ISSN 0772-9804

NATIONAAL COMITE VOOR RUIMTEONDERZOEK

SPACE SCIENCES

IN

BELGIUM

COMITE NATIONAL DE RECHERCHES SPATIALES

I INTRODUCTION

I. INTRODUCTION

The National Committee on Space Research (NCSR) of the "Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique" and the "Koninklijke Academie voor Wetenschappen, Letteren en Schone Kunsten van Belgie" is the Belgian interlocutor with the Committee on Space Research (COSPAR) of the International Council of Scientific Unions (ICSU). Through this committee the Belgian scientific community is represented within COSPAR. The concept of space sciences expressed in this document is therefore the same as that of COSPAR, namely the sciences using the space technologies employed on board space probes, artificial satellites, sounding rockets and stratospheric balloons. Their multidisciplinary aspect is particularly extensive for most of the unions within ICSU are represented in COSPAR; i.e. :

- the International Astronomical Union;
- the International Union of Biochemistry
- the International Union of Biological Sciences
- the International Union of Crystallography
- the International Union of Geodesy and Geophysics
- the International Union of Geological Sciences
- the International Mathematical Union
- the International Union of Physiological Sciences
- the International Union for Pure & Applied Chemistry
- the International Union of Pure & Applied Physics
- the International Union of Theoretical & Applied Mechanics
- the International Union of Radio Science

Owing to the absence of a national space programme in Belgium as it exists in other European countries where the scientific and technical infrastructures are coordinated (for instance by the Centre National d'Etudes Spatiales in France or the Deutsche Forschung Vereinigung für Luft und Raumfahrt in the Federal Republic of Germany), the NCSR wants to reinforce its cohesion for various purposes. It is a matter of

- making the national scientific potential more popular in Belgium and abroad,

- promoting, according to their own wishes, closer contacts with the national space industries which have developed for the scientists potentially useful infrastructures and which, in addition, can profit by their creativity,

- supporting, at their own request, the Belgian authorities being representative at the European Space Agency through which the industry is involved in the use of space technologies.

This document gathers the contributions of the six sub-committees of the NCSR :

- the sub-committee of External Geophysics
- the sub-committee of Space Astronomy
- the sub-committee of Space Geodesy
- the sub-committee of Materials Sciences
- the sub-committee of Biomedical Sciences
- the sub-committee for Remote Sensing.

The idea of these contributions is to expose the results of the researches during the last few years, the work being investigated for the moment as well as the perspectives.

December 1986.

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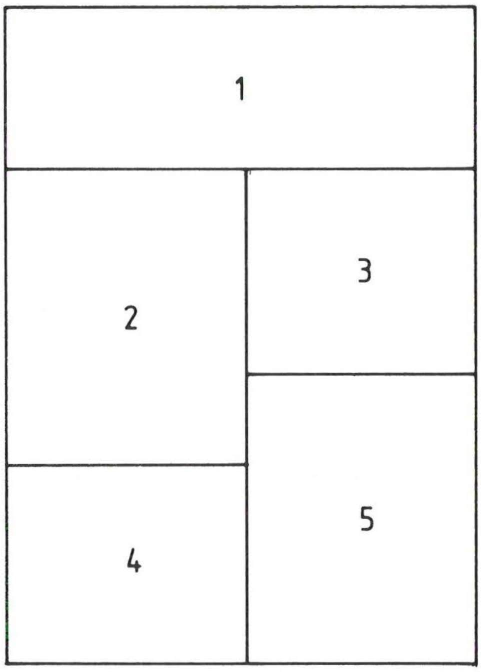
Acronyms

BISA : Belgian Institute for Space Aeronomy
KUL : Katholieke Universiteit Leuven
RUG : Rijksuniversiteit Gent
UIA : Universitaire Instelling Antwerpen
ULB : Université Libre de Bruxelles
ULg : Université de Liège
VUB : Vrije Universiteit Brussel

II EXTERNAL GEOPHYSICS



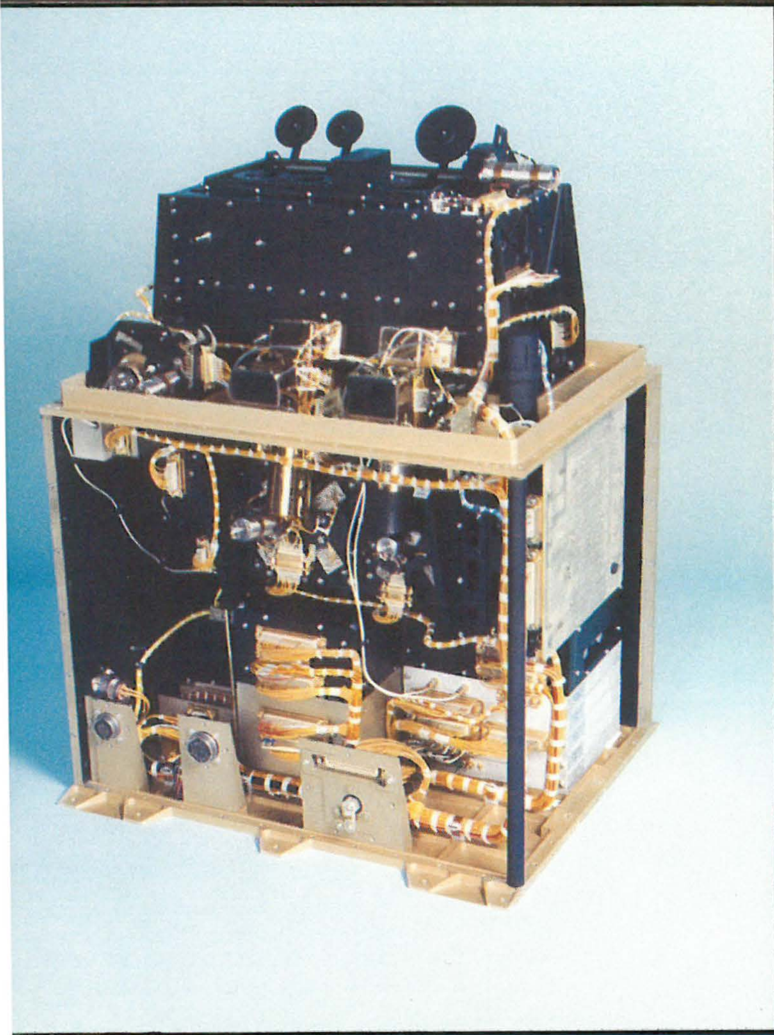
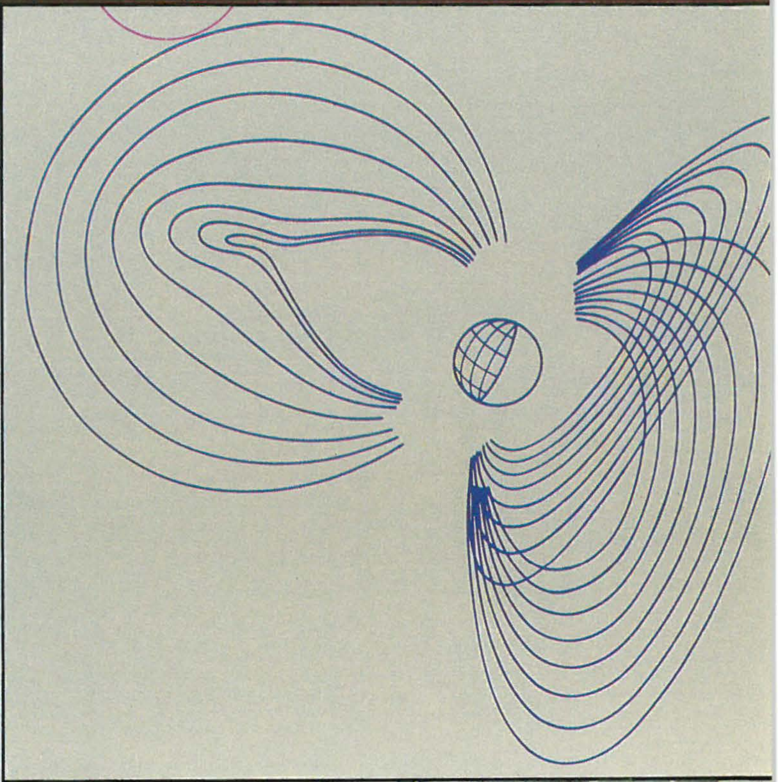
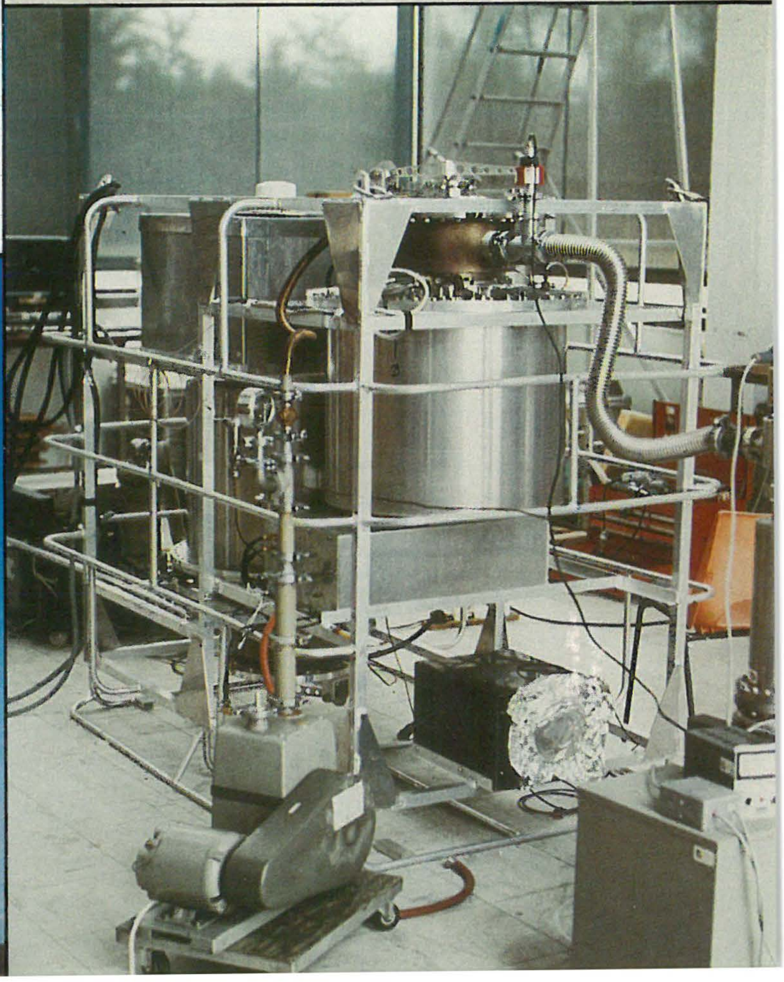
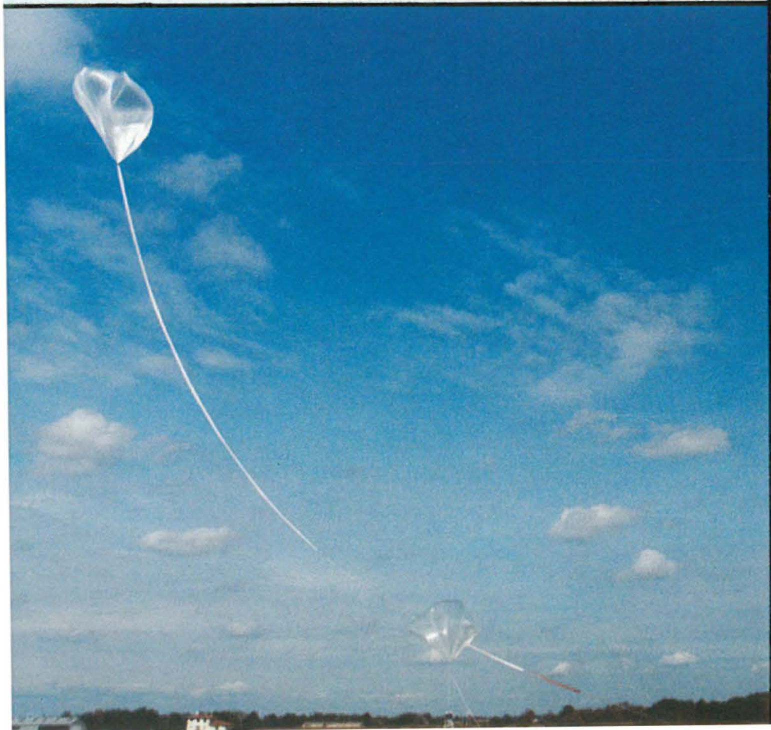
1. Sunset on October 15, 1980 observed from a 37 km altitude balloon and showing the volcanic aerosol after Mount St. Helens eruption.

