungu Plateau.

## **10.5. Results**

Some new concepts can be put forward:

- The presence in SE Shaba of two kinds of tabular (or sub tabular) formations : marine sediments with thick diamictites of Proterozoic age and Permian to Carboniferous continental rocks including tillites.
- The very uneven nature of the post Kundelungu / Pre Karoo surface, resulting in the emergence of numerous inselbergs of Precambrian rocks across the Karoo formations.
- Karoo occurs, as well in small patches which shape is influenced by pre-existing morphology, as in large zones like the Luapula-Moero plain.

- The progressive transition between folded Kundelungu in the Lufilian belt and the tabular formation of the Plateau.
- The identification of the Kundelungu with a post tectonic graben instead of an aulacogen.

The muddling effect of a complex overlay of Precambrian structures by Karoo formations will have to be considered in establishing further structural models and mining exploration programs.

## **11. GIS Development**

### ***11.1. General scope***

Geographic Information System techniques are currently set to spread in the domains of georeferenced data management and map edition. They have been introduced in the Department, as early as mid-1991 and in the meantime, the interest of the method has been evidenced by several applications and successful presentations.

### ***11.2. Objectives***

Before the present action, GIS had only been used in rather limited data integration, for own research or in the frame of studies carried out by Department colleagues. Building a GIS database meeting the requirements of an external partner, whatever they could be, was considered an ultimate test of the method, the best way of raising as many technical problems as possible.

### ***11.3. Progress***

The exercise consisted in transforming in digital format the data required for editing the map of the central part of the Lufilian copper belt of Shaba (Zaire) drawn up by A. François. The document consisted in : an unedited map at the scale 1:100,000, recently updated by the author and resulting from a synthesis of original drawings at the sc. 1:20,000, field descriptions, outcrop location, topographic maps showing the road network, hydrography, etc. Processing started in February; deadline for document edition was beginning of September.

### ***11.4. Results***

The required maps could be produced on time with a satisfactory accuracy and in a convenient format. The realisation of the database allowed to point many specific problems, e.g. :

- Management of very big GIS files : Benefits of splitting large project in several small sub-projects as well as splitting the total information in several levels, preliminary controls requested on the quality of the original documents, accuracy of the scale, matching of partial documents, characteristics of projections..., paper stability and reliability of the programs supposed to compensate distortions.

- Man power : estimation of time requested to achieve the different phases of a complete project, necessity of keeping people on the project, necessary professional training for people in charge of encoding and digitising data.
- Equipment : the realisation was a good testing ground in defining the requisite characteristics of the equipment, hardware and software to be purchased in the scope of creating, in a near future, a technical unit in charge of routine edition of the maps produced by the Department.

## **12. The GARS-transfer program**

The aim of this program is the transfer of knowledge and technology in the field of geological remote sensing towards developing countries.

### **12.1. Method**

- Training teams of geologists in geological remote sensing.
- Creating units of remote sensing within some African geological survey departments.
- Implementation of image processing stations and technical maintenance.
- Follow-up of a scientific program of investigation.
- Follow-up of an international program of investigation.

### **12.2. Achievements**

- Teams are active now in Burundi (Ministère Energie et Mines, Département de la Géologie), Rwanda (Ministère du Commerce et de l'Artisanat, Service géologique), Tanzania (Ministry of Natural Resources, Geological Survey department), Uganda (Department of Geological Survey and Mines) and Zambia (Geological survey department).
- The national themes of investigation comprise geological mapping and exploration, exploration for gold, structural analysis. The international theme will be devoted to the spectral and textural effects of granitic intrusion in a metasedimentary sequence in SW Uganda.
- Image processing and geological interpretation workshop. This one-month workshop has been held in MRAC/KMMA, Tervuren in September 1994. It has been devoted to advanced image processing techniques applied the international theme of investigation.

## **13. Publications**

DUMONT P. et HANON M., Le Plateau des Kundelungu, paléograbens ou aulacogène? Actes du Colloque International Cornet, Mons, Belgique, du 5 au 9 septembre 1994, (in press).

