

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 30th Plenary Meeting of the Scientific Committee on Space Research (COSPAR), Hamburg, Germany, 11-21 July 1994.

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. SOLAR IRRADIANCE MEASUREMENTS

The experiment "Solar Spectrum" which flew during the SPACELAB 1 (SL 1) mission in 1983 was selected by NASA for a series of missions called "Atmospheric and Terrestrial Laboratory for Application and Science" (ATLAS), to be launched by the Space Shuttle during the 1990's. The Solar Spectrum experiment made in collaboration with the "Service d'Aéronomie du CNRS" (France) and the "Landessternwarte" (Heidelberg, Germany) is aimed at measuring UV, visible and infrared solar irradiance during the current solar activity cycle and the rising phase of the next cycle, in order to study the long term variations of the Sun compared to those obtained during the declining phase of solar cycle 21.

The first mission (ATLAS 1) which flew from March 24, 1992 to April 2, 1992 was a combination of instruments for atmospheric and solar related studies. The second mission (ATLAS 2) flew from April 7, 1993 to April 16, 1993. About 80 solar spectra have been recorded during each mission. Preliminary results have been presented at the IAU Colloquium "The Sun as a Variable Star" held in Boulder (USA) in June 1993. The agreement between the results of the 2 missions is very good and the data very close to the UV irradiance values obtained in 1983 during the SPACELAB-1 mission. Final results will be available in a near future.

Another model of the "Solar Spectrum" experiment was part of the EURECA platform defined by ESA. It was launched on July 31, 1992 by the Space Shuttle and retrieved on June 24, 1993. In addition to irradiance values in the UV, visible and infrared ranges, variations related to the 27-day rotation period of the Sun have been observed.

Both missions had an overlap in time with the UARS mission and are part of its correlative measurement programme.

2. ATMOSPHERIC LYMAN ALPHA EMISSIONS

Experiment ALAE (Atmospheric Lyman Alpha Emissions) was on board of the ATLAS 1 mission in 1992. This instrument is the result of a collaboration between the Belgian Institute for Space Aeronomy and the French Service d'Aéronomie.

Its objective was to measure the Lyman-alpha radiation scattered by atmospheric atomic hydrogen and deuterium. The mission was a full success, since the high quality data return was a factor of two higher than initially scheduled in the timeline of the mission.

The Lyman alpha emission of the geocorona as well as the interplanetary emission of atomic hydrogen were observed several times.

The atomic deuterium emission was also detected during numerous limb observations. But a major achievement was the first nadir observations of deuterium which will give information on the total content of this element in the Earth's atmosphere. This has been accomplished due to a significant increase of the sensitivity of the instrument compared to the one launched in 1983 (Spacelab 1 mission).

The data analysis is now continuing. No further launch of this instrument is foreseen.

3. THE GRILLE SPECTROMETER

In 1975, ONERA and the Belgian Institute for Space Aeronomy started together the study of a space-borne grille spectrometer for the ESA SPACELAB which at that time was in an early stage of development. After a first successful flight in 1983, delays in the shuttle program postponed the second flight till the ATLAS 1 mission in March 1992. This flight, near equinox, led to a much larger set of usefull experimental data but they are confined to the southern tropical and mid-latitude belt. The first preliminary results indicate an increase of HCl in the upper stratosphere since 1975 (of the order of 25% at 40 km altitude). The results of the ongoing analysis will probably constitute an important database that will allow, an evaluation of stratospheric changes in the past and in the future. Moreover, the grille data were accepted for taking part in the UARS (Upper Atmosphere Research Satellite) correlative program. Unfortunately, degradation of the 18 years old

electronics of the instrument would have required a major refurbishment if a reflight had been envisaged. Therefore it was decided that the instrument would no longer be put into an orbit.

A new version of the spaceborne grille spectrometer, called MIRAS, was built for flying onboard of the future Russian space station. The MIRAS grille spectrometer can also be adapted to modules of the present MIR-1 station. This new instrument is designed such that it will be able to measure in addition to the ten original gases measured during the SPACELAB and ATLAS-1 missions several new gases such as nitric acid, N_2O_5 and the freon-12 (CF_2Cl_2). In the presence of volcanic clouds, it should observe HCN, OCS and other related gases. Scientific observations will cover a one year period, nominally, with focus on specific campaigns as, e.g. a spring polar campaign, a tropical campaign, etc. This experiment will be conducted in collaboration with the Russian Space Research Institute (IKI) and ONERA (France).

4. THE ORA EXPERIMENT : MEASUREMENT OF ATMOSPHERIC MINOR CONSTITUENTS WITH A SATELLITE BORNE RADIOMETER

The ORA project is a cooperation between the Belgian Institute for Space Aeronomy and the Department of Atmospheric, Oceanic and Planetary Physics of the Oxford University, aiming the measurement of trace gases such as ozone, NO_2 , water vapour and aerosols in the Earth's upper atmosphere. For this purpose a small and lightweight radiometer was built and delivered to ESA in 1991. The ORA radiometer was designed to determine vertical distributions of aerosols and trace gases by measuring the attenuation of solar radiation during occultation events as observed from a satellite at an altitude of 500 km, and consists of two separate units.

The UV-visible unit containing 8 similar modules, each composed of an interference filter, simple optics to limit the field of view and a photo diode detector aims to derive profiles of ozone, nitrogen dioxide, water vapour and aerosols in the stratosphere.

The infrared part of the radiometer, designed to measure water vapour and carbon dioxide in the upper atmosphere, consists of two channels and uses the gas correlation technique by switching (with a mirrored rotating chopper) the incoming light (after passage through the interference filter) either

directly to a detector or first through a gas cell, containing the gas to be measured.

The ORA instrument relies upon the pointing capabilities of the carrier itself and therefore uses a rather large field of view. Thus the full solar disk is used for the occultation and a limited altitude resolution but high signal to noise ratio is obtained.

In early 1992 the last tests of the instrument before launch were performed in the Astrotech building in Titusville (USA), where the final integration of the instruments on the EURECA carrier was done.

EURECA was launched by the Space Shuttle "ATLANTIS" (STS-46) from Kennedy Space Center on 31 July 1992 at 13:56 GMT. It was released from the Shuttle cargo bay on 2 August 1992 at an altitude of 424 km and subsequently maneuvered into its mission orbit, which was reached on 7 August 1992. The final orbit altitude was 508 km and the inclination 28.5°. The science operations started on 10 August 1992 and continued according to plan until the end of January 1993. On 26 January the freon cooling loop of the carrier was deactivated, concluding the baseline science operations. Due to the lack of sufficient thermal stabilization, the infrared part of the ORA experiment had to be shut down from that moment on. Nevertheless the UV visible part could continue working and has been active until the end of the mission.

On 21 June 1993 the shuttle "ENDEAVOUR" (STS-57) was launched for the retrieval of EURECA, which had been brought in a suitable orbit by transfer maneuvers from 20 May until 8 June. Grappling of EURECA was performed on 24 June and on 1 July 1993 EURECA landed safely on Earth.

During the 11 months that the EURECA mission lasted, the ORA instrument has been measuring almost continuously for about 9 months. Occultation data in the UV-visible were recorded successfully at each sunrise and sunset, apart from a few occasions where measurements were interrupted for short periods, due to operational requirements.

Although the sensitivity of two channels of the UV-visible part of the instrument (340 and 385 nm) degraded severely, the results are of good quality and can still be used, due to the fact that the occultation technique is a self calibrating

method. The infrared part of ORA (EOR) has collected data for more than 4 months. In total more than 6000 occultation events have been captured. As a result a huge volume of information concerning the composition of the Earth's atmosphere has been gathered, with a latitudinal coverage from 35°S to 35°N.

In October 1993 the ORA instrument has been shipped back to our institute and has been partly dismantled for recalibration of some optical components. To investigate the reason for the degradation of some of the UV channels a cooperation with ESA/ESTEC has been set up.

Although the conversion from the raw data into scientific results is still in progress, the preliminary results look very promising. It is hoped that the results of the infrared experiment will contribute largely to our understanding of the mechanisms controlling the water vapor budget in the upper atmosphere. The retrieval of the UV-visible data is also expected to be most interesting and instructive, especially in view of the effects of the Pinatubo volcanic eruption on the ozone and aerosol concentrations. These concentrations should be mainly affected in the equatorial regions, where ORA has performed most of its measurements.

5. 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 first ENVISAT payload, whereas AMAS is considered for future platforms.

5.1. MIPAS

The Institute was co-proposer of this high resolution infrared emission interferometer which is now funded by ESA, and participates in the evaluation of instrument design and in scientific studies.

5.2 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 20 km altitude. NO₂, NO₃, H₂O, aerosols and temperature vertical profiles, important parameters associated to vertical profiles the ozone budget, are simultaneously determined. The phase B study has been completed in 1993 and the phase C is now in progress. The Institute is represented at the Science Advisory Group appointed by ESA.

5.3. SCIAMACHY

The Institute was co-proposer of this UV, visible and near infrared sounder of the atmosphere which is developed by the University of Bremen (Germany) and the University of Utrecht (The Netherlands) with the participation of several other Institutes. The primary objective of SCIAMACHY (Scanning Imaging Absorption Spectrometer For Atmospheric Cartography) is to determine the stratospheric column and vertical abundance of ozone as well as the total amount of nitrogen dioxide, the aerosol amount and vertical profiles of other stratospheric trace species by observing the scattered sunlight in the nadir and the limb viewing modes. When possible, solar and moon occultation measurements will be performed. The infrared channel will also provide additional tropospheric contents of trace species.

6. GLOBAL OZONE MONITORING EXPERIMENT ON-BOARD ERS-2

ESA will launch in the beginning of 1995 a second Earth Remote Sensing (ERS-2) satellite with a new instrument, the Global Ozone Monitoring Experiment (GOME). This instrument is aimed at measuring the total column of ozone and other trace species absorbing in the 240-790 nm wavelength range (e.g. NO₂). Vertical profiles of ozone will be also derived.

The observations of the backscattered sunlight will be performed in the nadir viewing mode. The geophysical data will be retrieved by using the differential optical absorption spectroscopy (DOAS) technique. The instrument has four

different spectral channels and the spectra will be recorded by means of silicon photodiode arrays.

ERS-2 will fly in a Sun-synchronous orbit at an altitude of 780 km with a local crossing time of 10.30h at the equator (descending mode).

The institute is represented at the Science Advisory Group appointed by ESA and is chairing the sub-group defining the validation programme to be implemented at the launch date.

7. AEROSOL RESEARCH

In parallel with the study of the atmospheric gases, a stabilised gondola was used for limb studies using a set of Hasselblad cameras fitted with spectral filters. The analysis of these photographs led to several publications on the granulometry and density of stratospheric and mesospheric layers. It also led to a new appraisal of the use of the visible spectral range which was introduced in the SCIAMACHY proposal. These results provided independent observations of the Earth aerosol layers which are presently used for the validation of SAGE data. Since the 1992 results of the ATLAS 1 Grille Spectrometer were also affected by aerosol absorption related to the Mount Pinatubo 1991 eruption, these features are currently under study.

8. GROUND-BASED STRATOSPHERIC OBSERVATIONS

The Belgian Institute for Space Aeronomy has installed an UV-visible spectrometer for remote sensing of the stratosphere at the International Scientific Station at the Jungfrauoch (Switzerland - 3580 m altitude) which has been selected with the Observatoire de Haute Provence (France) as the mid-latitude Northern hemisphere station of the Network of the Detection of Stratospheric Change (NDSC). Daily measurements of ozone and nitrogen dioxide vertical column abundances are performed by means of differential absorption measurements on the scattered sunlight observed at the zenith. In addition, collaborations with the Institute of Astrophysics of the University of Liège and the Royal Observatory of Belgium have been initiated for observations at the same station, with two infrared Fourier transform spectrometers. This research is conducted in the frameworks of the European project "European Stratospheric Monitoring Stations" (ESMOS) and of the federal Global Change

Impulse Programme "Spectroscopic Measurements and Atmospheric Chemistry" (SMAC).

The NO₂ measurements performed at the Jungfrauoch will be used for the current UARS correlative measurement programme and, with the ozone total amount measurements, for the GOME validation programme starting in 1995.

The Belgian Institute for Space Aeronomy has also participated in the European Arctic Stratospheric Ozone Experiment (EASOE) coordinated by the European Union, with observations performed at the International Scientific Station at the Jungfrauoch and with observations of ozone, NO₂ and OClO vertical column amounts performed from Kevlavik (Iceland) during the winter 1991-1992. An UV-visible spectrometer looking at the zenith sky has been developed for these latter site. The results will be published in 1994. A new campaign, the Second European Stratospheric Arctic and Mid-Latitude Experiment (SESAME), is planned in 1994 and 1995 with similar observations at Harestua, near Oslo (60°N, Norway).

9. GROUND BASED UV-B MONITORING

As part of the European Project "Determination of Standards for a UV-B Monitoring Network" (STEP 076), an automatic UV-B Monitoring Station is fully operational in an urban site of Brussels (Lat. : 50°47'54"N, Long. : 4°21'29"E, Alt. :105 m) since the end of March 1993.