2. The "Solar Spectrum" instrument which was on board of the Spacelab 1 mission (28 Nov. - 7 Dec. 1983).

3. Simulation of interplanetary and geomagnetic field lines interconnection via a solar wind filamentary current system, engulfed deep into the magnetospheric cavity.

4. Launching of a stratospheric balloon with scientific gondola at Aire sur l'Adour (France).

5. Preparation of a balloon gondola, consisting of two quadrupole ion mass spectrometers, liquid helium cryopump and associated electronics mounted in shock-absorbing structure.

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Acronyms

BISA : Belgian Institute for Space Aeronomy
RMIB : Royal Meteorological Institute of Belgium
ROB : Royal Observatory of Belgium
ULg : Université de Liège

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1. INTRODUCTION

Belgian achievements in external geophysics related to Space Research are mainly in the field of atmospheric studies in its most general sense. This field includes several disciplines such as meteorology, aeronomy and space plasma studies which are closely interrelated and partly overlap. It has therefore been a difficult task for the redaction committee of this document to classify all inputs from the different scientists in a coherent table of contents.

The present document must be considered as a first attempt to come to such a classification which certainly is not definite nor unique. However, we believe that under its present form it reflects in a realistic way most of the Belgian achievements.

It was also unavoidable that some topics had to be treated again at different places. We have tried to avoid this by treating a subject more extensively the first time it appears in the description and refer to it further on. For example, the topic "atmospheric electricity" being related to meteorology appears first in 2.5 and is treated extensively. However, "atmospheric electricity" being also related to the study of the ionized atmosphere is again mentioned briefly in 6.1.

2. METEOROLOGY AND COMPLEMENTARY RESEARCHES IN ATMOSPHERIC PHYSICS

In this section, meteorology is not considered on its own, but is extended to complementary research in atmospheric physics. Indeed, in addition to purely meteorological activities, the Royal Meteorological Institute also makes daily balloon-borne or continuous remote ground observations in order to contribute to the acquisition of atmospheric and geomagnetic data. Meteorology is largely application-oriented and the techniques that are used evolve rapidly. Therefore, it is very important that new advanced techniques, based on space observations, be efficiently transferred for operational purposes. This is the case, for instance, when the requirements of hydrology must be met. The Royal Meteorological Institute and the Laboratory of Hydrology of the "Vrije Universiteit van Brussel" contemplate exploiting the satellite data for this purpose.

2.1. METEOROLOGICAL SATELLITE OBSERVATIONS

Through satellite pictures a new dimension was added to the global weather observing system. Data could be obtained from regions, such as vast ocean areas, where conventional surface and upper air data are very sparse. The most common use of satellite pictures is cloud image interpretation. Satellite pictures are also beneficial to numerical weather prediction. The conversion of satellite data into meteorological field values is performed in world or regional meteorological centers.

2.1.1. Achievements and ongoing programmes

The Royal Meteorological Institute has participated in satellite application programmes since 1967. It extensively uses satellite collected data either directly (Meteosat or polar satellites images) or, indirectly, through the products released by the European Medium Range Weather Forecast Center.

During the last 10 years, 3 receiving stations have been in use in Uccle, which communicate with American and European satellites. The US satellites are satellites from the ESSA, Nimbus and NOAA ATS 3 series. Since 1976, signals from the very high resolution NOAA (Tiros N) series are also processed by these facilities. The European satellites are up to now the geosynchronous Meteosat satellites : Meteosat 1 which was fully operational from November 1977 to November 1979 and Meteosat 2 which has provided data since June 1981.

The Royal Meteorological Institute also provides a regular hard copy pictures service to support weather analysis and forecasting [1, 2, 3].

2.1.2. Future perspectives

The Royal Meteorological Institute aims at improved exploitation of satellite data, in particuler to participate in the data acquisition programme of future Meteosat projects and to develop a modern equipment for processing and visualizing these data.

a. The Meteosat programme

As part of Europe's contribution to the World Weather Watch, the Meteosat programme will be expanded in the next years with the planned launch by Ariane IV in 1986 of Meteosat P2 which is a preoperational refurbished Meteosat prototype, and in 1987 and 1988 with the launches of MOP 1 and 2 which will be the operational versions of the Meteosat satellite. A later launch, MOP 3, is planned but not yet scheduled.

The next step is the continuation of the geostationary satellite system beyond MOP 3, i.e., after 1995. The objectives of the second generation Meteosat programme are :

- to contribute to the acquisition and to the distribution of these data needed in preparing meteorological forecasts and research;
- to acquire high quality recurrent images;
- to extract and distribute quantitative data on the vertical atmospheric structure.

b. Image processing from meteorological satellite data

The European Space Agency has defined an overall planning for the second generation Meteosat geostationary satellites. The proposed improvements (e.g. high resolution images, addition and splitting of spectral channels) will result in a flood of data coming from the satellites. To present these images in real time in the best possible way to weather forecasters and to provide facilities for research and development work, powerful computers and image handling systems are needed. The scientific and operational objectives, which can be achieved with the application of recent image processing techniques, are essentially :

- zooming for detection and study of mesoscale weather phenomena;
- image sequences (loops) to present changes and developments of cloud systems;
- merging of satellite data with data coming from surface stations, radio soundings and radar networks;
- pseudocoloring, improvement of image quality, addition of graphic information, and image transformations.

At present, out of date equipment is used at the Royal Meteorological Institute for direct, hardcopy image output (without storage facility). In order to obtain full benefit of available satellite image data, the installation of a modern system for receiving, processing and visualisation is required. In a near future, it is planned to install a new image processing system. This will provide interactive color displays, full resolution film loops, color enhancement and zooming. This system will ease the interpretation of images and will offer new opportunities for subsynoptic meteorology.

2.2. CLIMATOLOGICAL HYDROLOGICAL EXPLOITATION OF SATELLITE DATA

The Royal Meteorological Institute contemplates exploiting the satellite data, in particular :

- for establishing a climatography of cloud extent according to the weather types, and for assessing the ratio between cloud cover and precipitation over wide areas;
- for detecting warm and cold air streams near the ground level, for determining the influence of orography and vegetation on the air flow in the lower layers, and for assessing the detrimental consequences from the agricultural, horticultural and other (valley fog, e.g. viaduct at Beez) standpoints;

- for following the evolution of the snow cover and for assessing the influence of orography, vegetation cover and soil nature on the rate of snow cover melting;
- for identifying, according to weather types, zones which are more or less cold and humid, and for mapping riskful areas from the point of view of dangerous hydrometeors for which the state of the soil has some influence (dense fog, glaze ...);
- for assessing the importance and areal extent of urban heat islands.

The Royal Meteorological Institute also contemplates exploiting the satellite data for meeting the requirements of hydrology and in particular for improving the estimation of the potential and actual evapotranspiration from natural surfaces by the energy balance method, in order

- to have at hand correct values of the albedos of the various covers in the course of the year and according to the cultural growth cycle;
- to know the surface temperatures of the various vegetation covers and, hence, to be in a position to assess more precisely the heat exchanges between the surface and its substratum;
- to determine with accuracy the extent of water-impervious areas;
- to know the evolution of the soil moisture, an element useful for checking actual evapotranspiration models.

The Laboratory of Hydrology of the "Vrije Universiteit van Brussel" has developed rainfall-runoff models for operational use in real-time control of flood reservoirs and also waterbalance models on a regional scale for prediction purposes on a weekly or monthly base.

Both types of models could benefit from the exploitation of satellite data if the information would become available in a quantitative form. In particular, for type I models (flood forecasting) :

- quantitative short-term forecast of areal rainfall;
- short-term evolution of soil moisture and frost penetration on a catchment scale for the prediction of the runoff component;
- evolution of the snow cover and rate of snow melting.

For type II-models (waterbalance prediction) :

- soil moisture evolution on a weekly or monthly base;
- extent of water-impervious areas in a catchment and in general of land-use changes;
- all elements to estimate the potential and actual evapotranspiration as stated by the Royal Meteorological Institute.

Another class of important application of satellites for hydrological purposes is the data-transmission of hydrological measurements by satellite. A Data Collection Platform (DCP) can be installed at each field measurement station and data can be transmitted either to a central operations centre (e.g. ESA-Darmstadt) or to a local receiving station. The latter is necessary to real-time flood forecasts. Rainfall storms can also be analysed for areal extent, direction and speed.

2.3. EARTH'S RADIATION BUDGET

The Royal Meteorological Institute is involved in NASA's Earth Radiation Budget Experiment (ERBE) by close collaboration with NASA and its contractor (TRW) on the developments and calibration procedures of the instrument [4]. They consist of an absolute solar monitor, an active cavity with a large and medium field of view, total and solar irradiance radiometers. The ERBE programme, whose objective is to monitor the different components of the Earth's radiation budget (solar incident as well as reflected and emitted radiation fluxes on the top of the atmosphere), is the first radiation budget observation programme based on the use of a system of three satellites all equipped with the up to now most accurate radiation package [5, 6].

It contains a short wave and long wave scanner which can be used across track or intermittently along track for the determination of the reflected radiation indicatrix in the plane along track.

The two first satellites of the series were respectively launched on October 5, 1984 (ERBS) and on December 12 (NOAA-F). The third satellite (NOAA-G) was launched on September 17, 1986. This most important observation system in the frame of the running climate programme of the WMO is believed to be able to provide accurate enough data to question the validity of some radiative transfer models.

It will also provide the radiation data necessary to understand the radiative interaction of clouds with the atmosphere.

2.4. ATMOSPHERIC OZONE MONITORING

Ozone is by far the most important minor constituent in the atmosphere, mainly because of the fact that it is a very effective filter for the near ultraviolet radiation. The routine measurements of ozone at the Royal Meteorological Institute comprise balloon soundings to measure the vertical distribution of ozone and measurements of the integrated amount of ozone in the vertical with ground-based spectrophotometers.

2.4.1. Balloon-borne in situ ozone observations

a. Achievements

From 1966 up to 1982 regular ozone soundings were made three times a week at Uccle by the Royal Meteorological Institute. About 80% of these soundings reached the 10 mb level. This homogeneous series of measurements forms a very valuable contribution to the present knowledge of the climatology of the ozone distribution and its variability on different time scales, over middle latitudes, in the troposphere, lower and middle stratosphere [7].

From simultaneous measurements of other meteorological parameters such as temperature and wind, the correlation of ozone with these parameters and the latitudinal transport of ozone as a function of season and altitude was determined [8].

In addition to these routine measurements, additional ozone soundings were performed during special weather situations, such as passages of the polar front, which allowed to study the exchange mechanisms of air masses between the stratosphere and the troposphere [9].

In view of a continuous effort to increase the quality of the ozone soundings, a number of experimental studies were performed to determine the features of electrochemical ozone sondes that may contribute to a systematical distortion of the ozone profiles [10, 11].

The different components of the frequency response of the combined sensor and air-sampling system of an electrochemical ozone sonde and the analytical form of the corresponding transfer function were studied in detail [12].

The ozone soundings were also used to participate in international campaigns such as the MAP/GLOBUS 1983 campaign and to offer complementary parameters for an experiment of the Belgian Institute for Space Aeronomy dealing with photographic observations of stratospheric aerosols.

b. Ongoing programmes

Due to a severe cut in the funds, the programme routine for ozone soundings had to be reduced considerably. The routine soundings are continued mainly during winter and spring, because interesting phenomena related to the general air circulation, such as stratospheric tropospheric exchanges and stratospheric warmings, mostly occur during these periods of the year.