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- VOLON C., LAVREAU J. et BERNARD A., Monitoring Pinatubo paroxysmal eruption of June 1991 using NOAA and GMS satellite images, p. 318-326 in *Passive Infrared Remote Sensing of Clouds and the Atmosphere II*, Ed. D. Lynch, Proc. SPIE 2309, 1995.

## **B. Laboratory for Telecommunication and Remote Sensing of the "Université Catholique de Louvain"**

The Laboratory has an important activity in the field of microwave remote sensing of the Earth surface and of the atmosphere from space since 1978. We are involved in the analysis of atmospheric propagation effects and of scattering by random rough surfaces, for electromagnetic waves in the range 1 to 200 GHz. Our interest lies in the interpretation of both radar (including SAR's) and radiometric measurements and in the development of a synergy between various kinds of microwave sensors.

These research activities concentrate on the ocean surface, on soil surfaces and on vegetation covered soils, on atmospheric constituents (water vapor and liquid water), and on rain. The main goal is to analyse the characteristic signatures of the various targets and to determine the corresponding geophysical parameters. The atmospheric and surface characteristics are thus obtained by appropriate inversion procedures of the radioelectrical measurements. The resulting modelisations are implemented as simulation and inversion algorithms. The results are compared with real data collected during airborne campaigns, or from space observations obtained e.a. from such satellites as ERS-1, SSM/I, TOPEX, and more recently ERS-2.

During the period 1994-1995, the research activities have been concentrated along two main axis : the ocean and land. Over the ocean, our interest lies in the proper interpretation of altimeter and scatterometer radars under non-fully developed sea conditions. We have shown, e.a., that the altimeter echo would be sensitive not only to the wind speed, but also to a parameter describing the surface geometry. We have also shown how the scatterometer response can be perturbed when crossed sea conditions are observed. Another project is concerned with rain observation above the ocean, including both the detection of rain backscattering and surface smoothing effects by rain. Detailed experiments of drops impact effects on the surface and on the related radar echoes are under way. They are used to drive modelling effort of scattering by the sea roughened by both wind and rain. In particular they are implemented in new rain radar retrieval algorithms from space in the framework of an ESA study in cooperation with other European Laboratories. Finally we are also comparing brightness temperatures calculated by our electromagnetic models with measurements taken above the ocean with the microwave radiometers on the satellites : SSM/I, ERS1 and TOPEX as well as on aircrafts : MARSS.

The second axis of research is concerned with the observation of land targets, mainly with SAR instruments. We participated in the interpretation of the data collected during the MAESTRO campaign of 1989, where the NASA/JPL airborne polarimetric SAR was flowing above several test-sites in Europe. We received data from the Fribourg forest area and proceeded to analyse them and compare to polarimetric backscattering models. We also participated to the EMAC campaign of 1994, where the ESAR instrument of DLR (Germany) was flowing above the Belgian test-site of the Zwalbeek. Several corner reflectors have been designed, calibrated and deployed. They have been used for calibration testing during overflights of the EMAC aircraft and the SIR-C shuttle. On the other hand two studies are related

respectively to the interpretation of ERS-1 SAR data above the tropical forest in Côte d'Ivoire, and to the analysis of images taken above the Hesbaye in Belgium. In the first case, the interest lies in the determination of forest areas and of the importance of deforestation, and in the second case in the following-up of cultivations.

These studies are financially supported by the European Space Agency and the Federal Services of the Belgian Scientific Office. They are performed in collaboration with several European Research Centers and NASA, as well as with several other Laboratories of the University.

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## C. Space Centre of the University of Liège

### 1. Synthetic Aperture Radar (SAR)

The activities in the field of remote sensing of the Space Centre of Liège are focussed in the pre- and post-processing of Synthetic Aperture Radar (SAR) image data, including :

- The development of a frequency-domain processor for generating full-resolution (typically 4.5 m in azimuth x 7.5 m in slant range) SAR images from raw data (ESA contracts).
- The development of a frequency domain Scan SAR processor (ESA contracts).
- The study and laboratory demonstration of an optical SAR processor (in collaboration with the Moscow Space Research Institute, under Belgian Government Fellowship).
- The development of a SAR interferometry processor (under the TELSAT III Belgian Remote Sensing Program).