This fully automatic station consists of two instruments based on modified Jobin-Yvon H10D double monochromators witch have been optically characterised (band path, angular and azimuthal responses, slit function) and calibrated in absolute irradiance by means of standard lamps provided by NIST. The main characteristics of these instruments are given in table 1. They provide spectral measurements of the total solar irradiance (inst. # 1) with a field of view of 2π sr and spectral measurements of the diffuse irradiance at the zenith with a field of view of $\pm 5^\circ$, from 210 to 680 nm, every 15 minutes, for solar zenith angles smaller than 100°.

Table 1 : Instruments.

Modified double monochromators Jobin Yvon H10-D			
	Inst.#1	Inst.#2	Inst.#3*
Focal length (mm)	100	100	100
Gratings	holographic concave		
lines/mm	1200	1200	1200
FWHM at 300 nm (mm)	0.488	0.492	≈ 0.500
Step (nm)	0.3	0.3	0.3
Usual range (nm) from	211	206	≈ 210
to	683	684	≈ 680
Scan duration (s)	400	400	≈ 400
Field of view	2π sr	$\pm 5^\circ$	$\pm 1^\circ$
Diffuser	teflon	quartz-teflon	quartz
Detector	PMT	PMT	PMT
type	Hamamatsu R292		
Weatherproof	yes		
Automatic	yes		
Dark current	removed during treatment		
Stray light	negligible		

*To be installed during 1994.

Special care is taken in the quality control of the provided data. Periodical absolute calibrations are performed every 2-3 months and the relative stability of the instruments are verified every 1-2 weeks by means of the Transportable Lamp System (TLS) developed in our laboratory. Consequently, the uncertainties on the data can be estimated at $\pm 5\%$.

The 10 months period of measurements performed in 1993 is the first step of a data base which will be made available to every potential user. It includes spectral irradiance data in the UV-B, UV-A and visible regions (up to 600 nm) and UV-B, UV integrated irradiances. Moreover the first physical interpretations of the obtained data are presently undertaken by establishing the correlations between the penetration of UV and UV-B radiations and different atmospheric parameters like the ozone total column and concentration profile, the type of cloud layer, the Sun's position, the aerosol contents,

It is foreseen for the future to determine the UV and visible radiation fields at the Earth's surface using data from satellites (a proposal for the using of the results from GOME as been introduced recently) and to compare these determinations with the ground based measurements. It is also planned to install a third instrument in the beginning of 1994 in order to measure the direct component of the solar irradiance. These data will be very useful to understand the influence of the atmospheric parameters on the two different components (direct and diffuse) of the UV and UV-B radiation.

Monitoring stations, like the one in Brussels, are indispensable for the knowledge of the actual level of UV radiation at the ground level and to determine trends over medium or long time ranges. Such stations are also very useful to be able to compare determinations of the UV and visible radiation fields at the Earth's surface deduced from space measurements with accurate ground based measurements.

10. MEASUREMENTS OF ABSORPTION CROSS-SECTIONS OF ATMOSPHERIC CONSTITUENTS

Measurements of the temperature dependence (210-300 K) of the ultraviolet absorption cross-sections (180-320 nm) of alternative hydrobromo- and hydrochlorofluorocarbons have been continued in the laboratory of spectrometry.

During the 1992-1993 period, the studied halocarbons were :

HCFC-225ca - 1,1,1,2,2-pentafluoro-3,3-dichloropropane and
HCFC-225cb - 1,1,2,2,3-pentafluoro-1,3-dichloropropane

The photodissociation coefficients, the mean atmospheric life-time and the Ozone Depletion Potential (ODP) of these species have been calculated in collaboration with NCAR (Boulder, USA). The results will be published in 1994.

In addition, the determination of the temperature dependence of ultraviolet absorption cross-sections of carbonyl compounds, which can be formed by the tropospheric degradation of alternative halocarbons, has been completed.

The studied carbonyl compounds were :

Trichloroacetylchloride - $\text{CCl}_3\text{-CClO}$
Trichloroacetaldehyde - $\text{CCl}_3\text{-CHO}$
Acetaldehyde - $\text{CH}_3\text{-CHO}$
Phosgene - CCl_2O

Preliminary results were presented at the Quadrennial Ozone Symposium 1992.

As the Global Ozone Monitoring Experiment (GOME) to be launched in early 1995 on-board ERS-2 (ESA) will provide ozone total amount and altitude profiles with other minor species like nitrogen dioxide, reliable absorption cross-sections are needed at high resolution. This requirement is justified by the fact that the retrieval method is based on the Differential Optical Absorption Spectroscopy (DOAS). Absorption cross-sections of NO_2 , SO_2 and CS_2 have been measured by means of a Fourier transform spectrometer in the UV and the visible range with a resolution between 0.02 nm and 0.2 nm. The temperature dependence is also investigated. The results will be published in 1994. The work is performed in collaboration with the "Université Libre de Bruxelles (ULB), Service de Chimie Physique Moléculaire".

Another aspect, dealing with atmospheric absorption in the infrared, was also investigated in collaboration with the ULB and NCAR (Boulder, USA). Absorption cross-sections have been obtained in the infrared atmospheric window, between 600 and 1500 cm^{-1} , for alternative hydrohalocarbons ; HCFC22, HCFC123, HCFC124, HCFC141b, HCFC142b, HCFC225ca, HCFC225cb, HFC125, HFC134a, and HFC152a. The measurements were made at three temperatures (287 K, 270 K and 253 K) with a Fourier transform spectrometer operating at 0.03 cm^{-1} apodized resolution. Integrated cross-sections have been introduced into a two-dimensional radiative-chemical-dynamical model in order to calculate the Global Warming Potentials (GWP) of each gas. This research has been conducted in the framework of the federal Global Change Impulse Programme "Spectroscopic Monitoring and Atmospheric Chemistry" (SMAC).

11. MEASUREMENT OF ATMOSPHERIC CONSTITUENTS BY ACTIVE CHEMICAL IONIZATION MASS SPECTROMETRY

The objective of this project, which is a cooperation between the Belgian Institute for Space Aeronomy (BISA), the Laboratoire de Physique et Chimie de l'Environnement (LPCE) at Orléans (France) and the Physikalisches Institut of the

University of Bern (Switzerland) is the development of a new active chemical ionization (ACIMS) method for the simultaneous in-situ measurement of stratospheric nitric acid and dinitrogen pentoxide, two gases playing an important role in the stratospheric ozone chemistry.

The ACIMS method 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 balloon borne mass spectrometer. The mixing ratio of reactive trace gases can be derived from the analysis of the relative abundance of precursor and product ions in spectra, obtained with the ion source. The innovation of the method proposed in the MACSIMS project, lies in the fact that an attempt is made to develop ion sources, producing mainly Cl^- or I^- ions. Whereas the Cl^- ions react both with HNO_3 and N_2O_5 , I^- only reacts with N_2O_5 . Both reactions result in NO_3^- core ions. From the abundance ratios $[\text{NO}_3^-]/[\text{Cl}^-]$ and $[\text{NO}_3^-]/[\text{I}^-]$, measured with the ion mass spectrometer and the known rate coefficient of the ion-molecule reactions involved, the HNO_3 and N_2O_5 concentrations can in principle be inferred.

To reach these objectives, two major phases were foreseen. The first phase consisted of the development of a new sensitive ion mass spectrometer, allowing the recording of spectra in a short time, to obtain a high altitude resolution in the ACIMS method, as well as a first study of suitable ion sources and their testing in the laboratory. This work was performed within the projects SIDAMS (CEC contract: STEP-0009-M(A)) and SIMULION (funded by the "Fonds voor Kollektief Fundamenteel Onderzoek - Ministerieel Initiatief" (FKFO-MI) and the Belgian national Science Foundation (NFWO).

A new type of balloon borne Mattauch-Herzog magnetic mass spectrometer with simultaneous ion detection, including its cryopumping system and the control electronics has been developed and tested during two balloon flights (in 1991 and 1992). In 1992 the negative ion mass spectrometer has been finished and launched by stratospheric balloon. Although no valuable scientific results were obtained, due to a failure of a motor driven valve in the instrument, all other subassemblies of the instrument behaved as expected and it was decided to use this mass spectrometer for further development of the full ACIMS instrument.

The second phase includes the realization of flight models of the ion sources developed within the SIDAMS project and the testing of the unit in the stratosphere with two balloon flights. It also contains further required tests and measurements in the laboratory of ion-molecule reactions involved in the proposed method.

This work is included in the CEC projects MACSIMS (contract EV5V-CT92-0062) and SIMULION 2, with funding from FKFO-MI and NFWO.

In 1993, the ACIMS payload, consisting of the ion source, an ion transport device (flow tube) and the appropriate gas control units as well as the control electronics has been realized and tested in the laboratory. The first flight with the combined instrument (mass spectrometer and ACIMS package), which is scheduled in 1994, is prepared.

Parallel to these activities laboratory studies were undertaken to measure the rate constants of the ion-molecule reactions, playing a role in the developed method. The reactions of polyhalide ions Cl_n^- and I_n^- ($n=2,3$) with nitric acid were studied by means of a quadrupole mass spectrometer coupled to a laboratory flow tube of the classical design.

12. STUDY OF SPACE PLASMAS

12.1. Development study of improved models of the earth's radiation environment (Project TREND)

Improvements of the software used at ESA to compute B-L coordinates and energetic particle flux versus energy, B and L have been achieved. Additional magnetic field models have been added in the UNIRAD software package. Proton flux measurements from the PROTEL instrument of CRRES have been used to develop the software for future model implementation. A comparison between the NASA-AE8/AP8 radiation belt models and the corresponding russian models developed at the Institute for Nuclear Physics (Moscow State University), have been performed. The average of the atmospheric density over L-shells have been calculated using a standard atmospheric model.

The AE8 electron energy spectra have been fitted with two relativistic Maxwellian velocity distributions. The characteristic temperatures and densities corresponding to both maxwellians have been determined versus L.

A study of various observations of the plasmasphere has led to infer that the plasmasphere is slowly expanding, even during quiet geomagnetic conditions. This continuous expansion has been called the Plasmaspheric Wind.

Numerical solutions of Poisson's equation for a plasma in a gravitational field have been obtained. Besides the standard quasi-neutrality solution of Pannekoek-Rosseland, more general solutions corresponding to periodic potential structures with a wavelength of about 4 times the Debye length have been found.

12.2. Whistler waves propagation across tangential discontinuities

Propagation of electromagnetic waves across density gradients in inhomogeneous plasmas have been studied under many different physical conditions and using different mathematical methods. The refraction and reflection of electromagnetic waves propagating through tangential discontinuities have been determined in the case their frequency is close to the ion-gyrofrequency. The dependence of the refraction and reflection coefficients are obtained in the framework of plasma kinetic theory. The effect of magnetic shears on the reflection and transmittance coefficients of waves at frequencies higher as well as lower than the cyclotron frequencies are also examined. The potential application of these theoretical results to solar wind discontinuities and to the magnetopause is discussed. These results will be compared to the wave observations obtained by the Ulysses spacecraft.

12.3. Study of thin magnetospheric boundaries

The spacecraft INTERBALL (Russia), CLUSTER (ESA), WIND and POLAR (NASA), GEOTAIL (Japan) have the potential to revolutionize our understanding of the coupled solar wind-magnetosphere-ionosphere system. A special attention will be given in the near future to the boundaries between different plasma regions where a full kinetic description is required. Theoretical and numerical simulations have been developed for a detailed comparison with the future spacecraft data.

The electrical structure of the sheath which separates magnetospheric particle populations of different densities and temperatures has been modeled in the framework of a kinetic theory for tangential discontinuities. This model can also be applied to the plasmashet boundary layer (PSBL) in the tail or

to the boundary of some plasmashet cloud immersed in the central plasmashet (CPS). For plasma parameters typical for the Earth's outer magnetosphere and plasmashet, results bearing many features pertinent to magnetospheric processes, specifically the origin of discrete auroral arcs were obtained. The generated electric potential differences, consistent with the energy acquired by the precipitated electrons associated with discrete aurora, are identified with the source of the electromotive force (EMF) required for the auroral current circuit. Waves-particles interactions are likely to scatter the electrons into the atmospheric loss cone, establishing the current system threading both the EMF and the ionosphere by means of field-aligned currents.

The Vlasov kinetic approach is used to study the stability of the magnetopause current layer (MCL) when a sheared flow velocity and a sheared magnetic field both exist simultaneously within it. A modified Harris-Sestero equilibrium where the magnetic field and bulk velocity are changing direction on the same spatial scale is suggested to illustrate the generation of a y -component of the magnetic field in the center of the MCL. With this equilibrium it is shown that $B_y(0)$ can be of the order of $B_z(\infty)$ when the value of the shear flow tends to the ion drift velocity. The modifications of the initial symmetrical Harris configuration, introduced by the presence of a shear flow, strongly influence the adiabatic interaction of the plasma with low-frequency tearing-type electromagnetic perturbations as well as the nonadiabatic response of the particles near the center of the MCL. This results in a reduction of the growth rate of the tearing mode.