On the other hand, additional soundings are performed for a validation programme of satellite experiments, such as the Stratospheric Aerosol and Gas Experiment (SAGE) and within the framework of international measurement campaigns, such as MAP/GLOBUS.

c. Future perspectives

In view of the importance of trend studies of atmospheric ozone at different altitudes, the ozone soundings programme should be continued.

The high cost of the ozone sondes that are actually used, justifies the development and manufacturing of ozone sondes in Belgium. In a first stage a prototype should be developed in which some of the weaknesses experienced in actually existing electrochemical sondes (such as the change of the sensitivity of the sensor during the soundings and the uncertainty in pump efficiency in the middle stratosphere) are eliminated. After extensive performance tests, the possibilities for manufacturing the sonde should be examined.

Two major unsolved problems in the vertical ozone distribution need to be clarified in the near future :

- the ozone profiles derived from different observing techniques show a large discrepancy in the middle stratosphere, which may amount to about 40% around the 10 mb level. An ozone sonde with fewer error sources than in the currently used sondes might throw some light on this matter;
- in view of the ozone depletion theories, it is very important to determine whether the ozone trends at certain levels, that were found in a number of recent studies, are real or just instrumentally induced. Statistics of the ratio descent/ascent ozone values from soundings will offer the possibility to verify this. But, this necessitates to recalculate a great deal of all the ozone soundings made at Uccle in order to include a deconvolution and certain objective quality tests of the ozone profiles.

For a better understanding of the chemistry and transport processes related to the ozone problem, it will be of great importance in the future to measure simultaneously, in addition to ozone, as many pertinent parameters as possible, in cooperation with other research groups.

2.4.2. Remote ozone observations from the ground

a. Achievements

Since 1971 a homogeneous and high quality series of daily measurements of the reduced height of the ozone layer has been performed by means of a ground-based instrument, the so-called Dobson spectrophotometer. The results are regularly published in "Ozone Data for the World" by the Atmospheric Environment Service in Canada and were used in numerous studies on the global ozone network.

Recently, a spectral analysis of this time series revealed several hitherto unpublished highly significant periodicities [13].

b. Ongoing programmes

Since 1983 a partially automated Brewer spectrophotometer is operational, which allows the study of rapid fluctuations of the reduced height of the ozone layer, for example during passages of the polar front. In addition, this instrument allows to measure the reduced height of SO_2. This is not only interesting for air pollution monitoring, but also to study the behaviour of stratospheric dust clouds from volcanic eruptions.

The spectral analysis of the total ozone data will be extended on a global scale to all observing stations with a sufficiently long time series, in order to be able to reach some conclusions about the physical processes causing the periodicities.

2.5. ATMOSPHERIC ELECTRICITY

At different places on the Earth's surface and at different times, it is found that the Earth has an electrical surface charge, generally negative, which corresponds to a total charge of 54×10^4 Coulombs over the entire surface of the Earth. Consequently, there exists an electric field in the atmosphere at all times and all localities. When measuring the field strength distribution with height, it is found that the actual field distribution, does not correspond to a charge-free atmosphere, but to a distribution of positive space charge in the air. Atmospheric electricity is involved with the origin and maintenance of the charge distribution in the Earth's surface and adjacent atmospheric layers. Atmospheric ions, generated by radiation from radioactive substances in the ground and atmosphere and by the action of cosmic rays, are the sources of the positive space charge distribution of the air. Due to its ion content, the air possesses some conductivity and vertical downward currents are produced which tend to neutralize the intrinsic negative charge of the Earth. But the continued existence of the atmospheric electric field demonstrates that this neutralization does not occur and that some process maintains the field. The study of this process is the main object of research in atmospheric electricity. This process is likely related to the mechanism of thunderstorms and to the electrical structure of thunderclouds. Between the Earth and the ionosphere, considered as the plates of a spherical capacitor, a global electrical circuit is maintained, generated by thunderstorm activity. Atmospheric electricity is concerned with the regions of the atmosphere accessible to direct measurements, i.e., up to the limit for balloons of about 22 km. Direct measurements at much higher altitudes can only be made with rockets and satellites.

2.5.1. Achievements and ongoing programmes

Since 1966 the Royal Meteorological Institute measures continuously the vertical electric field and current, the polar conductivities of the air and the polar ion concentrations near the Earth's surface at Dourbes [14]. To ensure the continuity of the observations, all the necessary equipment was developed and constructed at the Institute [15 to 17].

The diurnal variation of the area of global thunderstorm activity seems to be in phase with that of the electric field at the Earth's surface, but some discrepancies between both still remain and are probably due to the poor reliability of the thunderstorm data which are based on audible and visible observations. From a statistical study made by the Climatology Department of the Institute, it became clear that a more objective and standardized way of observing thunderstorms was needed. Electronic lightning-flash counters were examined, in particular the one accepted by CIGRE (Comité International des Grands Réseaux Electriques). Important inconsistencies were found between the commercial CIGRE counters and therefore a counter was developed at the Royal Meteorological Institute [18]. This instrument is very reliable and inexpensive, so that it may be installed on a wide scale. At present, the lightning activity over almost the whole Belgian territory is observed by a network of these counters, installed in collaboration with Laborelec and the Faculté Polytechnique de Mons [19].

More statistical information about the thunderstorms as current-generator of the global circuit is necessary, because recent observations showed that the inversely polarized thunderclouds occur more often than previously expected. At the Royal Meteorological Institute this information is obtained from the study of the field changes produced by thunderclouds and lightning [20].

2.5.2. Future perspectives

To verify the validity of the global electrical circuit model for the ionosphere-Earth condenser, more accurate climatological data about the global thunderstorm activity are needed. These data may be obtained from a ground-based lightning detection network, or from satellite observations. The network can be built up with inexpensive electronic counters such as the CIGRE-counters developed at the Royal Meteorological Institute or with more sophisticated but also more expensive real-time lightning locators such as the magnetic direction finders or the time-of-arrival systems.

The CIGRE-counters installed in Belgium have to be calibrated; at the present time, the experimental set up for determination in situ of their effective range is ready. To determine their selectivity with respect to the ground flashes and to record the transient signals emitted by the lightning, a data-acquisition system is under development. In any case, inexpensive solutions that may be applied on a large scale are pursued.

Since 1982 the Royal Meteorological Institute requests a special budget for the acquisition of a modern real-time lightning location system; besides providing climatological data about thunderstorm activity, such a system also has several very interesting operational capabilities.

A lot of data obtained at the Earth's surface and related to the global circuit are available today, but for studying the whole global circuit and the extraterrestrial influence on it, such as solar and cosmic rays, observations in space (middle troposphere and higher) are required. For this reason experiments measuring the ionization rate, the vertical electric field, etc... at higher altitudes will be set up. Of particular interest are the measurements of the electric currents and fields between the thunderclouds and the ionosphere.

2.6. IONOSPHERIC STUDIES

The Dourbes station of the Royal Meteorological Institute is equipped with radiosounders in order to measure the different parameters of the ionosphere from which ionospheric propagation forecasts can be inferred.

2.6.1. Ionospheric remote observations

a. Achievements and ongoing programmes

Since 1957, ionospheric HF echoes are recorded each hour by means of vertical radiosounders at the Dourbes station of the Royal Meteorological Institute. Very long series of measurements are accumulated to know not only daily and seasonal variations but also solar cycle variations of different parameters of the ionospheric part of the upper atmosphere.

Continuous efforts are made to equip the station with up-to-date electronic instruments and sounders which, moreover, are completely digitized since 1970. The Digisonde 128 is a programmable radioradar with sophisticated processes including coding to increase signal to noise ratio and analyses amplitude, phase and wave polarisation. The Digisonde 256 is a programmable radioradar exploiting all parameters from reflected waves including Doppler shift and incidence angle.

Measurements for several international campaigns were conducted at the station. The results of these were sent all over the world. In autumn 1983, a series of oblique soundings was started in collaboration with the Communication System Division of the GTE Communications Products Corporation and the University of Lowell, Center for Atmospheric Research [21, 22]. Since 1970 on the other hand, a quick interpretation of the soundings results has been made each hour to extract at least three ionospheric parameters. These are immediately sent to a forecasting center of the Air Weather Service of the USAFE. During November 1985, a new system ARTIST has been put into operation. It uses powerful computation capability of an up-to-date personal computer to overcome the human factor by a complete software realtime processing of the sounding results. The ionospheric electron profile is available one minute after the sounding has been completed.

b. Future perspectives

The availability of digitized sounders has opened a possibility to overcome the human factor in interpreting the results. With the new instrument ARTIST, a new step toward a complete automatic ionospheric sounding station is made. The future development of the station will include two aims. The first one is to send to users, automatically, by telex, up to sixteen parameters deduced from the results of any sounding. The second one will make available for any user, by means of electronic mail, the result of the latest hourly sounding. These lines of development are relative to vertical sounding, but some efforts are made to develop an oblique ionospheric sounding network. With oblique sounding, the transceiver and the receiver are well apart (several hundreds or thousands of kilometers), very near the situation of users of radiocommunications. The station of Dourbes of the Royal Meteorological Institute intends participating in such a network.

2.6.2. Observations with the Transit satellites

a. Achievements and ongoing programmes

With the collaboration of the "Max Planck Institut für Aeronomie" in Lindau (West-Germany) and the "Institut für Meteorologie und Geophysik der Universität" in Graz (Austria), the external geophysical section of the Royal Meteorological Institute has built a receiver to measure the total ionospheric electron content (T.E.C.). This parameter is not measured by ionospheric sounder. The method is based on the Doppler effect using two frequencies transmitted by the Transit satellites. The receiving station at Uccle is working at 150 and 400 MHz and is automatically switched on to record signals from chosen satellites.

b. Future perspectives

Simultaneous corresponding measurements are planned at Dourbes and at a station of the "Koninklijk Nederlands Meteorologisch Instituut" (De

Bilt). Results of such measurements could be used to correct data collected by the radiotelescope of Westerbork (The Netherlands).

2.6.3. Ionospheric propagation forecasts

For more than ten years, the external geophysical section of the Royal Meteorological Institute has sent to several users some forecasts for a restricted number of radio links. At the end of 1983, the number of links grew to a hundred and the graphics were automatically edited by computer. Now, new methods for more accurate and faster predictions are under investigation.

2.7. EXTERNAL GEOMAGNETISM

The spectrum range of the geomagnetic field variations at the Earth's surface is enormous extending from a fraction of a second to more than 30 million years. Variations with the longest periods, such as the secular variation, are of internal origin. However, fluctuations with periods less than a few days are of external origin and are of interest to the external geophysicist.

It is clear that the studies of these phenomena cannot be separated from those made from in-situ satellite measurements in remote regions of the Earth's atmosphere. Furthermore, ground-based observations of geomagnetic field variations are complementary to those of natural pulsations generated in the magnetosphere and recording on-board satellites.

Since 1960 a high quality series of hourly measurements of the three components of the Earth's magnetic field has been obtained in a groundbased magnetic observatory (Dourbes). The results are regularly published and the observations are transferred to the World Data Center [23 to 27].

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3. THEORETICAL MODELS OF THE ATMOSPHERE

Although a great deal of knowledge concerning the Earth's atmosphere can be provided by observations including space-borne instruments, theoretical investigations are also very important. Moreover, interpretations of observed data require model calculations and comparisons with predicted values making use of theoretical knowledge.

The Belgian Institute for Space Aeronomy has developed middle and upper atmospheric models while the Institute of Astrophysics of the University of Liège has elaborated thermospheric models.

3.1. MIDDLE ATMOSPHERIC MODELS

In the last 10 years, model calculations related to the aeronomy of the middle atmosphere were performed. At the beginning, these included one-dimensional studies in which only the vertical direction was considered. Later on, these studies have been extended by the development of two- and even three-dimensional models. The purpose of these models is to calculate the distribution of trace species making use of laboratory data for the reaction rate constants and the absorption cross sections in the ultraviolet and visible spectral range [1]. This allows to calculate the formation and destruction rates of the minor constituents. Furthermore a parametrization [2] or, in the most sophisticated models, a self consistent calculation of the winds and the related transport of the long-lived species is required [3]. Finally, because of the role played by the temperature in the chemical kinetics and in the atmospheric dynamics, it is necessary to calculate the temperature field from radiative transfer considerations [4 to 6].