### 2. Publications

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## **D. National Geographic Institute**

The CORINE Land Cover geographical database has been compiled for Belgium at the National Geographic Institute during 1994 and 1995. This project was partly funded by the EEC. The programme meets a need for homogeneous spatial information about the environment of the whole European Union. Therefore, the method, the scale and the legend are common for all the member states.

The method required to use computer-aided photo interpretation with remote sensing images as main input data. The working scale is 1 : 100000 and the legend contains 31 themes for Belgium. Landsat T-M images, SPOT XS and aerial photos were used.

The global thematic accuracy was assessed by ground survey and the geometric accuracy was computed from a set of control points; in both cases, the results showed a better accuracy than required by the european recommendations.

A full report and documentation on the project for Belgium will be available during the first quarter of 1996.

## **E. Laboratory of Remote Sensing and Regional Analysis of the "Université Catholique de Louvain"**

Remote sensing is the main field of activities in the Laboratory since many years. The researches are aimed at the analysis and modelisation of the tropical land cover degradation in Africa under human pressure and activities. It is supported by grants and contracts with the S.S.T.C., NASA, USAID (Biodiversity Support Program) and recently (1995) by the EC (H.C.M. Program) and J.R.C. (Ispra).

The activities covered two main fields of investigation :

*(1) The characterization of land cover facets and land use features in rural areas.*

The purpose is to determine the relationships between agrarian systems and their natural environment by remote sensing techniques. The research investigated samples in different physical and cultural contexts : dry tropical forests and savannahs in Burkina Faso, mountain forests in Guinea (Fouta Djallon), rain forests in Ivory Coast, Cameroon and Zaïre.

*(2) The impact on the natural environment of urban growth and peri-urban outskirts.*

The investigation was focused, not only on land degradation, but also on population requirements in terms of water supply, sewerage and infrastructures. Accordingly, the use of satellite remote sensing was combined with aerial surveys, photo-interpretation and demographic sampling. Data bases were collected and structured and allocation models, tested.

From a technical point of view, the studies mentioned hereabove benefited from the use of satellite data collected by NOAA, LANDSAT, SPOT, MOS, ERS-1, JERS-1. Most of the researches were performed in the optical range. However, we participated also in some european experiments in the microwave domain (SAR : MAESTRO-1 organized by the JRC, Ispra) or collaborated with the UCL Laboratory of the TELE Unit of Applied Sciences in an ERS-1 Project (under the auspices of the SSTC) devoted to the Rain forest in the Region of Man (Côte d'Ivoire). This project is still in operation : it is aimed at testing an inversion model by the research team on hyperfrequencies of this laboratory.

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## **F. Unit of Forest Management and Spatial Information Techniques of the University of Gent**

### **1. Introduction**

The Unit of Forest Management and Spatial Information Techniques is a part of the Department of Forest and Water Management at the Faculty of Agricultural and Applied Biological Sciences, University of Gent.

The research activities on remote sensing of vegetation (aerial photography, airborne scanning, field spectroscopy) were initiated through a major research contract from 1976 to 1988 with Eurosense-Belfotop under co-sponsorship of IWONL. During the last ten years research contracts were signed with the Belgian Science Policy Office, the Belgian Agency for Overseas Development Cooperation, the Flemish Community, the Flemish Institute of Nature Conservation, WWF International, FAO, JRC-EEC, and DGI of EEC. In an international context, there are or have been research partners in the Netherlands, Poland, Egypt, Benin, Kenya, Botswana, Senegal, Central African Republic, Costa Rica, P. R. of China, Vietnam, Indonesia and India.