The stochastic percolation model based on the symmetrical charge-neutral equilibrium of Harris, is generalized for asymmetrical MCLs. Asymmetry in B field profile strongly modifies the dependence of the marginal MCL thickness (below which the MCL is subjected to percolation) on the polarity of the interplanetary magnetic field (IMF). Assuming that the magnetopause should, on the average, be close to its stability threshold, realistic asymmetrical MCLs should be thinner for a northward IMF than for a southward IMF. The redistribution of the equilibrium electric field after percolation should also provide the MCL with the feature of a semipermeable membrane at the early stage of the particle diffusion.

The impulsive penetration model has been reconsidered to emphasize the non-ideal MHD-effects. Contrary to the

conclusions obtained for infinitely long field-aligned plasma filaments it is shown that for 3-D plasmoids :

(1) the Faraday law is not violated, when properly applied,
(2) the solar wind plasma elements can penetrate in the geomagnetic field for any orientation of the dipole moment associated to their diamagnetic current system. Nevertheless, the direction of the IMF determines in some way the access of diamagnetic plasma elements into the Earth magnetic field, because of the dipole-dipole interaction between (i) the diamagnetic currents associated to the moving plasmoids, and (ii) the Chapman-Ferraro currents at the magnetopause and the magnetic moment of the magnetosphere.

13. STUDY OF THE PLANET MARS

The PHOBOS-AUGUSTE experiment, initially conceived to measure HDO in the Martian atmosphere, allowed the tentative identification of formaldehyde in the atmosphere of Mars. The observations were compared to a synthetic spectrum (see fig. 1) using the formaldehyde HITRAN spectral data file.

The deduced formaldehyde values are compatible with a two-dimensional model calculation of the Martian atmosphere. However a lot of problems remain unsolved, the main being the absence of methane which should be more abundant than formaldehyde if the chemistry is limited to the gas phase.

In view of the Mars 94 mission the institute continued the cooperation with the Service d'Aéronomie (France) and the Institute for Space Research (Russia) to develop the SPICAM instrument.

SPICAM is an optical package designed for the study of the composition of the atmosphere of Mars. It is composed of a stellar occultation spectrometer and a solar occultation spectrometer. The stellar spectrometer operates in the UV and visible regions while the solar instrument is double : one of the spectrometers covers the UV and visible while the other covers the middle infrared (see Table). Both solar spectrometers are based on the ORIEL 125 mm monochromator which had to be modified for space operations.

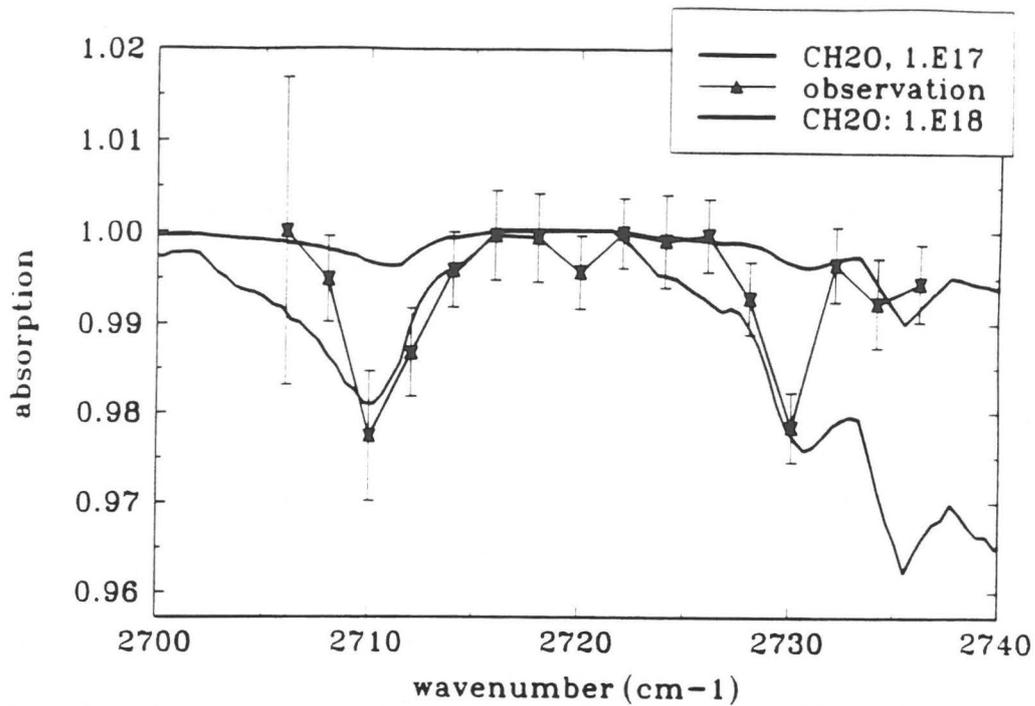


Fig. 1 : Comparison of the observed Martian average spectrum with a Martian simulation using the formaldehyde HITRAN data file.

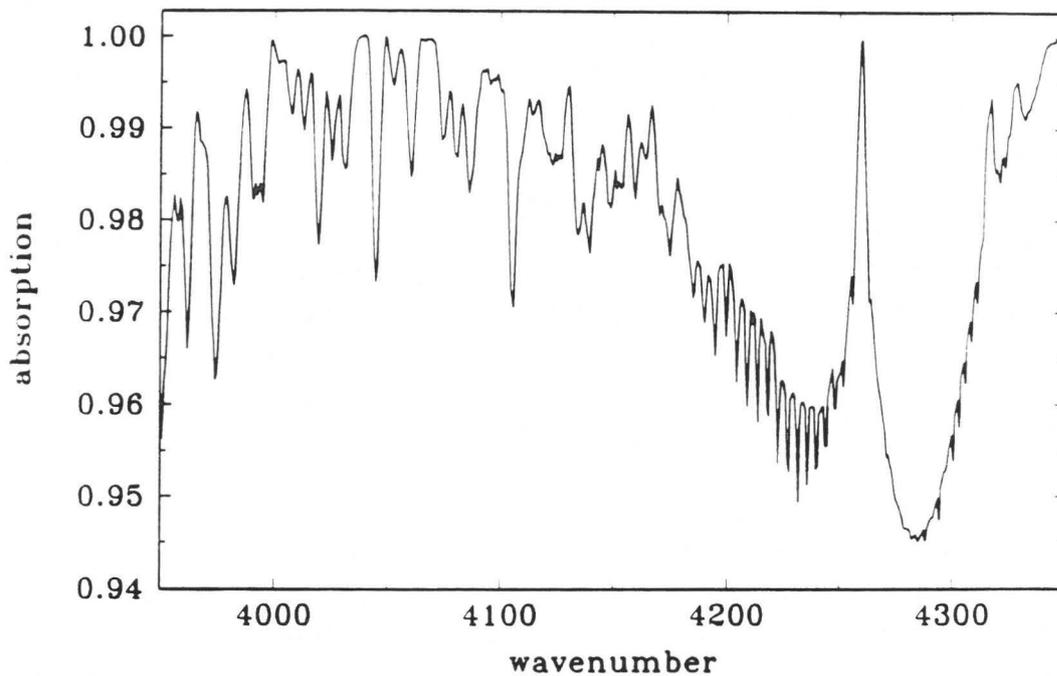


Fig. 2 : Computations of the Martian limb transmission for a tangent altitude of 10 km in the second order of the SPICAM infrared domain, carbon monoxide and dioxide, water vapor and formaldehyde are included, aerosols have not been included and the instrumental response is approached by a triangular function.

Table : Instrumental properties of the solar SPICAM package.

Infrared Channel	UV-visible channel
1950-3050 3920-5405	240-800 nm
resolution :better than 1000	resolution : 300
PbSe cooled to 240 K in two linear arrays of 128 pixels.	reticon: 1024 element diode array
S/N: 1000 at 5000 cm^{-1} 200 at 2000 cm^{-1}	better than 2000

The UV visible part of the experiment will be essentially dedicated to the observation of the spatial and temporal evolution of the concentration of ozone and aerosols in the atmosphere while the infrared part has been designed to realize a mapping of the atmospheric distributions of carbon dioxide, water vapor, and carbon monoxide (see Fig. 2). Though ozone is a trace constituent in the Martian atmosphere, analysis of its spatial distribution is useful for a good understanding of Martian aeronomy. Ozone was previously detected in high latitude regions by the Mariner 9 and Mars 5 spacecraft but is not yet detected in equatorial areas. Though CO and water vapor have been intensively observed during the last three decades, spatial distribution of these constituents in the Martian atmosphere remains a major scientific problem. Observations made during Phobos mission apparently show a higher abundance for water and a lower abundance for carbon monoxide over the volcanic Tharsis region leading to a renewal of interest in possible current Martian volcanic activity. Organic molecules, in particular: formaldehyde and methane, are also among the SPICAM scientific objectives.

The Martian aerosol population is represented by two main groups: the mineral dust and the ice or two-layer (dust core and ice cover) particles. Water ice is known to represent the dominant type of condensate layers, the solid CO_2 , however is also possible at high altitudes. Mineral dust forms the so called permanent haze of Mars in the lowest 20 km, where the dust is rather well mixed with gas. The SPICAM instrument will also study these aerosols.

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B. INSTITUTE OF ASTROPHYSICS OF THE UNIVERSITY OF LIEGE

1. ATMOS-RELATED INVESTIGATIONS

Jointly with the NASA-Jet Propulsion Laboratory, Pasadena, California, and the NASA-Langley Research Center, Hampton, Virginia, the Institute of Astrophysics of the University of Liège has pursued investigations of the chemical composition and physical structure of the middle and upper Earth's atmosphere, between about 10 and 150 km altitude. This study is based on the analysis of infrared solar observations (2 to 16 μm) made remotely in the occultation mode from aboard Space Shuttles by the ATMOS (Atmospheric Trace MOlecule Spectroscopy) high resolution Fourier transform spectrometer.

Following its first flight as part of the 1985-Spacelab 3 payload, ATMOS was further flown on March 24 - April 2, 1992, and on April 7 to 16, 1993, as a core experiment of the ATLAS (ATmospheric Laboratory for Applications and Science) program. It performed about 100 complete occultation measurements during both the 1992 and 1993 missions. Thus far, occultations (sunrises and sunsets) have been observed over the 30°N-60°S and 65°N-70°N regions of the globe.

Key scientific issues that have been addressed based on the retrieval of concentration profiles of some 30 telluric constituents deal with :

1. the determination of the budgets of nitrogen-, chlorine- and fluorine containing gases (sources, sinks and reservoirs combined)
2. the study of the minor telluric constituents CO_2 , CO , N_2O , CH_4 , O_3 and H_2O over the entire altitude range from 10 to 150 km
3. the production of a consistent set of concentration profiles for verification and for constraining model calculations and predictions regarding atmospheric chemistry
4. the production of a reference set of "pure" high resolution solar spectra from 650 to 4800 cm^{-1} , free of any telluric absorption.

In particular, the atmos data base has provided the first demonstration of the conservation of total chlorine (Cl) and fluorine (F) in the 12 to 60 km altitude region as well as

their commensuration with values reported for the tropospheric Cl and F concentrations, when allowance is made for the growth rate of their sources at the ground (mainly the chlorofluorocarbons) and the time required for tropospheric air to be transported into the stratosphere. Intercomparisons between results retrieved from the 1985 and the 1992-93 missions constitute the basis for an assessment of the evolution of the stratosphere and the impact of man-made activities, which are presently under investigation.

The next ATMOS flight is scheduled for October 1994.

2. BALLOON OBSERVATIONS

Two stratospheric balloon flights have been carried out successfully on May 4 and on June 11, 1993 from the National Scientific Balloon Facility (NSBF) of Fort Sumner, New Mexico, USA. These experiments were part of an international effort involving american, italian and belgian groups, coordinated to underfly the Upper Atmospheric Research Satellite (UARS) for validating some of its observations. The Liège measurements which were made from float altitudes near 36km, were primarily devoted to the determination of the stratospheric mixing ratio profiles of HCl, CH₄ and NO₂, for comparison with similar retrievals made by HALOE (Halogen Experiment) from aboard UARS.

3. GROUND BASED SOLAR OBSERVATIONS

The database gathered at the International Scientific Station of the Jungfrauoch (located at 3580 m altitude in the Swiss Alps) during the last years is part of a long lasting effort conducted and coordinated within the frames of the ESMOS (European Stratospheric MONitoring Stations) and of the NDSC (Network for the Detection of Stratospheric Change) programs. It is intended to provide secular trend information on the atmospheric burdens of some 20 telluric constituents of geophysical interest, including not only the stratospheric gases HCl, HF, ClONO₂, COF₂, HNO₃, NO, NO₂, O₃, but also sources of both natural and anthropogenic origin such as CO₂, CO, H₂O, CH₄, N₂O, C₂H₂, C₂H₆, HCN, OCS, CCl₂F₂, CCl₃F, CHClF₂, SF₆, H₂CO, H₂CO₂,... The results, generally reported in terms of vertical column abundances above the station, are derived from solar observations made with two high quality Fourier transform spectrometers operating in the 2 to 15 μm infrared domain, with a spectral resolution of a few mK (milliKayser, or 0.001 cm⁻¹).