These models have been used to understand the chemical balance in the atmosphere and predict the vertical and meridional distribution of the trace species belonging to the oxygen, hydrogen, nitrogen and chlorine families [7 to 10]. For example, the problem of nitrogen oxides has been studied in detail, showing the possibility for these gases, which are produced in the thermosphere, to be transported downwards in the winter polar region and to reach even the upper part of the stratosphere [11], [12]. This important mechanism has been recently confirmed by the measurements reported by the LIMS (Limb Infrared Monitoring of the Stratosphere) instrument on board Nimbus 7. The effect of the nitrogen and chlorine species on the ozone layer has been (and still is) a matter of great concern because of the potential large biological and climatic effects of any ozone depletion [13 to 16].

The response of the middle atmosphere to variation in the solar UV irradiance in relation with the 11 year solar cycle or the 27 day rotation period of the Sun has been studied by means of one- and two-dimensional models [17 to 20]. The predicted response in ozone to the 27 day solar variability is in good agreement with the data provided by LIMS for ozone and the SBUV experiment (Nimbus 7) for the solar irradiance.

With the appearance of a complete set of satellite data (good time and space coverage), it now becomes possible to study the interaction between dynamics and chemistry. A three-dimensional model which simulates the effect of the planetary waves during winter seasons, including major stratospheric warmings, has been developed in order to help the interpretation of the data provided by satellite [21], [22].

The problem of ions in the stratosphere has been treated using theoretical models in order to interpret some balloon-borne observations (see 6.3.1.) [23], [24]. The ionic scheme is rather complex and has to be coupled with some neutral species such as CH_3CN whose overall chemical budget has been extensively studied [25 to 28].

Finally, the models have been used to predict the future of the atmospheric ozone and temperature in relation with expected emissions of several gases such as carbon dioxide, methane, nitrous oxide and the chlorofluorocarbons [29 to 34].

In the future, sophisticated models taking into account the several couplings between chemistry, radiation and dynamics are expected to play an increasingly important role to interpret the new satellite data. For example, the observations of the Solar Mesosphere Explorer provide uniquely long term continuous observations of ozone and its variability [35]. Moreover, data from the LIMS and SAMS instruments on board Nimbus 7 provide data that should be interpreted by two- and three-dimensional models in terms of transport by planetary waves and probably (for CH_4 and N_2O) in relation with the quasi-biennal oscillation. Finally, the recent data from the ATMOS experiment will provide for the first time, the distribution of temporary reservoirs such as N_2O_5 which have never been observed before.

Finally, the models used up to now could easily be transformed to make theoretical studies of the atmosphere of other planets [36]. Such a work could be undertaken in relation with future missions in the solar system.

3.2. STRUCTURE OF THE UPPER ATMOSPHERE

The knowledge of the physical structure of the Earth's upper atmosphere, i.e. the vertical profiles of density and temperature above 150 km altitude, has been largely extended using the techniques of the orbital variations of artificial satellites. In this matter, an analytical theory has been developed to calculate the density from the analysis of variations of the orbital period, giving all possible values to the physical parameters of the problem. In particular, the so-proposed method supplies the possibility to determine very accurate densities in atmospheric regions when the density scale height gradient is important. This method was applied in the mean thermosphere, at a time when data were still scarse in this atmospheric region [37].

The physical parameters describing the upper atmosphere are submitted to different types of variations which are to be interpreted. Studies on these variations were made, in particular concerning those which are linked to the geomagnetic and semi-annual effects [38], [39].

3.3. THERMOSPHERIC MODELS

A new two-dimensional model has been developed to calculate the simultaneous transport by thermospheric winds of NO, $N(^4S)$ and $N(^2D)$. The results show that the $N(^2D)$ atoms and the associated 5200 Å airglow are efficiently carried by winds outside the auroral-source region. The precipitation measured on a rocket flight in Cape Parry (Canada) has been simulated with the model. Comparison with the model calculations indicates that the wind speed required to fit the measurements is in good agreement with the thermospheric three-dimensional circulation current models [40]. Other observations made with the VAE experiment on board the

Atmosphere Explorer D satellite confirm the influence of horizontal transport on the morphology of the $N(^2D)$ high latitude distribution.

The various rocket measurements of nitric oxide using the NO resonance scattering and ion composition have been reviewed and their seasonal/latitudinal variation has been compared with the results of a one-dimensional model of the odd nitrogen distribution between 50 and 250 km [41]. Solar activity, latitudinal variation of the eddy diffusion coefficient K and local time are sources of NO concentration variability. It has been shown that the importance of the NO downward flux ϕ from the thermosphere is strongly altitude- and latitude-dependent. From estimated values of this downward flux obtained by measuring vertical profiles, it has been found that the ϕ/K ratio at 85 km varies from 20 cm^{-4} at low latitudes to over 10^3 cm^{-4} at high winter latitudes [41]. These values and the trends observed are in agreement with the predictions of a two dimensional zonally averaged model of odd nitrogen between 70 and 350 km [42] [43] [44].

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4. INFRARED OBSERVATIONS OF THE ATMOSPHERE

Two groups respectively attached to the Belgian Institute for Space Aeronomy and to the Institute of Astrophysics of the University of Liège have performed outstanding achievements in the field of infrared observations of the Earth's atmosphere and have current ongoing programmes in this field. The scientific programmes of the Belgian Institute for Space Aeronomy have been carried out with the following instruments : the Girard balloon-borne grille spectrometer, a circular variable filter radiometer, a Michelson interferometer and the Spacelab grille spectrometer. In the case of the Institute of Astrophysics of the University of Liège, measurements have been made mainly with a stratospheric balloon-borne spectrometer and ground-based observations have been carried out at the International Scientific Station of the Jungfraujoch.

4.1. ACHIEVEMENTS

4.1.1. Balloon-borne grille spectrometer

The Girard grille spectrometer used for the balloon flights is a 60 cm focal length Littron spectrometer in which the entrance and exit slits have been replaced by a 15 mm x 15 mm hyperbolic "grille" giving it a luminosity comparable to an open slits instrument coupled with the 0.1 cm^{-1} resolution corresponding the theoretical grating resolution and the smallest step of the grille. This instrument was flown in continuation of a balloon programme using a classical Fastie spectrometer of lower resolution which had yielded the first stratospheric observations of nitrogen dioxide and repeated methane observations [1].

In September 1975, the Girard grille spectrometer [2 to 16], mounted on a stratospheric balloon gondola yielded a complete sequence of limb sounding spectra, leading to the first determination of a stratospheric vertical HCl-distribution [13]. CH_4 data obtained on the same flight led to an indirect determination of the efficiency of the chlorine cycle [14]. The instrument was again successfully launched several times in the period 1975-1977 and performed a series of observations of NO, NO_2 and HCl. For the first time, these species were mapped between 20 and 40 km at the resolution of 0.1 cm^{-1}.

4.1.2. Balloon-borne double pass grating spectrometer

Until 1975, the balloon programme of the Institute of Astrophysics of the University of Liège was mainly concerned with the investigation of the near-infrared solar spectrum as such [17,18]. After that date, the programme became more and more dedicated to the investigation of the chemical composition of the upper stratosphere. Two reasons justified this reorientation. The first one was that the initial solar objectives had been met satisfactorily. The second one was that, in 1974, the instrument detected the presence of hydrogen fluoride in the upper stratosphere [19 to 22]. This was a proof that chlorofluoromethanes such as "freons 11 and 12" diffuse in the stratosphere feeding the chlorine catalytic ozone-destroying cycle.

Ten subsequent flights, made between 1975 and 1983, provided opportunities to establish the concentration of HF above 20 km altitude and allowed also repeated measurements regarding other important species such as HCl, CH_4, CO, H_2O,... The gathering of observations about some of these gases over a sufficiently long time span is important in order to investigate their variability and their trends [23 to 26].

The basic instrumentation carried onboard the balloon gondola consists of a 35 cm-diameter telescope, coupled to a classical grating spectrometer of 2.5 m focal length, operating in double-pass with an intermediary slit. The spectral resolution achieved in the near-infrared (1.5 to 5.0 micrometers), using either cooled lead sulfide or indium antimonide detectors, is of the order of 0.004 cm^{-1}. The equipment operates under telecommand from the ground. The spectroscopic data which are recorded in absorption using the Sun as the source of radiation, are transmitted to the ground in real time.

In 1982 and 1983, this payload was retained as one of the four gondolas participating in the two international intercomparison campaigns BIC 1 (fall of 1982) and BIC 2 (spring of 1983). The main objectives of these campaigns were :

- to assess the accuracy of instruments currently used to obtain data on the composition of the stratosphere;
- to provide a comprehensive set of data of known accuracy likely to test theoretical models of the stratospheric photochemistry. The

molecules retained as critical for this aim were : HF, HCl, ClO, HNO_3, NO, NO_2, O_3, CH_4, H_2O and CO_2.

During these intercomparisons, observational priority was given to the following species : HF, HCl, CH_4, H_2O and CO.

At present, it can be stated that this participation has been very satisfactory and that the results produced are of excellent quality, justifying the use of a classical but well tested instrument for reference purposes [25,26].

4.1.3. Circular variable filter instrument

The circular variable filter instrument is an uncooled 10 cm^{-1} resolution radiometer. Between 1975 and 1979, it was operated from stratospheric balloons and aircrafts [27]. Its purpose was the determination of the vertical, longitudinal and temporal distributions of the stratospheric nitric acid from measurements of its infrared emissions in the ν_5 and $2\nu_9$ bands near 11-13 µm. The principle was based on similar radiometers used in the early seventies by American groups.

The analysis of the results suggested that the HNO_3 spectroscopy was misunderstood and that low resolution instruments of this kind overestimated HNO_3 concentrations. It also suggested that accurate determination of HNO_3 needed higher resolutions and sensitivities and that measurements of minor constituents should be made on a global scale.

4.1.4. Michelson interferometer

Between 1980 and 1982, an interferometer of 0.1 cm^{-1} resolution was operated at the Pic du Midi observatory (altitude 2975 m). This Michelson interferometer was custom designed, together with its data processing system, for the Belgian Institute for Space Aeronomy at the Block Engineering Company (Massachussets). Data acquisition is entirely programmable, this associated with flexible programmes for reduction of the spectra permits to use it in a wide range of atmospheric applications. Absorption spectra of $CFCl_3$, CF_2Cl_2 (the "freons 11 and 12") and stratospheric HNO_3 were observed with the Sun and Moon as sources. The freons were also observed in the emission mode of the instrument.

However, no emission spectra were observed for HNO_3, proving that the bulk of the nitric acid column is in the stratosphere.

The instrument is now being prepared for balloon flights in the emission mode. The campaigns will be scheduled in 1986-1987 [28 to 30].

4.1.5. Jungfraujoch programme

Since 1977, series of dedicated near-infrared solar observations have been carried out at the International Scientific Station of the Jungfraujoch, located at 3580 m altitude in the Swiss Alps [31 to 33].

The instruments available there are a double-pass grating spectrometer of 7.5 m focal length, providing a spectral resolution of 0.02 cm^{-1} in the near-infrared and a Fourier transform spectrometer whose unapodized resolution is 0.005 cm^{-1}. This last and quite new instrument, specifically developed at the Institute of Astrophysics of the University of Liège, is being used routinely out to 5.2 µm. It will be soon operational in the 8 to 13 µm window.

While it is important to know as accurately as possible the concentrations versus altitude of many atmospheric constituents, it also remains very useful to monitor their integrated column density from the ground. The frequency of such observations is still essential for establishing variability and secular trends.

The molecules which have been monitored over the last years at the Jungfraujoch are HF, HCL, CH_4, NO_2 and N_2O [34 to 41]. Comparison of recent observations with older ones made by Migeotte in 1950-55, allow to establish a time base over which it is possible to investigate changes which might have occured in the composition of the Earth's environment.