Research activities cover the following topics: remote sensing of temperate and tropical forests for the purpose of mapping, inventory and monitoring (using SPOT, Landsat, ERS-1 and NOAA-AVHRR data), development of an operational forest inventory system for the Flemish Region, remote sensing of agricultural areas for the statistics acquisition and monitoring, remote sensing of forest reserves in the tropics for conservation management, mapping of phytosanitary condition in forests, management models using GIS. More recently expertise has been acquired about the design of meta-database systems for use on the Internet, and development of reference software for distribution on CD ROM.

The Unit has been appointed Principal Investigator in a number of campaigns using new or experimental sensors (MOS, EISAC, MAESTRO) and holds membership of international scientific societies, such as EARSeL, ASPRS, RSS, FORS and ISTF.

Its research infrastructure includes a hardware section on PC platforms, and a section around an Intergraph server with Interpro and Interact stations. Amongst data input and output peripherals are CDROM (incl. recording), large and small format tape readers, digitizers, video digitizing unit, A4, A3 and A0 colour printers. Image processing and GIS software presently available includes ArcInfo, Arcview, Erdas, Idrisi, Ilwis, Earthview, ER MAPPER, PAMAP GIS (on PC platform), and the complete range of Intergraph's Microstation modules, inclusive the Oracle RDBMS. Field equipment include hand held GPS, 35mm cameras for aerial photography, and an in-house developed remotely piloted aircraft (delta wing type) which is operational for small-scale research (airborne still photography and videography).

## **2. Remote sensing monitoring of natural habitats in protected areas in Vietnam (WWF VN0007)**

*Period: 01.07.1992- 30.06.1996*

*Partners: WWF International (Asia and Pacific Programme) (WWF VN0007), Forest Inventory and Planning Institute, the Ministry of Forestry, Hanoi, Vietnam.*

The project's objectives are

- to assist the WWF Indochina Programme's protected area management and forest conservation projects by providing thematic forest maps based on satellite imagery; and
- to increase capacity building at the FIPI Remote Sensing Section in the subjects of digital image processing and GIS analysis for the purpose of forest mapping, multitemporal forest cover monitoring and management planning in order to ensure FIPI's capability to fulfill the WWF Indochina Programme's conservation planning needs.

The activities include on-site in-service training sessions on spatial information sciences, surveys of top priority conservation areas (Tam Dao, Muong Nhe, Nam Cat Tien, Phong Nha, Vu Quang, Pu Mat), and production of thematic vegetation maps. An image processing lab has been installed in FIPI's Remote Sensing Section in early 1993. Belgian undergraduate students assist with the field surveys and data processing.

## **3. Establishment of the Polish pine forest monitoring database: pilot study**

*Period: 01.01.1993 - 31.12.1995*

*Partners: Belgian Office for Scientific, Technical and Cultural Affairs (OSTC), Polish State Committee for Science (KBN)*

The project consisted of on-site assistance for

- the implementation of a geographic information system (GIS);
- the development of a spatial forest database, based on existing data;
- the use of the GIS and satellite data (SPOT, ERS-1) for forest monitoring and updating of information.

## **4. Forest monitoring by satellite and integrated watershed management in Costa Rica**

*Period: 01.01.1993 - 31.12.1996*

*Partners: EU (DGI), Universidad Nacional Autonoma at Heredia, Costa Rica*

The purposes of the project are fourfold:

- To collect all the information necessary to establish a database suitable for monitoring and resource management, in a pilot zone composed of a large watershed and a national park.

- To use the assembled data set in a monitoring system and an integrated management system, both aimed (and developed) at the regional/local level (practically) as well as at the national/regional level (methodologically).
- To enhance the training of experts in resource management at the PRMVS of the Universidad Nacional Autonoma of Costa Rica.
- To contribute to development of the operational phase of mapping, monitoring and management of the natural resources in Costa Rica.