4. MODELING THE ROLE OF "HOT" NITROGEN ATOMS IN THE NITRIC OXIDE PHOTOCHEMISTRY : COMPARISON WITH SOLAR MESOSPHERE EXPLORER SATELLITE

The variation of the nitric oxide peak density near 110 km with solar activity was calculated using a photochemical diffusive model of thermospheric odd nitrogen. This model includes the reaction of translationally excited ("hot") nitrogen atoms with O_2 as a source of nitric oxide, in addition to the classical photochemistry. It was confirmed that the dissociation of N_2 by energetic photoelectrons due to the ionization of atmospheric constituents by solar soft X-rays is an important source of atomic nitrogen which controls the observed NO maximum near 110 km. The consideration of the hot $N(^4S)$ source increases the NO peak density by 45 to 60% dependent on the solar activity level considered. The calculated NO peak density increases by a factor of ~ 3.5 from low to high solar activity conditions, in agreement with the SME satellite observations. The absolute concentrations calculated in the model with an $N(^2D)$ effective yield of 54% from N_2 electron impact dissociation are mid-way between the two sets of solar cycle NO variation measurements currently available.

The results reported in this study clearly demonstrate that the inclusion of the hot atomic nitrogen chemistry is important for the prediction of the absolute thermospheric NO density, especially in the E region. Its contribution is particularly significant at high solar activity conditions. These simulations also confirm the crucial role played by the soft solar X-ray ionization of N_2 as a source of fast photoelectrons. The dissociation and ionization of N_2 by these energetic electrons is an essential process for the control of the altitude and shape of the thermospheric NO peak. Their magnitude strongly varies with the solar cycle.

5. PLANETARY OBSERVATIONS WITH THE HUBBLE SPACE TELESCOPE

5.1. Jovian ultraviolet aurora

High spatial resolution images of the north polar region of Jupiter have been obtained with the Faint Object Camera (FOC) on board the Hubble Space Telescope. The first set of two images collected 97 minutes apart in February 1992 show a bright (≈ 180 kR) emission superimposed on the background in rotation with the planet. Both $Ly \alpha$ images show common regions

of enhanced emission but differences are also observed, possibly due to temporal variations. The second group of images obtained on June 23 and 26, 1992 isolates a region near 153 nm dominated by the H₂ Lyman bands and continuum. Both pictures exhibit a narrow arc structure fitting the L = 30 magnetotail field line footprint in the morning sector and a broader diffuse aurora in the afternoon. They show no indication of an evening twilight enhancement. Although the central meridian longitudes were similar, significant differences are seen in the morphology of the two exposures, especially in the region of diffuse emission, and interpreted as signatures of temporal variations. The total power radiated in the H₂ bands is $\approx 2 \times 10^{12} \text{ W}$, in agreement with previous UV spectrometer observations. The high local H₂ emission rates ($\approx 450 \text{ kR}$) imply a particle precipitation carrying an energy flux of about $5 \times 10^{-2} \text{ W m}^{-2}$.

The similarity with images taken with the FOC two days earlier by Canadian observers in the H₂ bands suggests that, at least occasionally, the late afternoon sector is enhanced as a result of local time inhomogeneous particle precipitation. The H₂ Lyman images confirm that the discrete aurora lies at the footprint of magnetotail magnetic field lines. The change of morphology from a narrow bright arc to a broad diffuse aurora is an important result suggesting two different populations of precipitated particle and/or two distinct acceleration mechanisms.

The energy supply constraints derived from the hemispheric emitted power are consistent with those already based on IUE and Voyager data. However, the very high emission rates measured locally in the H₂ arcs imply very large local fluxes of energy precipitation. Any viable acceleration mechanisms must be able to support such large local precipitation powers.

5.2. Photometry of Io surface

The geologically active trailing hemisphere of Io was imaged in the near UV at 2900 Å and in the visible at 4500 Å with the FOC on the Hubble Space Telescope (HST) for the first time with a resolution corresponding to 250 km at the sub-earth point. A direct comparison of the visual FOC image with a synthetic Voyager image of the same hemisphere at the same wavelength shows little change in the large scale distribution of surface materials in the 13 years elapsed between the two data sets. The simultaneous HST visual and ultraviolet images

showed an inverse correlation due to a complex surface structure and composition. The FOC visible and UV images present a good anticorrelation between bright and dark areas but there are also regions that are bright in both or dark in both images showing that grain size may also play a role in the 2900 Å brightness variation. The reflectivity of SO₂ and that of many possible compounds of Io's surface is very sensitive to the grain size at ultraviolet wavelengths. This work and follow-up observations should allow us to reach the goal of clarifying the nature and origin of this fascinating object.

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C. ROYAL METEOROLOGICAL INSTITUTE OF BELGIUM

1. IONOSPHERIC STUDIES

Since several solar cycles, the Dourbes ionospheric station accumulated ionograms and ionospheric characteristics. With the outcome of digital sounder and the associated software, the electronic distributions are produced for almost each sounding.

During the years 1992 and 1993, the effort was directed to reduce the long delay between the actual sounding and the validation and preparation of the data to build the ionospheric data base.

In the theoretical domain, an important improvement of the photochemical model of the lower ionosphere was achieved by the incorporation of the latest thermospheric Hedin model and UV model. 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. Three campaigns of oblique soundings were organised between the Dourbes station and the Observatori de l'Ebre (Spain).

Also preliminary investigations to produce a TEC value were made in order to compare with the one deduced from the GPS system of the Royal Observatory.

2. EXTERNAL GEOMAGNETISM

Most of the work was devoted to renew the Manhay magnetic observatory which is now completely under the responsibility of the Geophysics department of the Royal Meteorological Institute (previously operated by the University of Liège). This observatory is now similar to the one of Dourbes. An other important effort was to build two new apparatus: one is a hanging variometer (VARSUS) and the other is an absolute magnetometer (Tandem Potassium Cesium hyperfine structure optical pumping magnetometer).

3. SOLAR CONSTANT AND EARTH'S RADIATION BUDGET

3.1. NASA-ATLAS program

The SOLCON experiment that has flown on SPACELAB 1 has been redesigned as a core experiment of the NASA ATLAS program. SOLCON was launched respectively by the shuttle ATLANTIS and ENDEAVIOUR on March 24th 1992 and April 7th 1993 for the ATLAS 1 and ATLAS 2 missions.

During the ATLAS 1 flight, the effect of a set of active sunspots on the Solar constant has been well observed. The varying temperature conditions on the shuttle allowed to take full benefit of the unique dual differential absolute radiometer design and to improve the data treatment algorithm in detail.

During the ATLAS 2 flight the Sun showed no sunspots at all during several days. This condition was thus unique to materialize for the first time a Space Absolute Radiometric Reference. The involved instruments being SOLCON L & R (ATLAS), ACRIM II (UARS), SOL.MON. (ERBS), SOVA 1 L & R (EURECA) and SOVA 2-PMO2 (EURECA).

3.2. ESA-EURECA program

The SOVA experiment was launched on EURECA with ATLANTIS on July 31st 1992 and was brought back to Earth in June 1993.

The SOVA experiment is a collaboration between the Royal Meteorological Institute as lead and the Space Science Department (SSD) of ESA and the Physikalisch Meteorologisches Observatorium Davos (PMOD) as co-investigators.

Several radiometers and photometers have been operated continuously. In particular the SOVA 1 L & R dual differential absolute radiometer of the Royal Meteorological Institute and SOVA 2-PMO2 of PMOD have joined for the materialization of the first Space Absolute Radiometric Reference during the ATLAS 2 flight.

3.3. The belgian space remote operation center

During the ATLAS 1 flight, a first remote operation site with limited possibilities was installed at ESTEC to operate SOLCON and SOLSPEC.

During the ATLAS 2 flight a full operation center has been put in activity at the Royal Meteorological Institute, SOLCON as well as partially SOLSPEC, were provided with the full capabilities, they get at the POCC of the HOSC at the MSFC with inclusive televideo communications between the two places.

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II. SPACE ASTRONOMY

A. ROYAL OBSERVATORY OF BELGIUM

1. INTERNATIONAL ULTRAVIOLET EXPLORER (IUE)

The International Ultraviolet Explorer, launched in 1978 has since then obtained high- and low-resolution spectra of astronomical objects in the wavelength range 1150-3200 Å. All registered spectra can be found in the IUE data base. The ESA IUE Observatory has created a compact subset of the IUE Archive, in order to ease access to the low-resolution IUE data: ULDA (Uniform Low Dispersion Archive), which can be consulted by means of a user-friendly software package : USSP (ULDA Software Support Package).

The principal centre of ULDA is based at the ESA IUE Observatory at Vilspa (Spain) with national centres in different countries. The Royal Observatory is National Host for Belgian scientists. The Archive is installed on the μ Vax at the Observatory and 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 early-type stars. All of these stars have a strong stellar wind (with mass loss rates of up to 10^{-5} solar masses per year). This wind causes the P Cygni profiles seen in the IUE spectra. In collaboration with the Vrije Universiteit Brussel, we constructed computer models for these stellar winds. We then compared these models with the observations with data from the Infrared Astronomical Satellite (see contribution from the Vrije Universiteit Brussel). From the IUE data we derived the terminal velocities of the stellar winds, which were then used in our theoretical models.

We also studied the P Cygni profiles in more detail by fitting them with semi-empirical models. The fitting was done using MIDAS software developed by W. Hummel (VUB) and a stellar wind code by Lamers, Cerruti-Sola en Perinotto. From this work

we hope to derive some constraints on the turbulence which is present in the wind of these stars.

2. 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 (Spacelab 3 flight, April 29 - May 6, 1985; ATLAS 1, March 24 - April 2, 1992; ATLAS 2, April 8 - 17, 1993) using a very performant Fourier transform spectrometer, mainly to study the vertical distribution of molecular constituents of our atmosphere.

Our solar team (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 μm , free from any telluric absorption. Our work consisted of measuring and interpreting the ATMOS solar spectra of the 1985 and 1992 flights.

From these pure infrared solar spectra, we have made an analysis of different atomic and molecular species that are of great interest for the structure of the solar outer layers, from very deep to very high layers. The main results can be divided into two 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 molecular lines and on the new abundance of iron, interpretation of line shifts and line asymmetries in solar lines;
- Atomic and molecular spectroscopy: identification of new Fe I lines, determination of term energies and of solar-derived gf values for all relevant lines (in collaboration with the spectroscopic group at Lund); determination of a new refined set of spectroscopic constants for CO.

3. HIPPARCOS ASTROMETRIC MISSION AND DOUBLE STAR ASTRONOMY

3.1. Input catalogue consortium

The Hipparcos Input Catalogue has been published (Turon et al., 1992). Volume 6, entirely prepared at Uccle represents the annex of Double and Multiple Stars, containing the known

ground-based data concerning 18339 entries for a total of 14167 double and multiple systems (Annex 1). Of these 14167 systems 11434 are double, 1960 are triple, 536 are quadruple and 237 are multiple.

With the space mission ending on 15 August 1993, after an operational lifetime of 41 months, our task has shifted from the preparation of the Input Catalogue to helping in the preparation of the Output Catalogue.

In order to obtain the best possible double star data, a Double Star Working Group has been formed by the Hipparcos Science Team, gathering members from both Reduction Consortia (NDAC and FAST) and from the Input Catalogue Consortium (Inca Double Star Working Group). Within this group, our task consists in a systematic identification of double stars in the Output Catalogue : in addition to the already identified 14167 systems of the Input Catalogue, several thousands of other systems (some 5000 to 10000) have been observed during this mission, of which 10 to 20% may be ground-based detections, postdating the preparation of Annex 1.

3.2. Catalogue of components of double and multiple systems (CCDM)

From the beginning of our participation (1981), in order to proceed with the above-mentioned identifications, a specific catalogue of double and multiple systems has been simultaneously compiled. On a total of 70000 systems, half of them are correctly identified on the sky within 1" of accuracy. We intend to complete this catalogue after finishing our present work for the Hipparcos Output Catalogue. This catalogue will then be useful for both ground-based and future space astrometric programmes.

3.3. Double star astronomy

Expected contributions of this mission specific to double star astronomy have been reviewed and presented, at IAU Colloquium No. 135 and at the "16ième Ecole de Printemps d'Astrophysique de Goutelas" (Dommanget and Lampens, 1992a; 1992b).

Applications for early access of Hipparcos-data have been introduced to the Data Distribution Review Teams for proposals in connection with orbit (re)computation and the calibration of

the masses of stars through the mass-luminosity relation but also in connection with double star evolution and double star problems related to galactic dynamics.

A complementary ground-based photometric programme was started with the aim to supplement the Hipparcos magnitudes with astrophysically significant colour indices and to provide the information lacking for those components not included in the Input Catalogue (Oblak and Lampens, 1992). Observations are carried out in both hemispheres. Since conventional aperture photometry is not possible for the interesting angularly close binaries (separations inferior to 15"), the -to this domain - new technique of CCD photometry is being used.

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B. ASTRONOMICAL OBSERVATORY OF THE UNIVERSITY OF GENT

1. MAGNETIC FIELD TURBULENCE IN COMETARY BEAM-PLASMA SYSTEMS

Occurrences of resonant and nonresonant Alfvén instabilities in solar system beam-plasmas include hydromagnetic waves upstream of cometary bow shocks due to pick-up of cometary neutrals by the solar wind. We have applied our general multi-beam formalism incorporating Fowlers' theorem for fluctuations in unstable plasmas to show that nonresonant Alfvén modes can indeed be one of the potential mechanisms closer to the nucleus which lead to the scattering of the ion beams and their ultimate assimilation into the solar wind.