4.1.6. Spacelab-borne grille spectrometer

The Spacelab-borne Girard grille spectrometer, first proposed in 1975, accepted and finalized in 1977, was designed and built between 1978 and 1980. It was tested between 1980 and its flight data on November 28, 1983. The grille spectrometer is an 80 cm focal length grating instrument coupled with a heliostat and a Cassegrain telescope of 6 m focal length.

Two detectors ; InSb and HgCdTe are used providing two simultaneous signal channels, leading to the study of photochemically coupled species e.g. NO and NO_2.

This instrument was the result of a close cooperation between the Belgian Institute for Space Aeronomy and the Office National d'Etudes et de Recherches Aérospatiales (France). It is operated in solar absorption mode and allows to scan the whole atmosphere from the top of clouds to the heterosphere. It is fully programmable, either preflight, or during flight operations, emphasizing real time intervention [42 to 45].

The first plan was determined taking into account a preliminary study of the orbital conditions for such observations. During the first flight, middle infrared spectra of many molecules were observed from which ten were identified as : CO, CO_2, NO, NO_2, N_2O, CH_4, O_3, HF, HCl and H_2O. Retrieved vertical distributions have indicated the presence of CO_2 up to 120 km, and an important latitudinal variation of mesospheric CO and H_2O [46 to 52]. After landing, the instrument was brought back to Europe for refurbishment at the ETCA company in Charleroi. It showed the same performances as during the last preflight tests [51].

After implementation of new scientific programmes, based on the first flight results, the instrument is now back at Kennedy Space Center (Florida) for integration in a Spacelab payload for the first NASA mission of the programme called Earth's Observation Mission (EOM) [53].

4.1.7. Shuttle-borne ATMOS - Fourier Transform Spectrometer

The ATMOS (Atmospheric Trace MOlecule Spectroscopy) instrument is a double-pass Michelson interferometer operating in the occultation mode during sunrises and sunsets. From aboard the space shuttle, it allows to investigate the earth's atmosphere between 10 and 150 km altitude with a 2 km vertical height resolution. The operation is fully programmable in real time from the ground.

ATMOS is a JPL-developed payload for which the Institute of Astrophysics of the University of Liège has participated in the scientific programme definition and is actively involved in the analysis of the data obtained from 20 occultations covered during the first mission of April 29 - May 1, 1985.

From these data, 31 telluric molecules have already been detected through the analysis of their near- and middle infrared absorption characteristics and the retrieval of concentrations versus altitude is currently under way for 22 of them.

4.2. ONGOING PROGRAMMES AND FUTURE PERSPECTIVES

4.2.1. Mountain based observations

At the Institute of Astrophysics of the University of Liège it is intended to improve the Jungfraujoch laboratory equipment. This project is also conceived through international collaborations. For instance, the resolution of the Fourier transform spectrometer will be increased and new detectors will be installed in the next two years. It will then be possible to monitor upper atmospheric molecular species by recording regularly high resolution spectra of very good quality.

The design and construction of a simple but performing Fourier spectrometer, especially dedicated to such monitoring studies, is planned. This instrument will be easy to install and will be able to operate in various locations. It will therefore increase the knowledge of the geographic and temporal distributions of atmospheric constituents.

4.2.2. Balloon-borne emission interferometer

The 0.1 cm^{-1} resolution interferometer of the Belgian Institute for Space Aeronomy will be mounted on balloon platforms in order to fly in 1986-1989. During the flights, the instrument will operate in emission mode. These experiments will attempt to address the problem of the diurnal variations of stratospheric constituents by observing the transitions between night and day. They intend to put an upper limit on the mixing ratio of nighttime stratospheric species.

4.2.3. Stratospheric balloon-borne spectrometry

At the Institute of Astrophysics of the University of Liège, the near future of the balloon programme will take advantage of the actual gondola and equipment, and a few more flights are planned. However, after fifteen years of regular use, the useful life of the gondola is rapidly drawing to an end. In order to remain active in that field, a collaboration between all Belgian groups involved in balloon geophysics could then be considered.

4.2.4. Spacelab grille spectrometer

The Spacelab grille spectrometer will fly again in the frame of the NASA programme called "Earth's Observation Missions" (EOM). In the frame of this programme, the instrument is accepted by NASA for the first three missions. The new scientific projects take into account the results of the Spacelab 1 mission and emphasize the mesospheric and thermospheric NO and CO determinations. Provisions have been taken to measure more extended regions of the solar spectrum in the altitude above 150 km where no telluric absorptions have been observed. The H_2O spectral windows have also been extended in order to include more weak lines. Due to the new cryogenic gas bottle and better orbital parameters, more occultations will be scheduled. The latitudes of the observations will be chosen in order to perform a complete geophysical programme. The compatibility of the grille spectrometer with the ESA Eureca platform (see 10.3.1) is also actively studied.

4.2.5. ATMOS-Fourier transform spectrometer

The ATMOS instrument has demonstrated its outstanding performances during the recent Spacelab 3 mission. NASA has reconducted its operation from on-board future space shuttle flights until 1995, at a 1 mission per year frequency. The Institute of Astrophysics of the University of Liège has been invited by NASA to continue his cooperation and co-investigation for that whole programme.

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5. OBSERVATIONS OF THE ATMOSPHERE IN THE ULTRAVIOLET AND VISIBLE WAVELENGTHS

Several Belgian groups and individuals are actively engaged into research programmes in this field.

The Belgian Institute for Space Aeronomy has developed filter radiometers and solar spectrometers which, in the frame of the "Middle Atmosphere Programme", allowed the determination of vertical profiles of ozone and nitric oxide. In 1980, the Institute initiated a series of balloon-borne observations to detect atmospheric aerosols and determine their properties. Recently, it has also been involved in the development of a radiometer to detect minor constituents and aerosol layers from the EURECA (European Retrievable Carrier) platform.

Airglow observations were made by the Institute of Astrophysics of the University of Liège with a spectrophotometric device aboard an ESRO satellite.

At the Royal Meteorological Institute, daily measurements of the characteristics of the ozone layer are performed by means of a ground-based spectrophotometer.

Participation as guest investigators on American or European satellite missions also allow Belgian researchers to participate in international Earth and planetary atmosphere programmes.

5.1. ACHIEVEMENTS

5.1.1. Photographic observations of the stratospheric aerosols

The balloon-borne photographic observation equipment of the Belgian Institute for Space Aeronomy has flown several times since 1980. It consists of a solar azimuth controlled gondola with a minimum of 6 motorized 70 mm film cameras. These cameras are fitted with optical filters centered at 440, 650 and 840 nm. Three cameras are mounted on each side of the gondola which is rotated by steps of 36° at low solar angles. On each film, the evolution of the complete sunset at all phase angles can then be covered. During several flights, a seventh camera has been loaded with color film to provide a check of the 440 and 650 nm results.

This observation technique has led to direct observations over Europe of the stratospheric dust clouds generated by the 1980 Mount St. Helens and 1982 El Chichon volcanic explosions. Aerosol layers can also be detected directly by this technique. For each layer, the granulometry and the density can be determined from the Mie-scattering theory by measuring the scattering phase function for three wavelengths. The analysis of these data is in agreement with recognized properties of the Junge aerosol layers (0.15 for the effective radius). For the background aerosol at lower and higher altitudes, a smaller size for the particles has been inferred [1 to 3].

Moreover, the study of twilight has revealed the presence of a dust absorbing and scattering layer in the mesosphere at altitudes near 60 km with a low scattering albedo (0.1) at 440 nm; the optical efficiency of the layer increasing more than 10 times when the wavelength of the interacting light changes from 650 to 440 nm [4 to 6].

This photographic set of data is also used in correlation with measurements of the pressure and temperature distributions to study the dynamics of the stratosphere [7,8].

5.1.2. Ozone intercomparison campaign 1981

An intercomparison balloon and ground-based campaign for measuring ozone from the ground to the mesosphere was performed in the South of France from 9 June to 26 June 1981. Satellite data obtained above the sites for existing ozone experiments were also used in this intercomparison. A total of 11 experimental groups from Belgium, France and USA participated in the campaign with 15 different types of instruments. Two large stratospheric balloons were launched respectively on 19 June and 25 June with five experiments on each; on these specific days the comparison included up to 10 types of near simultaneous ozone measurements. The vertical distribution of stratospheric ozone was simultaneously measured by means of five different instruments carried on the same balloon payload including a filter radiometer developed at the Belgian Institute for Space Aeronomy. Vertical profiles were also deduced from Electrochemical Concentration Cell sondes, launched from the same location by small balloons, and from short Umkehr measurements made at Mt. Chiran (France). Systematic differences of the order of 20% between ozone profiles deduced from solar U.V. absorption and in situ techniques were found [9,10].

5.1.3. Remote ozone observations from the ground

A ground-based Dobson spectrophotometer of the Royal Meteorological Institute has been used at Uccle to perform daily measurements of the reduced height of the ozone layer. Achievements and ongoing programmes resulting from these measurements have been described in 2.4.2.

5.1.4. Artificial mesospheric clouds

Atomic oxygen density values in the 80-105 km altitude equatorial region have been obtained by analyzing the chemiluminescence of NO point releases from three Centaure II-C rockets launched from Kourou (French Guyana) on September 1974 (two rockets) and 13 September 1974 (1 rocket). The pyrotechnic system, fixed at the bottom of each NO container was constructed by the Poudreries Réunies de Belgique. The difficulties associated with this kind of experiments were greatly avoided by a new technique ejecting the NO gas into the backward direction of the flight. The ground-based photographic instruments included two triangulation cameras whose mechanical and electronical parts were designed and built at the workshop of the Belgian Institute for Space Aeronomy [11 to 14].

It has been found that below 90 km the derived values of atomic oxygen number densities were in relatively good agreement with those previously published in the literature. At approximately 105 km the measured values were about two times larger than the atomic oxygen concentration obtained by averaging a set of data from a great number of other flights [15].

5.1.5. TD-1 satellite geophysical results

In 1974, the TD-1 astronomical ESRO satellite obtained unexpected geophysical results with the S2/68 experiment of the Institute of Astrophysics of the University of Liège. This experiment [16] was composed of a relatively large telescope (27.5 cm diameter off-axis paraboloid) followed by a spectrophotometric device. The long wavelength photometric channel detected a significant increase above the background near the equator, restricted to the dusk portion of the orbit. This effect was attributed to the resonance scattering emission of sunlight at 2800 Å by Mg^+ ions. These ions are lifted up from the meteor ablation region by the so-called "fountain effect". Numerous maps of isophote contours of the intensity were generated. These observations gave an exceptional opportunity for measuring the seasonal, latitudinal and longitudinal distribution of metallic ions in the upper equatorial ionosphere. At the end of the active life of the spacecraft, vertical profiles of the ion distribution were obtained by scanning the atmosphere with the telescope turning about the Sun-pointing axis of the satellite. Other valuable airglow observations were made during this spinning phase. For example, the night airglow produced by the radiative recombination of atomic nitrogen with oxygen was measured by the satellite and used to determine the first experimental profile of N atoms in the Earth's atmosphere [17 to 22].

5.1.6. Participation in the NASA Atmosphere Explorer satellite programme

The Institute of Astrophysics of the University of Liège participated in this programme by analyzing and interpretating data, collected between 1974 and 1976 by the Visible Airglow Experiment and by the Ultraviolet Nitric Oxide spectrometer [23 to 39].

a. Visible Airglow Experiment

This experiment, built by the University of Michigan, consisted in different narrow band photometric channels. Scientists from the Institute of Astrophysics of the University of Liège were involved in the analysis of the observations gathered with the 2800 Å channel. Significant results were obtained concerning the local time and vertical distribution of equatorial Mg^+ ions. Data from the 5200 Å $N(^2D)$ channel collected by VAE when the AE-D perigee was in the auroral zones were combined with ion mass spectrometer measurements to investigate the auroral E-region chemistry and $N(^2D)$ production and quenching.

b. Ultraviolet Nitric Oxide spectrometer (UVNO)

Measurements of the distribution of NO between 90 and 200 km were made with the AE-C and D satellites with the UVNO instrument designed at the University of Colorado (USA). The problem of the latitudinal gradient of NO and the role of particles as a source of odd nitrogen were studied in detail both experimentally and theoretically. The UVNO observations revealed the existence of a strong latitudinal gradient between equatorial and auroral latitudes. These observations stimulated the development of one and two-dimensional models of odd nitrogen distribution. The two-dimensional model has been used to investigate the influence of horizontal transport on the nitric oxide distribution and to assess quantitatively the role of NO in the heat budget of the thermosphere.