## **5. Monitoring and management of tropical forests using spatial information techniques TELSAT III/02/005**

*Period: 01.05.1993 - 30.04.1995*

*Partners: Belgian Office for Scientific, Technical and Cultural Affairs (OSTC), FAO Rome*

The deforestation in the tropics has become an international issue (UNEP, IGDB): the scientific as well as policy making community requires up-to-date, relevant and accurate information on the distribution and status of natural tropical vegetation. In Central Africa, deforestation is still badly understood: deforestation and its spatial and temporal evolution needs detailed examination.

The proposed project made use of the information and liaisons built up in three international operational projects (Forest Resources Assessment 1990 Project, FRA 1990; TREES Project of EC-ESA; the EC-project Conservation and Sustainable Use of Forested Ecosystems in Central Africa) and contribute in turn to the solution of specific problems.

Data for two representative test sites have been collected and interpreted.

The principal objectives of the project were:

- To evaluate and enhance the standard methodology used in FRA 1990 and to orient the techniques more towards GIS; to monitor forest regeneration by satellite;
- To integrate the information contained in existing inventories (FORIS) and from different sources (TREES, GRID) in order to model forest biomass in Central Africa as a contribution to the international research on global carbon dioxide cycling.
- To elaborate models for the sustainable management of the forests in relation to the change in biodiversity in nature reserves established in Central Africa.

## **6. Land degradation in the dry tropics (TELSATIII/02/007)**

*Period: 01.05.1993 - 30.04.1995*

*Partners: Belgian Office for Scientific, Technical and Cultural Affairs (OSTC), FAO Rome*

An operational monitoring concept of land degradation in the dry tropics was developed. Different sensors and scales were used (regional to local) and a cost-information analysis was conducted at each level. The high resolution imagery (Landsat TM/MSS and SPOT XS) was

used to calibrate and validate low resolution time series (NOAA/AVHRR) . An assessment of the woody biomass on a regional scale has been performed and integrated with socio-economic parameters in a GIS in the framework of fuelwood consumption modelling. Test sites were located in the Northern Sudan and northern Cameroun.

Lastly, the concept of environmental accounting as proposed by the UN Handbook was explained in connection with land degradation. the possible role of GIS and remote sensing in general was examined, and the concept was illustrated for a study area in North Cameroun, using the data sets established for the socio-economic model.

## **7. Management planning for sustained yield in production forest using spatial information systems: case study in Sumatra, Indonesia (Ph.D. research)**

*Period* : 1 October 1993 - 31 October 1996

*Partners* : Belgian Agency for Development Cooperation (BADC), Ministry of Forestry of the Republic of Indonesia.

The principle of sustainable tropical forest is accepted by international institutions but generally lacks the tools for its management planning.

The study site for this research project is a concession of PT. ASIALOG, in Jambi province, (Indonesia). which now entering its second concession license.

The objectives of this research are :

- To evaluate the implementation of the first concession period. Some issues addressed here are deforestation, forest type change, and land use planning. GIS will be used to analyse multitemporal satellite data integrated with other spatial and attribute data.
- To asses the requirements for field data with special emphasis on forest inventory data.
- To elaborate models for sustained yield in forest production.

Some scenarios of sustained forest management from other ASEAN countries will be tested.

## **8. ERS-1 for monitoring of forest reserves in Costa Rica (TELSAT III/02/016)**

*Period*: 01.10.1993 - 30.09.1994

*Partner*: Belgian Office for Scientific, Technical and Cultural Affairs (OSTC)

This project has close ties with the ongoing EC project "Forest monitoring by satellite and integrated watershed management in Costa Rica". The following issues are being researched:

- Detection of forest perturbations using ERS-1 radar data in relation with the surface, form and intensity of the perturbation.
- Influence of relief and view angle on the precision of monitoring (using data of ascending and descending orbits).
- Study of radar image enhancement techniques, texture classification and radar-specific geometric correction.
- Determination of the necessary periodicity in data acquisition in relation to monitoring.

## **9. Remote Sensing in the integrated system for the management and control by the Ministry of Agriculture**

*Period: 1 November 1993 - 30 October 1995*

*Partners: Belgian Office for Scientific, Technical and Cultural Affairs (OSTC), Ministry of Agriculture, Catholic University of Leuven*

The aim of the project was to optimize the use of remote sensing for development and application of an Integrated Management & Control System (IMCS) of the Ministry of Agriculture. The IMCS will be an essential instrument for national control in the agricultural reform policy of the EC (Plan MacSharry).