Farther upstream resonant modes can be excited at Doppler-shifted frequencies equal to the cometary ion gyrofrequencies. The estimates of the present theory show that the turbulence level is fairly small, in agreement with observational evidence far-away from the cometary nucleus. Also, if the observed electromagnetic turbulence and associated frequencies far upstream of comet P/Grigg-Skjellerup during the 1992 Giotto spacecraft flyby can be attributed to relative streaming between the cometary ions and the solar wind, a selfconsistent approach yields resonant instabilities with wavelengths of 7000 ~ 8000 km, phase velocities which are subalfvénic and polarizations which are left-handed in the spacecraft frame.

We have also generalized to general geometries the expansion of kinetic equations in the limit of a strong magnetic field. This is used to describe parallel propagation of nonlinear Alfvén waves and obtain a derivative nonlinear Schrödinger like equation, including a new nonlinear term proportional to the heat flux along the magnetic field line and also a higher-order dispersive term. Our kinetic description avoids the singularities of multifluid approaches, and shows that one cannot neglect parallel heat fluxes, not even in the case of low parallel plasma beta. Finally, we derive a truly stationary soliton solution which could be related to the cometary bow shock.

2. AURORAL PLASMAS

Ion density holes can be generated by a large-amplitude electrostatic ion-cyclotron wave on auroral field lines. The rate at which the ion holes are excited is obtained. The

presence of ion holes may cause intermittent double layers observed in the auroral partical acceleration region. The predicted scale lengths and velocities of the double layers are in agreement with observations.

In the same vein, small amplitude ion-acoustic double layers and solitons in auroral plasmas are treated, taking into account ion beam effects. The analysis predicts the excitation of fast and slow hydrogen (as well as oxygen) beam-acoustic modes which can be either rarefactive double layers, or rarefactive or compressive solitons. Fast and slow hydrogen beam-acoustic modes are the first to be excited, whereas oxygen modes require larger beam speeds or temperatures. The typical width and speed of the nonlinear modes are in good agreement with observations of double layers and solitons by the S3-3 and Viking satellites.

3. DUSTY PLASMAS

Nonlinear dust-acoustic waves in a dusty plasma are studied, including a number of cold negatively charged dust grain species, in addition to the more usual isothermal hot and cold electrons and isothermal positive ions. Besides the usual modes several new low-frequency motions occur which are typical for the dust components. Weak dust-acoustic solitons can be described by modified Korteweg-de Vries equations for electrostatic waves, or derivative nonlinear Schrödinger equations or electromagnetic waves.

An application is give to a dusty plasma with one kind of negative grains, in the presence of protons, all electrons having been accreted unto the dust grains as in the F-ring of Saturn. Such dusty plasmas can support rarefactive supersonic solitions, in contrast to the usual ion-acoustic solitons which are compressive. Such conclusions are relevant for different kinds of astrophysical and heliospheric (cometary and magnetospheric) plasmas.

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C. ASTRONOMY GROUP OF THE "VRIJE UNIVERSITEIT BRUSSEL"

The stellar wind around early-type stars creates an excess of flux at infrared and radio wavelengths. In cooperation with the Royal Observatory of Belgium, we study the mass loss of the star, as well as the presence of clumps in the stellar wind, through the infrared and radio continuum. The observations were collected from the Infrared Astronomical Satellite (IRAS), and supplemented by data from ground-based observatories and radio-telescopes. The IRAS satellite has detected early-type stars at 12, 25 and 60 μm . In future we hope to use the Infrared Space Observatory (ISO) to extend both the number of detected stars and the wavelength range. We have developed a computer model that predicts theoretical continuum fluxes. These theoretical fluxes are then compared to the observations.

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III. SPACE GEODESY

A. ROYAL MILITARY ACADEMY

The Royal Military Academy investigates the high-precision positioning in the real-time with GPS-satellites.

The real time kinematic approach aims at developing a method capable of yielding position, velocity and time information derived from the L1 carrier filtered pseudo-range observable through the use of Kalman filter techniques. The program incorporates differential corrections generated by a static reference station situated in the vicinity of the kinematic vector. The data processing is specific and different from post-processing procedures.

In order to incorporate the position information in the traditionally used cartographic representation or a Geographic Information System, one needs to determine the transformation formulas between the World Geodetic Reference System WGS84 used by GPS and the Universal Transverse Mercator or Belgian Lambert projection. These formulas can only be obtained when the Belgian National Geoid is known at the cm level. Therefore a national fundamental geodetic network will be set up, consisting of about forty underground marks with three-dimensional geocentric coordinates and measured value of the gravitational acceleration. This project is realised in cooperation with the Belgian Royal Observatory, The Catholic University of Leuven and the National Geographic Institute.

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B. ROYAL OBSERVATORY OF BELGIUM

1. TRANSIT SYSTEM

Operation of the TRANET station has been maintained on a regular basis for the tracking of Transit and Geosat satellites. The world network stopped its operation on 30th September 1993. During the period January 1992 - September 1993, 26949 passes were observed by the Brussels station.

The total electron content has been regularly deduced from the observations on dual frequencies at 150 MHz and 400 MHz; the results are quite comparable to those obtained from the Global Positioning System measurements although an offset of a few percents is not yet explained.

2. GLOBAL POSITIONING SYSTEM

In 1989, the GPS group of the Royal Observatory of Belgium has begun to develop a GPS software allowing distances determination using GPS measurements. At that time, commercial GPS softwares were already available but they were black boxes and the accuracy of the results obtained was very difficult to evaluate. This is the reason why the Observatory decided to write its own software. In order to write this GPS software many error sources affecting the precision obtained by GPS are to be studied. Presently, the effects of the ionospheric and tropospheric refractions on the GPS signals are the main limiting factors in the precision of distances measured by GPS. A research on this topic has been undertaken at the Royal Observatory.

A collaboration with the Royal Meteorological Institute has been established to study the ionospheric total electron content. Indeed, the measurements made by the ionosond of the Meteorological Institute in Dourbes can help to correct the ionospheric refraction effect on GPS data but on the other hand GPS measurements can also give important informations on the state of the ionosphere.

Since November 1993, the GPS station of Brussels is included in the IGS (International GPS Geodynamics System) network. This network is the successor of the TRANET network and partly has similar goals : to define global Earth fixed reference systems and to compute precise satellite ephemerides.

Brussels is used as a fixed point in the computation of the precise satellite ephemerides over Europe. The GPS data are automatically transferred to the CODE Processing Center in Bern on a daily basis.

At the moment, Belgium has not yet established a national geodetic network using the space techniques. This is the reason why the National Geographical Institute, the Royal Military Academy and the Royal Observatory of Belgium decided to realize a new geodetic network. In this project, the main role of the Royal Observatory is to connect the future national network to the international reference systems and to give support to the field measurements. In order to achieve these goals, 4 continuously operating GPS stations were installed in Belgium. These stations are located in Brussels, Dentergem, Dourbes and Wareme. In collaboration with the Belgian Geographical Institute and the Royal Military Academy, a first part of the Belgian geodetic network based on GPS will be accomplished during the spring 1994.

Considering the growing number of applications where GPS is used in the scientific research but also in the public domain, the Observatory is willing to provide permanent references and support for local geodetic applications by means of its four continuously operating GPS stations.

The Royal Observatory also plays a part in the prediction of the natural disasters by its participation in a european science project entitled : "Volcanic Deformation and Tidal Gravity Effects at Mount Etna". In this project one part of the work of the Observatory is to implement a geodetic GPS network on the Etna to monitor ground deformations on this volcano. The precisions obtained after the '92 and '93 surveys demonstrate clearly that GPS is a useful tool in the study of the Etna volcano. Indeed the precision reached in the measurement of the geomagnetic deformations in the Etna network is at the centimetre level.

3. EARTH ROTATION

Analysis of solar data (Wolf numbers, Corona index) and geophysical data (Earth rotation, atmospheric angular momentum) conducted to identify common oscillations with a period of 2.2 years (Djurovic et al., 1993).

The effects of a possible contribution of the solar wind on the Earth rotation has been estimated (Gu et al., 1993).

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IV. MATERIAL SCIENCES

A. MICROGRAVITY RESEARCH CENTER OF THE "UNIVERSITE LIBRE DE BRUXELLES"

1. THERMOVIBRATIONAL INSTABILITIES WITH THE SORET EFFECT

Thermovibrational instabilities, theoretically investigated by Gershuni (Perm, Russia) and experimentally by Putin and Kolesnikov (Perm, Russia), are now studied in collaboration regarding binary mixtures with the Soret effect. The experimental system is under development in Brussels.

2. INSTABILITIES IN A TWO LAYERS SYSTEMS

Oscillations were observed at the onset of convection between thermal and mechanical coupling conditions. These oscillations appear in particular systems with a given thickness ratio. They appear as progressive waves and disappear when the Rayleigh number increases, giving rise to a mechanical coupling.

3. MODULATION EFFECT IN ROLL TYPE CONVECTIVE PATTERN

The local compression of rolls, with distortion along axes and zig-zag/Eckhaus secondary waves instabilities are similar under gravity and non-gravity conditions as were critical exponents and correlation length which are non-significantly different. The study was applied to modulated hexagons in which case the difference between Rayleigh and Marangoni mechanisms are significant. This will be further investigated with an experiment on Marangoni convection as foreseen on board of Foton (1996).

4. BOILING UNDER MICROGRAVITY CONDITIONS

Under these particular conditions, the classical theory of boiling is not applicable because of the modification of the capillary length. At low level of microgravity, boiling is still existing showing a divergence between theoretical and experimental results. Phase change interacts with Rayleigh-Taylor instability and Marangoni effect. Considering gravity as

a variable, the relative importance of physical values changes, explicating partly boiling under microgravity conditions.

In addition, the Clausius-Clapeyron law has to be reconsidered when there is no thermodynamical equilibrium or when the interface is not flat or when an external force field is considered. This law has been replaced taking into account that, if during a phase change, the mass transfer from one phase to the other one is a chemical reaction, this mass flux is proportional to the affinity of the reaction which is characterized by the difference of chemical potential.

This study has to give basic explanations on the mass transfer phenomenon, existing under microgravity conditions, and for which the theoretical calculation is up to now based only on the Rayleigh-Taylor instability. It is shown that thermocapillary and phase-changing instabilities are completely hidden when the level of gravity increases.

In the frame of this study, a numerical simulation programme by finite elements, FIDAP, is used, to model the Marangoni convection around axysimetric bubbles, in contact with heating elements and under reduced gravity. It has been possible to show that the deformation of the bubble surface results from the convection. From a mathematical point of view, a phenomenological expression has been derived describing mass transfer through the liquid-vapour interface. Thus, the classical Clausius-Clapeyron formula is modified regarding the temperature of the interface, because of the non-equilibrium from a mechanical and thermodynamical point of view. During the phase change, the flat interface instability could generate vapour bubbles and thus nucleate boiling under microgravity. These theoretical results could contribute to the explanation of the studied phenomenon as presently observed under microgravity conditions.

5. AMPLITUDE EQUATIONS IN RAYLEIGH-MARANGONI-BENARD, IN BOXES WITH SMALL ASPECT RATIO

The calculation method of amplitude equation is extended to more complex problems as two-layers systems (like methanol-octane system) or three-layers systems. Theoretically, surface deformation and/or Soret effect could be included in the equation, because of the common symmetries of all these problems (translation in the layer plan, reflection and invariance by time translation). It could be possible to

elaborate a calculation programme. Presently, the programme calculates the form of the amplitude equation, but not the coefficient values of the different terms.

This could determine the kind of configuration (hexagons, rolls, travelling waves, etc.) that appears in those systems.

6. CAPILLARY CONVECTION IN A THREE-LAYERS SYSTEMS - PREPARATION OF THE MAXUS 2 LAUNCH

Three immiscible phases are submitted to a temperature gradient perpendicularly to the flat interface. The observation of the oscillation mechanism can be realized under microgravity conditions, if external phases are identical. The thermocapillary convection is oscillatory if the fluids have the same thermal diffusivity, for that reason, the methanol-octane system is selected. Linear perturbations analyses in a three-layer system with different thickness have been investigated taking into account the deformation of interfaces.

The Rayleigh-Benard instability dynamic in the FC70-silicone oil-air system has been studied by holographic interferometry. Globally, the numerical calculation is in accordance with the experimental results. Numerical simulations in an oscillatory three-layers system show travelling waves for periodic boundary conditions and for large aspect ratio. Unexpected combinations between travelling and standing waves appear.

7. DIRECTIONAL SOLIDIFICATION

The Soret effect as an oscillations source during directional solidification is studied, taking into account the difference of densities in the Gibbs-Thompson law. In this case the threshold of instability can be displaced under microgravity conditions. The linear stability of the problem is also investigated.

8. POTENTIAL BARRIERS AND OSCILLATORS

The role of the potential barrier on the mass transfer of a surface-active agent has been studied. The capillary waves due to surface deformation are well known but longitudinal waves exist also with high wavelenghts. This corresponds to 2 types of oscillators that could start to resonate.