5.1.7. The MAP/GLOBUS programme

An international project on stratospheric chemistry "Global Budget of Stratospheric Trace Constituents" (GLOBUS) has been implemented in the frame of the "Middle Atmosphere Programme" (MAP).

Two campaigns were organized in Europe in 1983 and 1985 in which observations made from stratospheric balloons played a major role.

The first campaign dealed with short- and long-lived species in the stratosphere like ozone, nitric oxides, halocarbons, radicals... Comparison between in-situ and remote techniques have been conducted by means of eleven balloon flights and daily ground-based observations performed in september 1983.

The second campaign was more specifically devoted to NO_x studies. Its goals were to obtain experimental information on the total NO_x concentration in the stratosphere, on the partition between the nitrogen family and on the species diurnal variation. In addition, new comparisons between in situ and remote-sensing observations provided information on instrument performances.

In both campaigns, solar occultation measurements in ultraviolet and in visible layers were performed by means of spectrometers developed at the Belgian Institute for Space Aeronomy. Vertical profiles of ozone and nitric dioxide were obtained. Ozone was also determined from ultraviolet absorption measurements by means of the filter radiometer already mentioned in 5.1.2.

5.2. ONGOING PROGRAMMES

5.2.1. Middle atmospheric aerosols and minor constituents

a. The balloon-borne photographic observation equipment

The well tested balloon-borne photographic observation equipment of the Belgian Institute for Space Aeronomy is flown periodically in order to follow the evolution of the stratospheric aerosols. The main improvement on the present equipment would be the use of more automatic techniques for the interpretation of the photographs. Image processing would permit to treat more information on each image than the current photodensitometer technique, and could also lead, by digital enhancement, to the resolution of even more detailed layerings.

b. The Occultation Radiometer (ORA)

In view of the possibility of putting an instrument on the European Retrievable Carrier (EURECA), an instrument (ORA) is presently developed to obtain more detailed information about these aerosol layers and other trace constituents. The project EURECA-ORA is a programme developed by the Belgian Institute for Space Aeronomy in collaboration with the Atmospheric Physics Department of the University of Oxford (U.K.). The goal of this project is the realization of a radiometer which will be installed on the European space platform EURECA 1. This platform will be launched with the shuttle which will bring it on a circular orbit at an altitude of 500 km, where it will remain for about 6 months. During this period, one of the axes of the EURECA-carrier will be pointed towards the Sun, if the satellite is out of the Earth's shadow. The ORA-radiometer will then be able to measure the solar radiation, attenuated through the absorption in the atmosphere during sunrise and sunset (occultations). This measurement will be performed in 10 wavelengths. Two of these wavelengths are chosen in the infrared in such a way that measuring the radiances should allow a derivation of the concentration of water vapour and CO_2 in the mesosphere and stratosphere. To perform these measurements, the group of the Oxford University is developing the infrared part of the radiometer.

The optical part of the radiometer, constructed by the Belgian Institute for Space Aeronomy in collaboration with the Belgian Company OIP (Ghent) consists of 8 channels in the wavelength domain 250 to 1000 nm (near UV to near IR). Two wavelengths have been chosen in order to obtain information about Rayleigh scattering and scattering by aerosols (Mie scattering). The measurements in the other 6 wavelengths will allow the determination of the concentration of ozone, NO_2 and water vapour. The final objective is to measure simultaneously a series of parameters, which must allow a better understanding of the climatology of aerosols and of the physico-chemical processes determining the atmospheric equilibrium between water vapour, ozone and CO_2.

The Belgian Institute for Space Aeronomy is also responsible for the complete electronics of the ORA-occultation radiometer. It is totally conceived at the institute and will be industrialized, according to space specifications, by the Belgian electronics company ETCA (Charleroi). The complete mechanical structure of this experiment will be realized at the institute. The thermal control of the instrument will be realized with two heat pipes developed by SABCA (Haaren).

c. Atmospheric Radiation and Minor Species instrument (ARAMIS)

A newly designed instrument, ARAMIS (Atmospheric Radiation and Minor Species), is dedicated to measure the upward and downward radiation in the atmosphere related with trace species and photodissociation phenomena. This instrument has been developed using a photodiode linear array as detector. The first balloon flight took place in September 1984. Such an instrument will fly in a near future in order to measure atmospheric absorptions in the ultraviolet and visible ranges and to provide data on the upward radiation (scattered and reflected) which contributes to the photodissociation of ozone and nitric dioxide. Flight models for rockets and space platforms will be developed and flown by the Belgian Institute for Space Aeronomy during the next years.

5.2.2. Airglow-solar spectrometer on the SAN MARCO D/L satellite

An instrument built by the Fraunhofer Institute für Messtechnik in Freiburg (Switzerland) will be launched in 1987 on board the American-Italian SAN MARCO D/L equatorial satellite. It consists of a series of 4 scanning spectrometers with multiple exit slits covering the spectral range 500Å-8000Å with a resolving power of about 1000. The spacecraft is spin-stabilized parallel to the Earth's rotation axis. The instrument will view consecutively the Sun and the Earth's atmosphere on each rotation and will provide new information concerning the solar radiation and its interaction with the atmosphere.

The participation of the Institute of Astrophysics of the University of Liège and the Belgian Institute for Space Aeronomy will consist in the analysis and modelling of the solar airglow and occultation data. In particular, the temporal variations of the solar UV irradiance and the airglow response to such fluctuations in the incident radiation will be investigated. Vertical profiles of O_2 and O_3 will be derived by measuring the occultation of the Sun by the Earth's atmosphere.

5.2.3. Measurements of the reduced height of O_3 and SO_2

These measurements performed by the Royal Meteorological Institute since 1983, are made by means of a ground-based Brewer spectrophotometer (see 2.4.2).

5.3. FUTURE PERSPECTIVES

The photographic observations of aerosol layers can be easily performed from space. The nature and variations of the 60 km layer can be analyzed much better from orbital altitudes.

Film cameras remain an acceptable instrument for a manned space instrument, but in the case of a free flying satellite, another type of high resolution imaging device should be developed to telemeter the data to the ground. In a later development, an imaging high spatial resolution ultraviolet and visible spectrometer would constitute the best way to perform simultaneously composition, aerosols and radiation observations. As for all Earth observations, these should be made preferably from low orbits.

The presently developed ORA instrument has some major constraints, due to the limited Sun pointing capabilities of the EURECA-carrier and to the simple design of the present radiometer. Future developments should therefore focus on the development of a more refined and more powerful instrument to be flown on other missions. It is evident that the choice of interference filters for the wavelength selection in the region 250 to 1000 nm imposes some limitations. One of the first efforts would therefore be to design and develop an instrument with a much better spectral resolution. The use of several techniques (diffraction gratings, Fabry-Perrots, ...) should be investigated in this context. At present, the use of a diffraction grating together with a photodiode array is believed to be a promising technique. In this case, it might become necessary to add a small telescope to the instrument or to fly it together with other experiments using a common light focussing device. In any case, the technology developed for this project should not be wasted and further efforts will be made to enhance its capabilities. For future flights of the ORA-occultation radiometer, missions should be chosen where the spacecraft allows a better pointing towards the Sun. In this respect, it is believed that one of the future EURECA-missions may fulfil the appropriate conditions. In any case, a better overview of the future flight opportunities scheduled by ESA or NASA should be available before all possibilities can be evaluated.

5.4. PUBLICATIONS

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6. THE IONIZED ATMOSPHERE

6.1. ATMOSPHERIC ELECTRICITY

Atmospheric electricity is involved with the origin and maintenance of the electrical charge distribution in the Earth's surface and adjacent atmospheric layers. Atmospheric-electric phenomena find their ultimate origin in meteorological processes. Therefore, their study is closely related to meteorology. Achievements, ongoing programmes and future perspectives in this field have been presented in 2.5.

6.2. IONOSPHERIC STUDIES

Achievements, ongoing programmes and future perspectives in this field have been presented in 2.6.

6.3. ION COMPOSITION STUDIES

Ion composition measurements in the altitude region between 15 and 50 km are of primary importance for understanding the phenomena of atmospheric electricity and aerosol formation. A study of the ion composition of the stratosphere can give additional information on trace gases and chemical processes in the stratosphere.

6.3.1. Achievements

Before 1977, no measurements about the stratospheric ion composition were available. In order to fill in this gap a set of balloon-borne ion mass [1,2] spectrometers have been developed at the Belgian Institute for Space Aeronomy [3]. Since 1977, these mass spectrometers, consisting of a quadrupole mass filter built into a high speed helium cryopump, have regularly been launched from the French CNES balloon launching bases in Aire-sur-l'Adour or Gap-Tallard [4,5]. These measurements resulted in a detailed set of data on the positive and negative ion composition in the stratosphere in the altitude region from 20 to 45 km and allowed a better insight in the processes and trace gas profiles governing the stratospheric ion chemistry [6]. The results can be summarized as follows :

- for positive ion composition : apart from the theoretically predicted proton hydrates ($H^+(H_2O)_n$- ions), a second family of ions, called non proton hydrates, have been detected. These ions can be represented by the formula $H^+X_\ell(H_2O)_n$ [7,8,9]. High resolution mass spectrometer measurements have allowed an unambiguous mass determination of X, namely 41 amu [10]. At present, the most likely candidate for the molecule X is acetonitrile (CH_3CN). An analysis of the ion spectra has allowed the derivation of a mixing ratio profile of CH_3CN in the altitude domain 20 to 45 km [11,12];
- for negative ions, two major ion groups were detected : $NO_3^-(HNO_3)_n$ and $HSO_4^-(HNO_3)_\ell(H_2SO_4)_m$. A comparison of the abundances of these two ion families resulted in a concentration profile of H_2SO_4 vapour between 25 and 45 km [13 to 17]. These measurements which, at present, are the only available from which H_2SO_4 vapour profiles can be deduced, are very important for our understanding of aerosol formation and sulfur chemistry in the stratosphere.

Some of these experimental results have been explained by model calculations simulating the vertical distribution of acetonitrile in the atmosphere (see also 3.1.) [18].

It should be noticed that the group of ion mass spectrometry of the Belgian Institute for Space Aeronomy is one of the only two groups in the whole World, which have obtained valuable results in the measurements of stratospheric ion composition. Together with the group of the Max Planck Institut für Kernphysik in Heidelberg (West Germany), they have delivered all the experimental in-situ data in this field, which are regularly referred in the literature.

Some remarkable achievements of the Belgian groups are :

- first ion composition measurements with ballon-borne instruments;
- first high resolution spectra of positive and negative ions;
- first measurements of the ion composition above 40 km (from 45.6 to 42 km) with a 1.000.000 m^3 balloon.

6.3.2. <u>Ongoing programmes</u>

At present, three complete instruments, based on quadrupole mass filters, are available in the Belgian Institute for Space Aeronomy.

Through several improvements, which are still going on, an extension of the mass range (up to 600 amu) as well as autonomy (flight duration) has been possible. The ongoing programme, at present, foresees in regular launchings from the French bases to complete the data set. At present, there still exists a gap in the data between 42 and 39 km and below 20 km. Modifications are foreseen in the focusing parts of the instrument to avoid cluster break-up.

Furthermore, a laboratory calibration unit is now built to allow more refined calibrations of the flight models.

6.3.3. Future perspectives

At present a data base concerning stratospheric ion composition at mid-latitudes is available, which gives a fairly consistent picture as far as the major ions are concerned. However, not all problems are resolved and the lack of data is clearly felt in the following domains :

a) more data are needed at high altitudes (above 40 km);

b) the data set should be extended to other latitudes;

c) correlations with other measurements should be made such as for negative ion measurements, e.g. a simultaneous measurement of aerosols, sulfur compounds and negative ion composition may lead to a better understanding of the sulfur chemistry and aerosol formation process. For positive (and negative) ions a simultaneous measurement of total ion density (with Guerdian condensers or other probes), ionizing radiation and ion composition would allow a better interpretation of data;

d) the development of high sensitivity instruments is of vital importance for the measurement of minor ions and other trace gases (such as methanol and chlorine compounds) and for the measurement of major ions without cluster break-up;

e) furthermore, the existing ion mass spectrometers can be converted to powerful analytical instruments, by adding for instance an external ion source, which can enhance the signal significantly and allow detection of trace gases such as HNO_3 on a regular base.