The research issues can be summarized as follows:

- Definition of the architecture of the database
- Optimisation of data acquisition at producer's level
- Set-up of a sample survey
- Automation of the control of parcel borders
- Automation of crop identity checking procedures
- Development of a decision system

## **10. Introduction and demonstration package: "Satellite Images as Information Source for Spatial Management" (T3/XX/601)**

*Period: 01.01.1994 - 31.10.1994*

*Partners: Belgian Office for Scientific, Technical and Cultural Affairs (OSTC), SURFACES Laboratory of the University of Liège.*

The aim of the demonstration package is to inform potential users of the different applications of satellite images. The demo is available on CD ROM and is developed in Dutch and French. The demo can be divided into 3 main chapters:

1. *Remote sensing*: a brief description of the most important image processing procedures and of the main characteristics and applications of the most often used satellites and sensors in Europe;
2. *Applications*: an overview of possible applications of remote sensing which can be accessed by means of three keys: satellite, study area, subject;
3. *Belgian research in remote sensing*: a presentation of the TELSAT-programme and the Belgian research centers.

## **11. Development of the TELSAT GUIDE FOR SATELLITE IMAGERY (T3/XX/750)**

Periods: 15.04.1994-31.08.1994, 01.08.1995-29.02.1996

Partners: Belgian Office for Scientific, Technical and Cultural Affairs (OSTC)

The TELSAT GUIDE FOR SATELLITE IMAGERY is an INTERNET service developed as part of a set of educational and promotional products of the TELSAT programme of OSTC. It is a catalogue on satellite data, products and services, which aims to provide both inexperienced and experienced users with the necessary information to choose the products and services most adapted to their needs.

Emphasis has been put on the description of *products* related to satellites/sensors included, and practical information on the *services* related to these products (service providers, catalogues, prices...). When applicable, the catalogue gives connection to main sources of technical information by means of on-line links or referring to documents. For each satellite/sensor, a fixed structure has been observed.

A separate chapter deals with *Remote Sensing in Belgium*. It represents in fact the expertise that has been gained by Belgian research teams in the field of Remote Sensing under the TELSAT programme.

The TELSAT GUIDE FOR SATELLITE IMAGERY Guide is available at the following INTERNET address: <http://www.belspo.be/telsat/>

## **12. The use of remote sensing as information source for environmental accounting of coastal areas in Kenya**

Period: 01.09.1994 - 30.11.1994

Partners: Belgian Office for Scientific, Technical and Cultural Affairs (OSTC),

- Kenya Marine Fisheries Research Institute, Mombasa, Kenya

- Laboratory of Ecology and Systematics, Free University of Brussels, Belgium

The main objectives of the feasibility study were:

- the detection of degradation (qualitative indicator) and depletion (quantitative indicator) of the natural resources of the coastal area of Kenya, focused on the mangrove ecosystem, using high resolution satellite imagery (SPOT P and XS, Landsat MSS and TM);

- to show how these results can be incorporated into environmental accounting.

### **13. ERS-2 Research on the capabilities of ERS-SAR for monitoring of land use changes in the Neotropics**

*Period: 1 Jan 1995 - 31 Oct 1996*

*Partners: Belgian Office for Scientific, Technical and Cultural Affairs (OSTC), Universidad Nacional de Heredia, Costa Rica*

The main objective of this study is the analysis of the capabilities of satellite-borne C-band SAR to detect changes in land use in the Neotropics. In order to achieve this aim, a processing chain is being designed, for which a segmentation procedure is being developed, based upon the pyramidal multiresolution algorithm.

The change detection is being performed by comparison to an old land use map, and will focus on the fringe area between forest and agricultural land.

Finally, the influence of meteorological conditions on the radar signal is being studied.