9. INTERFACIAL TENSION MEASUREMENTS BY A LIQUID BRIDGE METHOD

A new technic of surface tension measurement between liquids with similar densities has been developed. New test weights have been constructed in order to obtain cylindrical bridges with water/butylbenzoate system.

10. SPACELAB D2 MISSION

The MBI experiment (Marangoni-Benard Instability) has been realized on May 2nd, 93 during the Spacelab D2 mission on board of the US spaceshuttle Columbia. The onset of Marangoni-Benard convection has been observed under steady state conditions and non steady state conditions.

Onset of convection under non steady state conditions has been determined visually, following the displacement of tracers mixed in the liquid, and thermally, by measurement of drop of temperature in liquid layers. Experimental values of the critical Marangoni number correspond to the predicted theoretical values.

The onset of convection under steady state conditions could not be determined because of a technical problem.

11. EURECA

The Soret Coefficient Measurement (SCM) on board of EuReCa 1 was a success. The detailed analysis of the results are presently under investigations.

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B. DEPARTMENT OF METALLURGY AND MATERIALS ENGINEERING OF THE "KATHOLIEKE UNIVERSITEIT LEUVEN"

The ongoing microgravity research in the Department of Metallurgy and Materials Engineering of the Katholieke Universiteit Leuven is concerned with particulate reinforced metal matrix composite materials. The main objective is to improve the properties of these materials as prepared by casting.

A problematic aspect of the preparation is the incorporation of the reinforcing particles in the metal melt. As the particles are often very poorly wetted by the liquid metal, considerable effort is needed to achieve incorporation. Moreover, the particle-metal interface tends to be contaminated by the surrounding atmosphere; this contamination has a negative influence on the resulting material properties. Another problem is the tendency of the particles to settle down in the melt due to buoyant motion and their tendency to cluster together into particle aggregates.

A possible solution to these problems is the generation of the particles in situ in the melt. Thus clean interfaces with the metal are obtained and the interface particle-metal is established in a handsome way. Currently, research is focused on aluminium-silicon-transition metal ternary alloy systems.

Efforts are also made to come to a more thorough understanding of the phenomena governing particle aggregation, by modelling of the material system behaviour and comparing the model outcome to reality. As a model system for the behaviour of inert particles in a liquid metal, the systems aluminium-alumina and aluminium-titaniumdiboride are currently studied.

Microgravity is a very helpful tool in this research, as it allows the study of material systems unstable on earth and as in several gravity driven phenomena, such as buoyant convection and setting of reinforcement particles, do not occur. Therefore, an experiment proposal was submitted to ESA for the Columbus Precursor Flights (Proposal 380), having as subject the behaviour of particles in a liquid aluminium melt, and their interaction with the solidification front. This proposal was accepted in a revised form for the EuroMIR 94 flight and is currently being prepared.

During the experiment, aluminium samples containing titanium diboride particles will be molten in the CSK-1 furnace of the MIR space station. After a short holding time, the samples will be directionally solidified. Upon returning to earth of the samples, the particle rearrangement will be assessed and compared with the particle arrangement in 1g reference samples and with the predictions made by models.

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V. LIFE SCIENCES

A. INSTITUTE FOR INTERDISCIPLINARY RESEARCH AND BIOMEDICAL PHYSICS LABORATORY OF THE "UNIVERSITE LIBRE DE BRUXELLES"

THE RESPIRATORY SYSTEM UNDER WEIGHTLESSNESS : PREPARATION OF ANTHROPRACK EXPERIMENT B-55 FOR MISSION D-2

The study of the respiratory system in microgravity was an important part of biomedical space research during the D-2 mission of Spacelab. Some of the experiments consisted of single and multiple inert gas washouts to study the ventilation distribution in microgravity. The single breath washout in its conventional form consists of an inspiration of O_2 , the N_2 concentration being recorded during the following expiration. We have shown that the role of gravity on the distribution of ventilation can be better studied by using a gas mixture containing a high diffusive (He) and a low diffusive gas (SF_6). The multibreath washout maneuver consists of 30 one liter breaths with a gas mixture containing O_2 with He and SF_6 as tracers. Most of our work was related to ground studies aimed at preparing the Anthrorack experiment B-55 for the mission D-2 which flew successfully in 1993.

1. EXPERIMENTS UNDER HYPERGRAVITY

The experiments were designed to extend to hypergravity our observations obtained during three campaigns of parabolic flights (Estenne et al., 1992). They were performed with the human centrifuge of DLR in Cologne (F.R.G.) and the main results are the following :

- 1) The temporal pattern of breathing is not altered in hypergravity.
- 2) There is a consistent positive relationship between g and the resting lung volume (FRC).
- 3) The change in FRC results primarily from a change in the abdominal compartment.
- 4) The abdominal contribution to tidal volume does not change significantly in hypergravity (we have previously shown that it increases substantially in μg).
- 5) There is a positive linear relationship between g and end expiratory gastric pressure.

- 6) The tidal change in gastric pressure tends to increase in hypergravity although it does not change in μg .

Previous results show that it is not possible to extrapolate to μg some of the observations made in the human centrifuge.

2. MEASUREMENT OF THE HUMAN DIAPHRAGM SHAPE IN VIVO

Our previous observations (confirmed by the preliminary analysis of the data from mission D-2) have shown that the pattern of breathing is dramatically modified during short periods of μg . Furthermore, the ribcage dimensions are also modified. Using pairs of magnetometers to measure changes in rib cage dimensions in five normal seated subjects during parabolic flights, we have found (Estenne et al., 1992) that microgravity was associated with a consistent motion of the sternum in the cranial direction and an increase in the anteroposterior diameter of the lower rib cage (measured at the level of the 5th intercostal space). In contrast, there was a systematic decrease in the transverse diameter of the lower rib cage, which therefore adopted a more circular shape in weightlessness. The increase in rib cage anteroposterior diameter in μg was anticipated. In the upright posture at 1 g gravitational loading of the abdomen produces a hydrostatic gradient of pressure that lengthens and stretches passively the ventral abdominal wall. Because the abdominal muscles insert on the sternum and the lower ribs, this passive tension is applied to the lower rib cage and acts to pull it downward. By removing the weight of the abdominal contents, transition to weightlessness removes the tension in the abdominal wall and transabdominal pressure becomes nearly zero. As a result, the sternum and the ribs move upward and the ventral rib cage expands.

It is more difficult to understand why the transverse diameter of the lower rib cage did not similarly increase in μg . In order to explain this paradoxical result we measured, for the first time, the shape of the diaphragm in vivo, using magnetic resonance imaging (Paiva et al., 1992). The more likely explanation is that the transverse diameter of the lower rib cage is primarily driven by transabdominal pressure. To the extent that the transverse diameter was measured in the abdomen apposed portion of the rib cage (Estenne et al., 1992), its dimension at end-expiration should be primarily influenced by transabdominal rather than transthoracic pressure. The

observation that the former consistently decreased on going from 1 to μg might thus account for the response of the transverse diameter. The much smaller length of diaphragm apposed to the ventral as compared to the lateral aspects of the rib cage (Paiva et al., 1992) presumably explains why the fall in transabdominal pressure did not act to decrease the anteroposterior diameter.

3. COMPUTER MODEL SIMULATIONS

Single breath and multibreath washouts were performed in rats where we expect a negligible effect of gravity due to small dimensions of their lungs. Using a Cray supercomputer and based on the detailed anatomical data of the rat lungs, we could simulate accurately the experimental observations (Verbanck et al., 1993). The same computer model, based on human lung anatomy, will be used for the interpretation of the same experiments performed in men during mission D-2.

4. CLINICAL APPLICATIONS

The techniques developed for our research on the respiratory system in microgravity lead to several clinical applications. Two of them have been actively pursued.

4.1. Diagnostic of small airway diseases

He-SF₆ single breath washouts were performed in rats with elastase-induced emphysema. The alterations in the lung structure were quantitatively assessed and it was demonstrated that the HE-SF₆ slope difference was not related to structural alterations in the alveolar zone of the lung (Gonzalez-Mangado et al., 1993). In a second study, the same tests were performed in 27 men who underwent a lobectomy for peripheral bronchial carcinoma. A significant correlation was obtained between an index derived from the He-SF₆ single breath washout and the structure of small airways, opening the way for the early diagnostic of small airway diseases (Van Muylem et al., 1992).

4.2. Sudden infant death syndroms

A more efficient detection at home of obstructive apnea, leading to sudden infant death, may become a spinoff from the respiratory instrument RIP (Respiratory Inductive Plethysmograph) built for our respiratory experiments on

mission D-2. Several prototypes are presently under development.

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B. SPACE PHYSIOLOGY LABORATORY OF THE "RIJKSUNIVERSITAIR CENTRUM ANTWERPEN"

1. BRAIN ACTIVITY IN MICROGRAVITY

The waking electroencephalogram (EEG) was recorded during parabolic flights in trained astronauts and non trained volunteers as well. The campaigns were held at the Centre d'Essais en Vol (CEV) in Bretigny (France).

The data were collected with portable Medilog-recorders in 5 subjects, some of them having been recorded several times, and analyzed with two different methods :

- 1) The fast Fourier Transform (FFT). A comparison between the mean values of the power in the different EEG frequency bands, measured with this method as a function of various g-levels did not evidence significant correlations. The data suggest that changes did occur but that the FFT-techniques do not allow to measure them with precision. However they allowed to evidence more asymetry between the two brain hemispheres in the non trained volunteers than in the trained astronauts in any g-situation;
- 2) The method of attractor reconstruction which allowed to discriminate between the signal and noise components in the EEG and to assess whether the EEG evolved from one kind of behavior to another as a function of different gravity situations.

The method of attractor reconstruction is derived from research on chaotic dynamical systems. The chief merit of this method is to discriminate between the deterministic and the random nature of the neuroal system activity. By sampling the EEG readings several times a second, one is able to quantify the degree of chaos in the brain as a function of g during the parabolas and over several consecutive days of flights. The dimension (d) of an attractor gives a lower bound on the number of state variables needed to describe the dynamics of the system. When the dimensionality of the brain's pattern of activity is high, it is more chaotic. The correlation dimension can be found directly due to Grassberger and Procaccia, (Phys. Rev. Letters, 50, 346, 1983) and can be obtained using the correlation $C(r)$. It is the slope of a log-log plot of $C(r)$ versus r . The non-vanishing of $C(r)$ measures the extent to

which the presence of the data point x affects the position of the other points. The saturation value d is regarded as the dimensionality of the attractor represented by the time series. Babloyants et al. used this procedure with the EEG patterns during the different stages of sleep (Babloyants, A., Salazar, J.M. and Nicolis, C., Evidence of chaotic dynamics of brain activity during the sleep cycle, Phys. Letters, 111A, 3, 1985).

With the same method, an effect of the parabolic flights was detected on the EEG's which were recorded from trained astronauts and non trained volunteers as well. The changes which appeared in the dimensionalities d of the chaotic attractors for different g -values varied however from one parabola to another within one individual.

However, in the trained astronaut the d values tended to decrease over the days of flight. The changes of d as a function of g were small and variable though some increase appeared at zero- g . Over the 3 days of the campaign with this subject, the values of d on the first day of the flights were higher than on day 2 and they in turn were still higher than on day 3.

In the non trained subjects, the EEG's of whom were recorded during one day of flight only, the dimensionalities d were as low on their first day as in the trained subject on his third day.

The method of discriminating between deterministic chaos and randomness in the EEG signals, which uses only small data sets, looks promising. It provides a quantitative means of following in time the brain activity of a space traveller. Technically, such an EEG analysis strains the computer resources but it meets the need to obtain quantitative data on the brain system of astronauts working and sleeping in space. In general, the application of this method may allow interpretation of a gamut of behavioral states that might range from quiet wakefulness and to the extreme focusing of attention. In space it would allow the evaluation of "fatigue" and its corollary decrease in attention.

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VI. REMOTE SENSING

A. LABORATORY FOR REMOTE SENSING AND FOREST MANAGEMENT OF THE UNIVERSITY OF GENT

1. AGROFORESTRY RESEARCH, XHISHUANGBANNA RESERVE, CHINA (WWF 3194)

Period : 1991-1992

Partners : WWF International (Asia and Pacific Programme), the Southwest Forest College in Kunming, P.R. of China.

In this project maps were prepared showing erosion risks in selected areas of Xishuangbanna using aerial photography and GIS. The results helped in determining the establishment of agroforestry pilot projects in badly eroded zones in the nature reserve.

2. TREES PHASE 1

Period : 1 February 1991 - 31 July 1992

Partner : JRC, EC, Ispra, Italy

Detailed forest maps of Southern China and Indochina were prepared based on high resolution satellite data. These were used by the JRC for validation and calibration of the results from NOAA AVHRR imagery analysis.

3. REGIONAL INVENTORY IN THE EUROPEAN PROGRAMME MONITORING AGRICULTURE BY REMOTE SENSING - MARS

Period : 1 April 1992 - 31 December 1992

Partner : JRC, EC, Ispra, Italy; Ministry of Agriculture, Belgium; Belgian Science Policy Office; SURFACES Laboratory of the University of Liège.

Statistics on general land use and crop acreages have been produced for 1992 for Belgium using a stratified approach and based on a 1% sampling field survey and remote sensing data. In total 21 satellite images, all multispectral SPOT, have been processed.