In view of the foregoing remarks, the future developments planned in the Belgian Institute for Space Aeronomy for the next ten years have to include :

- the development of very sensitive instruments (point d of foregoing paragraph). In order to arrive at this objective a collaborative programme will be started with the University of Bern (Switzerland) and the "Laboratoire de Chimie et de Physique de l'Environnement du CNRS" in Orléans (France), which intends the development of a balloon-borne magnetic ion mass spectrometer based on simultaneous detection techniques. An instrument ready to be launched should emerge out of this effort within the next five years;
- participation in collaborative international balloon campaigns with the intention of correlating ion mass spectrometry data to other measurements (point c of foregoing discussion) and extending the experiments to other latitudes (point b);
- the developments of new powerful, long standing cryopumps to allow low altitude flights and long duration balloon flights;
- the use of 2 or 3 high altitude balloons with existing or preferably newly developed more sensitive instruments (point a);
- finally, the development of a reliable ion source which can be added to the ion mass spectrometer and open new perspectives for trace gas detection through the so-called "active chemical ionization" technique (point e).

The realization of these objectives will certainly take 10 years even if the number of scientists within the Belgian group working on the programme would raise by 2 units.

Flight opportunities for balloon-borne experiments consists of two kinds :

1. those organized individually (or per institute) : such opportunities merely depend on financial means and development of ballooning techniques (reliable high altitude balloons);
2. campaigns : these opportunities depend upon international initiatives and are difficult to foresee on long term for ballooning. It is hoped, however, that within the framework of MAP/Globus a sulfur campaign will be organized in 1987, in which ion measurements would play a key role.

6.4 IONOSPHERIC D REGION STUDIES AND INCOHERENT SCATTERING STUDIES IN THE LOWER IONOSPHERE

6.4.1. Negative ions in the D region

The negative ion chemistry is characterized by numerous reactions involving positive, negative and neutral species. Classical solutions of the mathematical system describing such a chemistry do not point out the role played by each parameter. In order to overcome this difficulty the chemical system is considered as a graph, so it is possible to apply the signal flow graph technique which allows a quantitative evaluation of the various paths and loops. By this way it is possible to analyze the role played by the parameters. A daytime D region negative ion model was analyzed, by using this technique, in terms of transmittances, path gain and loops gain [19]. Using those concepts it was shown that five "equivalent" processes are sufficient to reproduce the total positive, negative and electron concentration in the D region [20]. This equivalent model was used in incoherent scattering studies of the terrestrial D region.

6.4.2. Chemical fluctuations and incoherent scattering

The attachment of free electrons to neutral molecules followed by detachment from the resulting negative ions leads to fluctuations of electron density in the lower ionosphere [21]. Such fluctuations superimposed on thermal fluctuations, enhance the scattering cross section for an incident electromagnetic wave. In order to take these fluctuations into account the continuum theory of incoherent scattering of an electromagnetic wave was modified [20]. The consequence of this, is that it is possible to understand the high power levels encountered in incoherent scattering studies of the D region in terms of this chemical fluctuation. The concept of chemical fluctuations implies the existence of new characteristic lengths of the ionized medium over wich these phenomena can be observed. Those "chemical lengths" have been analyzed for the daytime D region. The incoherent scattering studies of the D region are developed in relation with French groups i.e. the CEPHAG in Grenoble and the CNET in Paris. Experimental data are provided by both the French incoherent radar (St. Santin) and by the European incoherent system (EISCAT) located in polar regions (Norway, Sweden and Finland).

6.4.3. Future perspectives

The availability of super-computers like CRAY has opened the possibility of analyzing the incoherent radars data during polar precipitations in relation with informations coming out from polar orbiting satellites. A new project is now developed between the Belgian Institute for Space Aeronomy, the CEPHAG (Centre d'Etudes des Phénomènes Aléatoires et Géophysiques, Grenoble, France) and American teams (The National Research Laboratory, Washington D.C. and the Stanford Research Institute, California) in order to integrate numerical programmes on high-speed computers.

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7. SOLAR AND TERRESTRIAL RADIATION

Most physical and chemical processes in the Earth's atmosphere are mainly driven by solar radiation, with the Sun acting as the main energy source for the whole system. The maximum of the solar flux in the visible part of the solar spectrum is less attenuated during its penetration in the terrestrial atmosphere than the ultraviolet and infrared radiations. This selective penetration controls most of the parameters of the atmospheric environment.

Atmospheric photochemistry is initiated by the ultraviolet part of the solar spectrum leading to the dissociation of molecular oxygen in the mesosphere and lower thermosphere and the destruction of ozone in the stratosphere. The atomic oxygen produced in these processes is in turn the main source of stratospheric ozone. Absorption by ozone is responsible both for the heating of the stratosphere and the filtering of abiotic UV radiation received at surface level. Beside these important photochemical effects, important transfers of energy involve absorption of infrared radiation by minor constituents. In order to be analyzed, these phenomena also require the knowledge of the spectral distribution of solar radiation at the Earth's surface [1].

7.1. ACHIEVEMENTS

7.1.1. Balloon-borne observations

Observations of solar UV irradiance beyond 200 nm have been made by means of stratospheric balloons by the Belgian Institute for Space Aeronomy. The first accurate irradiance values for stratospheric studies were obtained from balloon flights in 1972 and 1973 [2,3]. These irradiance values are still valid and have been confirmed by more recent measurements performed by rockets, satellites and during the Spacelab 1 mission [4,5,6]. Measurements below 200 nm have also been conducted by means of rocket sondes [7].

The question of the long-term variability of solar UV irradiances has been addressed during the 70's. This problem is still under investigation because no quantitative values concerning the variability over a solar cycle can be deduced from available data. Balloon observations performed during the rising phase of solar cycle 21 (1976-1979) have provided an upper limit of 7% for long term variability around 40 nm [8]. This value has been confirmed by more recent observations. Theoretical investigations have been made by means of two-dimensional models of the stratosphere [9] in order to assess the chemical and thermal response of the stratosphere to solar UV variations.

7.1.2. Spacelab solar spectrum experiment

In recent years, indications of slight, global variations came from precise measurements of the solar constant from satellites. As such variations remained below 0.5 percent, very accurate irradiance data are needed to find out which spectral regions are responsible for these fluctuations. It is also evident that the needed accuracy solely concerns the relative radiation scale. It was an aim of experiment 1ES016 to yield the first solar irradiance data in such a relative but very precise radiation scale. The primary aim was to improve the absolute accuracy in the ultraviolet and infrared. While the irradiance is very accurately known between 330 and 1250 nm, data published recently have an internal accuracy better than 0.2 percent and seem to be absolutely correct at least within $\pm$ 1 percent. The irradiance data outside these spectral limits are relatively poorly known (in ultraviolet, errors up to 20 percent cannot be excluded) and need significant improvement. As these spectral regions are not accessible from the ground, only observations in space can improve the situation [10].

The solar spectrum experiment (1ES016) on Spacelab 1 measured spectral irradiances from 200 to 3000 nm on December 5 and 6, 1983 during the so-called full sunlit orbit [11]. It was the first time that such a broad wavelength range was investigated from space by means of one instrument. These solar observations lasted in total 13 hrs divided in two groups of respectively 7 and 6 hrs. Twenty-six solar spectra were finally recorded.

The instrumentation includes three spectrometers which are double monochromators using concave holographic gratings of 10 cm focal length as dispersion optics. The three spectrometers cover simultaneously the ultraviolet, visible and infrared domains. The scanning of each spectral range is made by setting the six gratings mounted in the same mechanical rotating shaft at 650 discrete positions by means of a stepping motor.

The bandpass of the three spectrometers is bell shaped and as a full width at half maximum of about 1 nm in the ultraviolet and in the visible, and of about 200 nm in the infrared. A transmitting diffuser is placed in front of the entrance slit in order to ensure a full illumination of the gratings, to reduce errors resulting from small drift in the solar pointing and to allow the measurement of the inflight calibration source output discussed below. The absolute solar radiation data are obtained by comparing the solar irradiance with the irradiance of an artificial light source, the radiation of which is known in absolute units. According to the procedure used in measuring absolute intensities in the center of the solar disk, this comparison is a differential one. The final comparison source, a blackbody with a circular diaphragm, lights the slits under almost the same circumstances as the Sun does in orbit, i.e. with nearly the same solid angle of the same (circular) shape.

Scientific and technical teams of the Belgian Institute for Space Aeronomy were involved in the design of the experiment, the development of mechanics (entirely made in the institute workshop) and of some electronic parts. They were also involved in the radiometric characterization of the three spectrometers. Pre- and post- flight calibrations were performed by means of transfer sources mounted in a dedicated calibration box which can be fitted to the instrument during ground operations. This project was an international cooperation between the Belgian Institute for Space Aeronomy, the "Service d'Aéronomie du CNRS" (France), the "Landessternwarte" (Heidelberg, FRG) and the Hamburger Observatory (FRG).

7.1.3. Long-term astronomical variation of solar irradiance

The insolation parameters depend upon 4 astronomical variables which affect the total energy received by the planet and 2 other ones which re-distribute differently the energy among the latitudes and months : the climatic precession and the obliquity [12,13]. This dependence has been carefully analysed and the long-term variations of the insolations computed over the last 5×10^6 years and the next 10^6 years [14]. The accuracy of these long-term variations of the astronomical elements and of the related insolation values and the stability of their spectrum have also been analysed [12 (p. 3-40), 12 (p.83-112)]. Against these long-term insolation variations, there is a secular trend which amplitude varies between hundredths to tenths of one per cent (more or less similar to the one associated to solar activity as measured by satellites) with quasi-periodicities associated to the motion of the moon (~19 yr) and perhaps of Jupiter. The predictability of the Wolf sunspot number has also been investigated [15].

7.2. ONGOING PROGRAMMES AND FUTURE PERSPECTIVES

7.2.1. Solar Irradiance Monitoring by Balloon (SIMBA)

The SIMBA project started in 1983 and is dedicated to measure the solar total irradiance and spectral irradiance in the ultraviolet and visible domains. The scientific objectives are the determination of the solar constant and its spectral distribution, the short-term variations of solar irradiance, the penetrations of solar radiation in the stratosphere and the determination of trace species like ozone and nitric dioxide by absorption spectroscopy.

The SIMBA project is an international cooperation between the Belgian Institute for Space Aeronomy, the Belgian Royal Meteorological Institute, the World Radiation Center (Davos, Switzerland), the Space Science Department of ESA (Noordwijk, the Netherlands), the Geneva Observatory (Switzerland), and NASA (USA).

7.2.2. Spectral distribution of solar irradiance variability during solar cycle 22

The purpose of this project is to measure the spectral irradiance of the Sun between 180 and 3000 nm. This wavelength range corresponds to 98% of the total energy output of the Sun. Consequently, comparison with simultaneous measurement of the solar constant will be possible. The periodicity of the flights (one per year) in the frame of the Space Shuttle NASA programme over the next solar cycle will provide quantitative values of the long-term variability from the ultraviolet to the near infrared.

This project is an international cooperation between the Belgian Institute for Space Aeronomy and the "Service d'Aéronomie du CNRS" (France).

7.2.3. Spectral distribution of solar irradiance variability related to solar rotation

Variations of the solar irradiance to the solar rotation will be quantitatively measured by means of an instrument integrated in the "European Retrievable Carrier" (EURECA) to be launched in 1988 (see 10.3.1). Spectral irradiances ranging from 180 to 3000 nm will be measured once per day during six months. Solar observations will be compared in orbit with in-flight calibration sources in order to check the radiometric characteristics of the instrument in orbit. This project is an international cooperation between the Belgian Institute for Space Aeronomy and the "Service d'Aéronomie du CNRS" (France).