### **14. Feasibility study: Forest Inventory of the Flemish Region**

*Period: 01.01.1995 - 31.07.1995*

*Partner: Ministry of the Flemish Community, Administration of Environment, Nature and Land Use, Department of Forestry*

The aim of the project was to develop different alternatives for forest inventory of the Flemish Region in terms of (1) level of detail, (2) number of parameters, (3) cost, and (4) accuracy. The study also considered constraints pertaining to current capacity of the Department of Forestry (in terms of staff, infrastructure, cooperation with other departments) and presently available data (forest mapping)

### **15. A database and network service for tropical vegetation in Central Africa**

*Period: 01.05.1995 - 31.12.1995*

*Partners: Belgian Office for Scientific, Technical and Cultural Affairs (OSTC)*

The main objectives of the feasibility study were:

- to define the demand for information and an on-line information system, and supply of the existing information;
- to evaluate similar initiatives abroad;

- to define the most relevant format of the database - the minimal scenario being a meta-database containing a description of the data (satellite images, maps, field observations, etc.) and their localisation - through the establishment of a prototype.

The WEB site of this database is as follows: <http://allserv.rug.ac.be/~cvits/metafro/>

## **16. Relation between the architecture of tropical forest and the spectral signature for diverse spatial resolutions (Telsat III/02/37)**

*Period: 01.7.1995 - 31.12.1996*

*Partners: Belgian Office for Scientific, Technical and Cultural Affairs (OSTC), Tropical Ecosystem Environment Observations by Satellites; Université Catholique de Louvain; Faculté Universitaire des Sciences Agronomiques de Gembloux.*

The general objective of the study is to describe tropical forest architecture with the aim of incorporating the latter forest characteristic in a remote sensing based forest typology classification. The study is carried out in the south-west of the Central African Republic.

Other objectives of the project are:

- To identify the architectural parameters significantly influencing the remotely sensed signal at different spectral and spatial resolutions (use of different imagery such as NOAA, Landsat and SPOT)
- To develop a methodology for measuring and quantifying tropical forest architecture on the field at a remote sensing compatible scale
- To explore alternative tropical forest classification strategies which operate in the spatial domain

## **17. Modelling the quantitative and qualitative evolution of a mangrove ecosystem using spatial information techniques (Ph.D. research)**

*Period: 01.11.1995-30.10.1997*

*Partners: The Flemish Institute for Support of Scientific-Technological Research in Industry (IWT, Brussels); Kenya Marine Fisheries Research Institute, Mombasa, Kenya, Laboratory of Ecology and Systematics, Free University of Brussels, Belgium*

Study objectives:

- Primary: Modelling the evolution of a mangrove ecosystem (Kenyan coast), examining direct influences such as logging and indirect influences such as changes in ground water flux and salinity. The changes of floristic composition and mangrove forest structure will be studied, using remote sensing time series spanning 25 years.

- Secondary:
  - Study of remote sensing techniques for mangrove mapping, including microwave sensors
  - Development of a valorization index to assess the economic and ecological value of mangrove associations in view of the identification of key areas for conservation purposes

## **18. The application of Remote Sensing and hydrological modelling techniques for land and water resources management in the karst regions of Guizhou province, China**

*Period: 01.12.1995 - 31.12.1997*

*Partners: Belgian Office for Scientific, Technical and Cultural Affairs (OSTC); State Key Centre for Remote Sensing in Territorial Management and Disaster forecasting of Guizhou Province (CRSG),*

The general objectives of the project are:

- develop a geographic information system based on remote sensing and existing reference data for a demonstration area in the centre of Guizhou Province; this GIS will support land and water resources management in the karstified region of the province;
- study the hydrological processes in the karst region of Guizhou Province and develop a distributed hydrological model for prediction and evaluation of different land and water management actions in a 81 km<sup>2</sup> experimental site in Puding County;
- study the process of soil erosion and develop a soil erosion risk mapping model for the selected experimental site in Puding County in order to locate priority areas for land rehabilitation through reforestation.

## VII. Addresses

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