Maps on agricultural land use in 1992 for Belgium have been produced from the classified satellite images at a scale of 1/300000 and 1/100000.

4. INVENTORY AND MODELLING OF MANAGEMENT OF WOODY VEGETATION IN A FORESTED ZONE IN SOUTHERN SENEGAL (B7-5040/91/041)

Period : 1 May 1992 - 31 October 1993

Partners : EC, Laboratory of Tropical Agriculture and Ethnobotany, University of Gent

SPOT data recorded at the end of the rainy season were used to map the natural vegetation in the Moyenne Casamance. Field data were collected with a GPS system. The results were used in a GIS database to assist in preparation of a management plan for the natural vegetation of the area. Time series analysis allows to assess the effect of seasonal burning on the vegetation.

5. REMOTE SENSING MONITORING OF NATURAL HABITATS IN PROTECTED AREAS IN VIETNAM (WWF VN 0007)

Period : 1991-1993

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

This project features the preparation of detailed vegetation maps of protected areas in Vietnam using high resolution imagery. The reserves of Tam Dao, Nam Cat Tien and Muong Nhe have already been surveyed for this purpose. Forest classification and GIS modelling is expected to facilitate the preparation of management plans for the protected areas of Vietnam. In addition an image processing lab (featuring a fast 80486 PC, HP Paintjet XL printer and ILWIS software) has been installed in early 1993. Training courses in Gent (1992) and Hanoi (1993) for forestry officers of the Vietnamese Ministry of Forestry (Forest Inventory and Planning Institute) have been conducted.

6. FOREST MONITORING BY SATELLITE AND INTEGRATED WATERSHED MANAGEMENT IN COSTA RICA

Period : 1 January 1993 - 31 December 1996

Partners : EC, Universidad Nacional Autonoma at Heredia

The purposes of the project with a duration of four years are fourfold :

1. To collect all the information necessary to establish a database suitable for monitoring and resource management, for a pilot zone composed of a large watershed and national park;
2. To use the assembled data set in a monitoring and an integrated management system, both aimed (and developed) at the regional/local level (practically) as well as the national/regional level (methodologically);
3. To enhance the formation of experts in resource management at the PRMVS of the Universidad Nacional Autonoma of Costa Rica, a program with international emanation;
4. To contribute in the development of the operational phase of mapping, monitoring and management of the natural resources in Costa Rica.

7. THE ESTABLISHMENT OF THE POLISH PINE FOREST MONITORING DATABASE : PILOT STUDY

Period : 1 January 1993 - 31 December 1994

Partners : Belgian Science Policy, Polish State Committee for Science (KBN)

The proposed project consists of on-site assistance in

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

8. 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 Science Policy Office, Ministry of Agriculture, Catholic University of Leuven

The aim of the project is to optimize the use of Remote Sensing for the building 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).

1. Definition of the architecture of the databank;
2. Optimisation of data acquisition at producer's level;
3. Set-up of a sample survey;
4. Automation of the control of field boundaries;
5. Objectification and automatisisation of the crop control;
6. Development of a decision system.

9. FEASIBILITY STUDY : THE USE OF SATELLITE IMAGES IN THE STUDY OF WILDLIFE IN AND AROUND NATIONAL PARKS IN SOUTHERN AFRICA (T2/XX/601)

Period : 1 October 1992 - 1 March 1993

Partners : Belgian Science Policy Office; Catholic University of Leuven.

The main objective of this study is to evaluate use of satellite imagery (Landsat TM and SPOT XS) to recognize and map relevant vegetation units in a limited time period, determine their spatial distribution, and detect changes in a test zone in the Chobe district, Northern Botswana.

This study was executed in the framework of nature conservation in the area in which the relation between the ecological parameters (vegetation and their spatial distribution) on the one hand, and the behaviour of the African Elephant (*Loxodonta africana*) is investigated.

10. FEASIBILITY STUDY : MONITORING OF THE WINTERING HABITAT OF MIGRATORY BIRDS IN THE FLEMISH POLDERS USING SATELLITE IMAGERY : FEASIBILITY AND COST EVALUATION (T2/XX/605)

Period : 1 October 1992 - 31 December 1992

Partners : Belgian Science Policy Office; Institute of Nature Conservation, Hasselt

The general objectives of the feasibility study included the location and quantification of changes in surface of grassland areas in the Flemish Polders in the recent past. Based on the developed techniques a system for permanent monitoring was proposed to interact in an efficient way with further changes of the wintering habitat of migratory birds.

The specific objectives included mapping of the actual extent of grasslands, change detection and monitoring procedures.

The data were processed in a GIS environment.

11. MONITORING AND MANAGEMENT OF TROPICAL FORESTS USING SPATIAL INFORMATION TECHNIQUES (TELSAT III/02/005)

Period : 1 May 1993 - 31 April 1995

Partners : Belgian Science Policy Office; FAO

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 need detailed examination.

The proposed project will make use of the information and liaisons built up in the three international operational projects (Forest Resources Assessment 1990, 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 tests sites are collected and interpreted.

The objectives of the project are :

1. to evaluate and enhance the standard methodology used in FRA 1990 and to orient the techniques more towards GIS; to validate the methodology in use in TREES on the relation between patterns and evolution in deforestation in Central Africa; to monitor the forest regeneration by satellite;
2. 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;
3. to elaborate models for the sustainable management of the forests in relation to the change in biodiversity in nature reserves established in Central Africa.

12. LAND DEGRADATION IN THE DRY TROPICS (TELSAT III/02/007)

Period : 1 May 1993 - 31 April 1995

Partners : Belgian Science Policy Office; FAO

The current project is aimed at following points :

1. The development of an operational monitoring concept of land degradation in the dry tropics on different scales, based on different sensors (NOAA-AVHRR, Landsat TM, Landsat MSS and SPOT XS).

On a regional scale broad vegetation units will be distinguished by means of NOAA-AVHRR time series and, if possible, their degradation status will be assessed. In the dry tropics, the seasonality will be incorporated as a main factor in the classification procedure. High resolution imagery (Landsat TM/MSS and SPOT XS) will be used for calibration and validation of the low resolution data. In this way, knowledge will be gained about the spatial distribution of the main vegetation types and their temporal evolution on a regional scale.

2. Regional modelling of woody biomass in the dry tropics. In a first step, baseline data will be assembled regarding information on stand wood volume from existing inventories. Other information layers required for the modelling will be incorporated in a GIS. The actual vegetation map will be compiled using NOAA-AVHRR data. In addition, a relation between woody volume and total biomass for each of the broad forest types defined in the forest should be established. Finally, these data will be integrated in a socio-economic model.

13. ERS-1 FOR MONITORING OF FOREST RESERVES IN COSTA RICA (TELSAT III/02/016)

Period : 1 October 1993 - 31 September 1994

Partners : Belgian Science Policy Office; FAO

The current project is closely collaborating with the ongoing EC project "Forest monitoring by satellite and integrated watershed management in Costa Rica" and will be aimed at following points :

1. Detection of forest perturbations using ERS-1 radar data in relation with the surface, form and intensity of the perturbation. As a large area of the humid tropics is very often covered by a dense cloud cover, cloudfree optical images such as SPOT and LANDSAT are often scarce or even non-existent. For those regions radar images can offer a solution.
2. As ERS-1 images are taken sideways looking, they are sensitive for distortion by relief. A study of the influence of relief and view angle on the precision of monitoring (using data of ascending and descending orbits) will therefore be executed.
3. Study of radar image enhancements techniques, texture classification and radar specific geometric correction. As radar is sensitive to physical parameters, rather than spectral characteristics with optical images, field work will be carried out to trace possible parameters.
4. Determination of the necessary periodicity in data acquisition in relation to monitoring.

**14. FEASIBILITY STUDY :INTRODUCTION AND DEMONSTRATION PACKAGE:
SATELLITE IMAGES AS INFORMATION SOURCE FOR SPATIAL MANAGE-
MENT (T3/XX/601)**

Period : 1 January 1994 - 28 February 1994

Partners : Belgian Science Policy Office; SURFACES Laboratory of the University of Liège

The main objectives of the feasibility study are :

1. To make an overview of existing introduction- and demonstration packages;
2. To list possible applications of satellite images and to analyse their priority/relevance;
3. To evaluate the possible forms of the introduction- and demonstration package (video, CD-ROM, computerprogram), including cost price and distribution possibilities;
4. To investigate the need for such an introduction- and demonstration package;
5. To give an overview of the updating possibilities for the different forms;
6. To make a cost-benefit analysis for the different alternatives and to look for potential partners for the production/distribution of the package;
7. To elaborate a detailed plan for the realisation of the most suitable type of package.

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B. LABORATORY FOR GEOLOGICAL REMOTE SENSING AND INFORMATION MANAGEMENT OF THE ROYAL MUSEUM FOR CENTRAL AFRICA

1. THE GEOREFLECTANCE PROGRAM : DETERMINATION OF LITHOLOGY AND MINERALISATIONS

Because of its intrinsic crystallo-chemical origin and hence its geological significance, the spectral signature of remotely sensed geological objects is likely to allow the characterization and the mapping of the sedimentary, metamorphic and igneous rocks and as well as mineralized plots, in areas where these objects are fairly well exposed. In poorly exposed areas, the spectral properties of superficial materials and the landscape forms are likely to be in relationship with the underlying rocks.

Taking the former statements as a working hypothesis, a methodology has been developed for the recognition of lithologies and mineralisations in a variety of climatic zones and geologic environments, based on presently available satellite-borne sensors (i.e. Landsat TM for spectral data completed with Spot P when more spatial information is required).

In desertic areas displaying varnish-free outcrops, digital data are used after calibration in reflectance; lithologies are identified by comparison with high resolution spectral measurements obtained in the field or in the laboratory. When the desertic patina is important, derived data enhancing spectral properties are used, taking advantage of the transopaque behaviour of the varnish.

In tropical areas, either cultivated or not, where vegetation conceals the mineral information, data calibrated in reflectance concerning mineral objects are deconvolved for the amount of shade and vegetation present, using the spectral properties of the latter objects, in an unmixing procedure based on linear algebra. When spectral information is not available, statistical results can be employed instead.

The application of this methodology results in thematic images enhancing geological information, most time devoid of the disturbances due to the atmosphere, vegetation and/or anthropic effects.

Beside these targets, subsidiary programs have been developed, including

- the creation of a database of spectral information (with ancillary crystallo-chemical data);
- the evaluation of internal and external factors affecting the spectral properties;
- the correction of general as well as local atmospheric disturbances;
- the calibration in reflectance of satellite data;
- a deconvolution algorithm for spectral data.

The application and training regions encompassed during this study comprise the (Co-Cu)-mineralized metasedimentary and volcanic Bou-Azzer (Morocco), the subvolcanic stock of Jabal al'Awaynat (Lybia), the metamorphic area of Air (Niger), the sedimentary and sand-covered area of Damagaram-Mounio (Niger), the sedimentary basin infill area of Rwindi-Rutshuru (Zaire) and the metasedimentary areas of Kayanza (Burundi) and Kibuye (Rwanda).

2. GEOMORHOLOGY OF EASTERN ITURI (NORTH EASTERN ZAIRE). MORPHOLOGICAL AND STRUCTURAL ANALYSIS OF THE EFFECTS OF A REACTIVATION OF THE WESTERN DRIFT

The following aspects have been investigated during this multidisciplinary study :

- the morphostructural context, derived from the analysis of satellite imagery (Landsat MSS and TM imagery) completed by the analysis of topographical maps (comprising for instance a digital analysis of the river network). This analysis has yielded a structural map displaying the dynamics of the fracturing pattern and its effects on the location of the erosion surfaces and its consequences for the river network. Geochronological (K/Ar) investigations subsidiary to this part of the work, devoted to doleritic dykes formerly associated to the development of the Rift, have yielded a Precambrian age for the analysed dykes.
- the morphological context and the superficial deposits, as resulting from field work devoted to the different erosion surfaces and the associated deposits (i.e. mainly laterites), which concluded at the non-existence of criteria allowing to link the nature of the deposits to a definite surface.

- the paleoclimatic context, established on the base of an analysis of landforms, of sedimentary processes in disequilibrium with the present day climate as well as palynological indications, resulting in an overview of the climatic conditions going down to the Upper Pleistocene.

3. THE CONTRIBUTION OF MULTISPECTRAL AND MULTITEMPORAL REMOTE SENSING TO THE STUDY OF DESERTIFICATION IN THE DAMAGARAM-MOUNIO (SOUTHERN NIGER)

The methodology developed in this work was included in the TELSAT II-11 program of SPSS (Science Policy Office of Belgium) and is integrated into the second phase of a general multidisciplinary program of AUPELF (Association des Universités entièrement ou partiellement de langue française) called : "Evolution de la désertification dans le Sud du Niger (Zinder) pendant la Pléistocène supérieur et l'Holocène ainsi que les tendances actuelles : l'apport de la télédétection".

A field campaign including high resolution spectral measurements has been organized in January 1992. The spectral properties of the most important components of the landscape have been determined in connection with the evolution of desertification : altered surfaces of granitic and metamorphic rocks of the basement, red sand of fixed dunes, beige and white sands, lateritic soils and crusts, water, organic matter and different types of vegetation.

The measured spectral signatures have been used for calibration purposes, and compared to the calibrated satellite data in order to define spectral endmembers to be introduced in image processing (spectral unmixing).

- Four sets of data were available :
 - Landsat MSS of March 11, 1973
 - Landsat MSS of January 10, 1976
 - Landsat TM of January 4, 1987
 - Spot XS of November 22, 1987

Due to its better spatial resolution (20m x 20m), the Spot imagery was used for location on the field. After geometric coregistration, each set of Landsat image data was calibrated from raw radiance values to reflectances, including an atmospheric correction and the calibration related to the specific characteristics of the sensors.

Since important differences in the quantitative spectral reflectances were present for reference targets between field, MSS and TM (due to approximations in the characterization of atmospheric conditions and instrumental differences), a further relative calibration step (by histogram matching) was necessary.

Images of the variations of the elements of the landscape in time were then produced with several methods : principal components analysis, vegetation indexes, and spectral unmixing models. The interpretation of all these images of "change detection" give the following results :

- there is no dramatic change in the global proportions and distribution of the elements of the landscape (rock outcrops, laterites, sands of transversal and longitudinal dunes, water, vegetation) between 1973, 1976 and 1987.
- local variations are clearly detected, such as the gradual extension of white sand in a small river delta, the decay of vegetation in a valley after 1976, and the progressive extension of villages.

The comparison with archive data (climatic, historic, air photos) before 1973 confirms that the main changes occurred before 1973.

4. LITHOLOGIC MAPPING WITH LANDSAT THEMATIC MAPPER GUIDED BY LABORATORY SPECTRAL MEASUREMENTS, AIR, NIGER (AFRICA)

The identification of different lithologies in the Air massif from satellite data is based on the knowledge of the spectral signatures from minerals and rocks collected during several field surveys. This spectral study is thus performed by a deterministic type of image processing.

High resolution spectral reflectance signatures of these samples have been measured and interpreted in the laboratory. The link with the remotely sensed data is established through a calibration procedure, using the 5S atmospheric correction model.

After calibrating TM data to reflectance factors, a ratio technique has been adopted in order to minimize the effects of topography. Colour composites of various ratio combinations of TM bands (5/7, 5/1, (3+5)/4), are displayed and interpreted to emphasize the spectral features related to hydroxyl or

carbonate band absorptions and to the presence of ferrous and ferric ions.

5. TARGETING COBALT MINERALIZATION BY REMOTE SENSING IN THE DISTRICT OF BOU-AZZER EL GRAARA (MOROCCO)

The tectonic/erosional window known as the Bou-Azzer El Graara buttonhole is situated in the semi arid area of the central Anti Atlas of Morocco. It displays Precambrian series overlaying an ophiolitic complex (peridotites, ultramafic cumulates, quartz diorites, gabbros and lavas). Vein type hydrothermal deposits of Cobalt Arsenides are found in a well defined lithologic (at the vicinity of serpentinized ultramafic bodies) and structural (controlled by the fault pattern) context.

The spectral signatures of the serpentinites and their surrounding rocks were measured in the field (with their coating or varnish) and in the laboratory, with a GER IRIS MARK V spectroradiometer. The absorption features related to vibrational or electronic processes were analysed in terms of mineralogy, and used as a guide for remote sensing data processing (LANDSAT Thematic Mapper, SPOT), after correction for the atmospheric effects. Several image processing techniques were applied including spectral unmixing based on end-members derived from the measured reflectance properties or from the images, in order to delineate the lithologic boundaries and to identify local variations of composition of the main rock types. The surface expression of faults was enhanced by spatial filtering. These lithological and structural informations were combined to produce a map of potentially mineralized sites.

The results were cross checked with existing data (geological maps, known mineralizations, field surveys) and new targets were selected for detailed exploration.

6. THE WORLD MAP OF ACTIVE FAULTS IN A GIS ENVIRONMENT

The objective of the project is to gather (all) the available data concerning evidences of recent tectonic activity in Southern and Central Africa, in order to assess the potential geological hazards in these areas. A specific objective of the Department is to stimulate on-going research in neotectonics in that part of the world by providing a

compilation of (most of the) available public-domain information on this topic.

The large amounts of data to be processed, and their lack in homogeneity, imposed the use of a GIS to store the information and to integrate it in standard formats. This GIS was then used as a multisource database, both for the edition of a range of maps for the ILP Special Working Group and for in-house research on Central and Eastern Africa.

The database was constructed on a SPANS v5.2 and -v4.3 GIS (TYDAC), which operates both on an IBM RS6000 workstation and on an IBM PS2/80. The following broad geological topics were entered into the base :

- Topographic background, political boundaries, ...;
- Geological maps : limits, units, features suggesting recent tectonic activity (landslides, Quaternary volcanic and (hydro)thermal activity, faults..);
- Structural geology : coming from fieldwork, maps, satellite and airborne imagery interpretations, ...;
- Geophysics : epicentres, seismic profiling interpretations, heat-flow measurements, thickness of the lithosphere, gravimetric surveys and airborne magnetic and radiometric surveys;
- Remote sensing : satellite imagery.

Different examples of the benefits of this GIS will be discussed and illustrated with applications on the Tanganyika-Ruka-Malawi rift branch in Eastern Africa.

The GIS allowed us to evaluate the existing, very heterogeneous, cartographic information in a common geographic reference. It also enabled to compare different regional structural interpretations based on the same original data (subset), helping us to propose a new, more valid synthesis using the whole available dataset in the GIS.

Moreover, a GIS environment allows direct incorporation of Lat-Long positioned geological information (GPS or other navigation system), without having to digitise "the traditional interface of in-the-field localisation tool"; the latter consisting in positioning the data on a topographic map or air photographs. Appending them to the GIS database, such new data, collected during recent fieldwork by the Department's geologists in Central and Eastern Africa, allowed an easier and

faster update of our geological and structural knowledge of these areas. However, in places where the existing information in the GIS does not allow a valid synthesis, (new) research programs can be stimulated by providing to the research community, for use in the field, correctly georeferenced documents stating the problems.

7. THE GARS-TRANSFER PROGRAM

7.1. Aims

Transfer of knowledge and technology in the field of geological remote sensing towards developing countries.

7.2. 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.

7.3. 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 mineralization associated to shear zones.

8. PUBLICATIONS

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C. LABORATORY FOR REMOTE SENSING AND REGIONAL ANALYSIS OF THE "UNIVERSITE CATHOLIQUE DE LOUVAIN"

The Laboratory for remote sensing and regional analyses of the "Université Catholique de Louvain" comprises 16 members on a multidisciplinary base : geographers, agronomists, historians, informaticians. Its activities are spatial organization studies by means of Remote Sensing Techniques (space borne and airborne data) and Geographical Information System, especially in the tropical realm.

The equipment used consists of :

- GPS and aerial photography equipment (Hasselblad, video HI8);
- laboratory for color photography processing;
- A4 scanner, video frame grabber, digitizing tablet;
- softwares IIS/S600(M75/uVAXII), ERDAS and ILWIS (PC486), ERDAS (SUN), IDL (SUN), IDRISI (PC486);
- cartography, G.I.S. and imaging systems INTERGRAPH (stations 6280 and 2020);
- bulk processing on IBM 3090/VEC (VM370/XA), Multiflow Trace 14/300;
- outline mass storage : 9 tracks reel to reel streamer (6250 and 1600 bpi), EXABYTE 8 mm tape, Optic disk 1Gb;
- color thermal proofing Versatec A3.

The Laboratory participates in many national and international projects :

- analysis of the processes of desertification around the great Sahelian towns (ECC Project on Sahel);
- improvement of agricultural surveys in Zaïre;
- analysis and modelling of the agrarian systems in Burkina Faso, Guinea, Senegal, Zaïre (National Project of the Ministry of Science Policy) and in the Dominican Republic;
- follow up and analysis of deforestation in Equatorial Africa (SPPS-FAO and WWF-NASA);
- study and estimation of the urban population in less developing countries (SPPS).

1. STUDY OF AGRARIAN SYSTEMS AND IMPROVEMENT OF THE AGRICULTURAL STATISTICS IN WESTERN AND CENTRAL AFRICA

An analysis and characterization of the agro-pastoral systems facing environmental degradation has been performed. Regions of interest have been identified in Burkina Faso, Guinea, Senegal and Zaïre.

For Guinea, satellite data and auxiliary cartographic or statistical data are integrated in a geographical information system in order to propose a spatial segmentation method of homogeneous agro-pastoral systems. Such a segmentation can allow to minimise the costs of the ground survey (stratification). First, the research has tried to define the relevant variables and their measure. Afterwards, numerical and analogical methods of spatial segmentation, with or without satellite data, have been compared.

In the context of the follow up of agriculture in Senegal and in Zaïre, new spatial sampling methods have been applied. These methods based on the theory of regionalized variables (geostatistics) increase the sampling performance and improve the estimation accuracy. They allow an easy integration of different analysis scales (satellite data, aerial photographs, ground survey) and the optimal spatial interpolation of the variables. The methods developed have been compared with the classical methods during an operational feasibility study in Senegal.

Since 1990, the Walloon Region has funded a research-development project in Burkina Faso. Originally based on the elaboration of methods to "characterize the agricultural areas by remote sensing", the project takes place now in the scope of the research on agrarian systems and on the population-resources relationship. The particularities of the project are twofold. First, the methods of estimation of natural and food resources use the concept of landscape facet and rely upon processing of digital terrain model. Secondly, the methods of characterization and estimation of rural population rely upon the study of settlement patterns by remote sensing.

Recently, a new project was set up about the identification and the characterization of agrarian systems in Central Africa (Cameroon and Congo). Its particularity is to try to understand the interface between the agrarian systems and the evolution of the forest.

In the same field the Laboratory has continued research work on the zairian deforestation in order to identify their local factors. This last research is carried out in the context of the Biodiversity Support Program and funded by the WWF-US.

Agricultural evolution in the Dominican Republic is studied. The research is focused on the analysis of the agrarian system's dynamic in a dual economy. It tries to emphasize the adaptive strategies concerning land use and its relationship with the population growth.

2. URBAN GROWTH IN TROPICAL AND SUBTROPICAL REGIONS

Urban studies have been performed on towns like Kinshasa, Lubumbashi, Bamako,.... Apart from the usual applications of remote sensing data to urban management (landcover maps, modelization of the urban structure, ...), the emphasis has been laid on the urban population evaluation. The method is currently developed on Marrakech (Morocco) and Ouagadougou (Burkina Faso).

3. WOODY BIOMASS ESTIMATION AND ANALYSIS OF THE DEFORESTATION PROCESSUS IN SUDANO-SAHELIAN REGIONS

More than six years ago the Laboratory began studies on the woody biomass in Mali (Bamaka region) and in Burkina Faso (Bobo-Dioulasso region). The goal is to perfect an operational method to estimate the woody biomass by using remote sensing. The method uses satellite data in association with aerial photographs and ground collected data, and has allowed to estimate the impact of firewood collection and uncontrolled agricultural clearings on desertification in the Sahelian region. This research funded by the E.C.C. (DG VIII), was carried out in collaboration with the malian and burkinate authorities.

The assessed method was applied to estimate palmtree densities in Nigeria. In the same context, a quick method to follow up and evaluate the impact of bushfires on woody biomass was elaborated. With its low cost and easy implementation, this method meets many of the needs of Western Africa.

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D. LABORATORY FOR TELECOMMUNICATION AND REMOTE SENSING OF THE "UNIVERSITE CATHOLIQUE DE LOUVAIN"

Research is conducted at UCL-Telecommunication and Remote Sensing Laboratory (Electrical Engineering Department) in the field of remote sensing of the earth surface by space-borne microwave instruments : radiometers, radar altimeters and scatterometers, polarimetric radars, synthetic aperture radars (SAR). Microwave signals are known to have the large advantage of a low attenuation by the atmosphere and therefore present the attractive potential of allowing all-weather observation capabilities. Their main drawback as compared to measurements in the visible and infrared frequency ranges, is their poor ground resolution, related to the longer wavelengths involved. However the advanced technique of the SAR has provided a way around this and such instruments appear as being among the most promising for future space missions.

Our work is centered on basic questions related to the scattering of electromagnetic waves by the Earth's surface and their propagating properties through the intervening atmosphere, and to the inversion of microwave measurements, such as brightness temperatures obtained by radiometers, or scattering coefficients obtained by radars, in terms of physical quantities in the atmosphere and on the ground.

One major topic is the modeling of the sea surface, from the point of view of its hydrodynamical and electromagnetic behaviour. Models and algorithms have been developed that can simulate the response of a microwave payload, comprising various instruments that allow the retrieval of geophysical parameters as the surface wind speed, the atmospheric water vapor and cloud liquid water contents. In 1992-1993 this effort focused on the corrections that have to be introduced in the radiative transfer equation. It has been also extended towards the detection of rain from space by using radars. The perturbation by rain has been also addressed.

A second important topic deals with the observation of land surfaces covered or not by vegetation. Electromagnetic modelling along with data analysis of SAR images in both polarimetric and non-polarimetric modes has been performed. This included measurements analysis from campaigns across the world (ESA-Maestro). In 1992-1993 a particular effort has been

directed to polarimetric characterization of vegetation, especially targets like forests.

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