7.2.4. Absolute solar irradiance observations

An absolute radiometer was developed at the Belgian Royal Meteorological Institute and flown on Spacelab 1. Its principle [16] is based on the comparison of radiative energy to electrical energy generated by the Joule effect. This radiometer is one of the three instruments which are used to define the World Radiation Reference, an internationally agreed standard in radiation meteorology. Any calibration based on the utilization of a radiation source or the use of another reference is excluded. This implies that all the nonequivalence parameters originating from the comparison of electrical and radiative power sources that are different in nature must be characterized. For that reason, the laboratory for absolute radiation measurements of the Royal Meteorological Institute has been equipped with an installation where these determinations can be made with a high stability laser source, either in air or in vacuum. The non-equivalence parameters take account of the difference in response of the radiometer to the solar radiation that passes through the aperture and to the electrical power that substitutes for it when the instrument shutter is closed.

The instrument whose ultimate purpose is to study the variations of the so-called "solar constant" during at least one solar cycle, was flown for the first time during the Spacelab 1 mission [17,18,19]. This radiometer, together with instruments developed by the Belgian Institute for Space Aeronomy for the SIMBA programme, is placed on board balloons for yearly flights. Furthermore, yearly space flights in the frame of the

Earth Observation Mission of NASA should carry a complete solar package including the absolute radiometer of the Royal Meteorological Institute.

A version of the instrument is also in the process of preparation for the ESA Eureca payload which is scheduled to be launched in 1988 (see 10.3.1). During this 6 months of the mission, solar oscillations of short to medium periods will be observed in the total solar irradiance.

This entire programme, on Spacelab, balloons and Eureca is accomplished in a close cooperation between the Royal Meteorological Institute and the Space Science Department of the European Space Agency.

Another programme, involving the measurement of all the components of radiative balance made with absolute pyrheliometers and pyranometers is accomplished in the frame of NASA's Earth Radiation Budget Experiment (ERBE). This programme has been described in 2.3.

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8. SOLAR SYSTEM PLASMA PHYSICS

Plasma physics is the study of partially or fully ionized electrically conducting gases. It is an interdisciplinary science based on classical electricity and magnetism, hydrodynamics, statistical physics and atomic physics. Solar system plasma physics is the study of plasma phenomena throughout the solar system, from the solar photosphere to the outer boundary of the heliosphere which is the cavity formed into the interstellar medium by the solar wind. The solar wind is a fully ionized plasma flow generated in the solar corona. It is magnetized and flows radially outward from the solar corona with a supersonic speed. The solar wind interacts with all the planets in the solar system. When a planet has a sufficiently intrinsic magnetic field, the interaction forms a magnetosphere, a cavity curved out in the solar wind flow by the planetary magnetic field.

Various physical processes link the Earth's magnetosphere, its ionosphere and upper atmosphere. The ionosphere is a transition zone between the fully ionized plasma of the magnetosphere and the lower layers of the atmosphere lying below. The Earth's magnetic field controls the dynamics of the magnetosphere. The study of the external geomagnetic field near the Earth's surface is the subject of external geomagnetism. Plasma phenomena occur also in the Earth's lower atmosphere, like those related to thunderstorm activity and ionization caused by cosmic rays and radioactivity. The study of these phenomena are subjects covered by the science of atmospheric electricity.

The external geophysical section of the Royal Meteorological Institute has performed achievements in atmospheric electricity, ionosphere and external geomagnetism. These achievements have been described in part 2 "Meteorology and complementary researches in atmospheric physics", respectively in sections 2.5, 2.6 and 2.7. Achievements of the Belgian Institute for Space Aeronomy in solar system plasma physics include studies of the Earth's magnetosphere and adjacent interplanetary space.

8.1. ACHIEVEMENTS

8.1.1. Kinetic models of the solar and polar winds

The polar wind, which is the escape of thermal ions out of the polar ionosphere along the open geomagnetic field lines is a phenomenon rather similar to the well-known solar wind flow of thermal protons out of the solar corona. Kinetic descriptions of these polar and solar winds were proposed and steady state models have been calculated [1 to 9].

The kinetic description of the polar wind was also particularly appropriate to study the interpenetration of the cold ionospheric plasma and the suprathermal plasma of magnetospheric origin [10]. This study led to the formulation of a non-linear relationship between the field-aligned current and the field-aligned potential difference along the open field lines of the polar regions [11,12]. In 1979, this theoretical result was identified in auroral observations. The current voltage relation along auroral field lines is in fact of primary importance if one needs to understand the formation of auroras.

8.1.2. The formation of the plasmapause and of the Light Ion Trough

The magnetosphere contains a large toric region in which ions and electrons of low energy (1 to 2 eV) are trapped. This region is called the plasmasphere. It extends 4 to 5 Earth radii in the equatorial plane. At this radial distance, the ionization density decreases rather abruptly. The surface where this drop in the density is observed is called the plasmapause.

A theory for the formation of this boundary layer has been developed. It is based on a physical mechanism which had been overlooked or neglected in earlier theories. This mechanism is a plasma instability, called plasma interchange motion, which is driven unstable beyond a critical surface called the Zero-Radial-Force (ZRF) surface. Beyond this surface the centrifugal force acting on corotating thermal plasma becomes larger than the gravitational force. Therefore, any plasma density enhancement located beyond this ZRF surface drifts outwardly across magnetic field lines and across the equipotential lines of the external electric field. From this theory a numerical model has been developed which allows to calculate the position of the plasmapause as a function of longitude [13 to 16]. It takes into account time variations of the plasmapause as a function of universal time and as a function of the geomagnetic activity index K_p. The results of this time dependent model have been successfully compared with observations of GEOS 1 for a period of 4 days in July 1977 and with other experimental results obtained by the whistler technique [17 to 20].

The Light Ion Trough (LIT) is another characteristic frontier of the plasmasphere observed in the topside ionosphere at mid-latitude along magnetic field lines which are slightly closer to the Earth than those corresponding to the equatorial plasmapause. Across this low altitude boundary the concentrations of the light ions (H^+, He^+) decrease rapidly as the latitude increases. The topside ionosphere at latitudes beyond the LIT is significantly depleted from its light ion contents. It has been demonstrated that the LIT is related to another critical surface called the Zero-Parallel-Force (ZPF) surface where the field-aligned components of the gravitational plus centrifugal forces balance each other [20].

8.1.3. Modelling of current layers in space plasmas

One important achievement in space plasma physics is the development of theoretical simulations of boundary layers in collisionless plasmas. This achievement is related to the recent discoveries of a number of space boundary layers separating regions of plasma, with drastically different parameters.

A type of current layer which is often observed in solar system plasmas is the so-called tangential discontinuity. In 1976, two models of such a current layer were developed, quite simultaneously, to explain the structure of the plasmapause [21] and of current sheets in the solar wind [22,23]. One of these models was also applied to the study of magnetic holes in the solar wind [24,25]. Finally, both models were combined to include all plasma and field parameters which may change across the transition layer [26]. This led to the build-up of a sophisticated model, of which the predictions can only be obtained by numerical computations made with a high-speed computer [27 to 29]. It can simulate the structure of current sheets in a collisionless magnetized plasma with multiple species. This model uses the most fundamental description, namely the kinetic theory treating the plasma as a collection of individual interacting particles rather than the magnetohydrodynamic formalism describing the plasma as a conducting fluid, since models based on this approach were unable to describe the structure of thin current sheets [30,31].

Transport processes are sometimes important in such thin layers and cannot be evaluated to collision-free plasmas without considering the kinetic approach. The dissipation can then be due to microscopic plasma waves which play a similar role as particle-particle interactions in collision-dominated gases. A study of the conditions for which these waves will grow or be damped has been made in order to determine the stability and thickness of the current layers [27,28]. The computer simulations of the structure of the Earth's magnetopause (the current layer bounding the magnetosphere) set up a lower limit to the thickness of a stable boundary (2.5 Larmor radii of solar wind protons). They are also able to mimic the observed magnetic hodograms recorded during selected satellite magnetopause crossings [26 to 28].

8.1.4. Mechanisms of penetration of the solar wind into the Earth's magnetosphere

The non-steady interaction of the solar wind with the Earth's magnetosphere has also been studied. It was suggested in 1976, at the European Geophysical Society Symposium on the Magnetopause Regions, that the solar wind plasma carries small-scale filamentary density irregularities which penetrate impulsively into the magnetosphere [32,33]. Thereafter, it was also shown that the direction of the interplanetary magnetic field controls the impulsive penetration of small-scale solar wind plasma irregularities into the magnetosphere [34,35]. This conclusion has been supported by Prognoz-7 satellite observations of intense solar wind-like plasma deeply engulfed inside the high latitude boundary layer, at the outermost of the magnetosphere during periods of southward turning of the interplanetary magnetic field direction.

This solar wind-magnetosphere interaction mechanism can also produce effects at the level of the ionosphere, which is heated [36], or at the level of the so-called magnetospheric boundary layer, which has been shown to be the stopper region of engulfed solar wind plasma elements [37]. The plasma irregularities present in the solar wind are plasmoids, i.e. plasma-magnetic entities which basically differ from ideal magnetohydrodynamic filaments [38]. The penetration of a plasmoid across a tangential discontinuity has been studied from a plasma kinetic point of view. The theoretical results apply to the Earth's magnetopause [39].

8.1.5. Magnetospheric plasma distribution

Modelling of the electron density distribution along a geomagnetic field line has also been carried out [40]. This modelling has proved to be useful for the experimenters interpreting the 'whistlers' spectra (whistlers are electromagnetic waves in the kilohertz range propagating back and forth between hemispheres along field-aligned ducts of enhanced ionization).

8.2. ONGOING PROGRAMMES

8.2.1. The International Sun Earth Explorer (ISEE)

ISEE is a joint ESA/NASA mission designed to measure the dynamic properties of the magnetosphere and the solar wind in front of the magnetosphere. ISEE-1 and -2 were launched in tandem in October 1977 and placed in an eccentric orbit with apogee at 22.5 Earth radii, so that a good coverage of all magnetospheric regions would be achieved in one year. ISEE-2 has a manoeuvring system to maintain a preselected separation relative to ISEE-1.

The Belgian Institute for Space Aeronomy has a participation in ISEE Guest Investigator Programme of NASA. It consists of a quantitative modelling of the interface between the magnetosphere and the solar wind (the so-called magnetopause boundary). The Belgian project has for primary objective a comparison between ISEE-1 and ISEE-2 observations of magnetopause crossings and calculations obtained from kinetic models of directional discontinuities.

The Guest Investigator Programme of NASA offers the opportunity to analyze and interpret the data in collaboration with the ISEE experimenter groups. Several ISEE magnetopause crossings are being analyzed and interpreted using the magnetic field data from the University of California (Los Angeles) and the plasma data from the University of Iowa.

8.2.2. Ulysses

The primary objective of the Ulysses mission is to investigate, for the first time, the properties of the uncharted third dimension of the heliosphere. Besides nine flight experiments and radio-science investigations which - at specific mission periods - make use of the spacecraft and ground-communication systems to perform scientific measurements, interdisciplinary investigations have also been selected. The latter will use data from more than one Ulysses experiment to address specific questions of out-of-ecliptic science.

The participation of the Belgian Institute for Space Aeronomy lies in an interdisciplinary study of directional discontinuities [41]. To achieve this goal, simultaneous magnetic field and plasma data obtained during the Ulysses mission will be analyzed and the results will be interpreted by means of theoretical models of discontinuities in collisionless plasmas.

The European contribution to the Ulysses programme consists of the provision and operation of the spacecraft and about half of the experiments. NASA will be responsible for providing the launch, the remaining experiments and the spacecraft power generator, and will support the mission using the deep-space communication network.

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9. PLANETOLOGY

Although no planetary science programme has been carried out by ESA so far, considerable interest exists amongst Belgian scientists for this field of research. In the past, there have been individual collaborations with NASA planetary programmes and participation in several ESA payload definition teams.

Possible planetary missions now under consideration by ESA are expected with interest by the Belgian scientific community (Kepler, Venture, Cassini,...). Theoretical aspects have also been investigated. Furture Earth orbiting telescopes will be used by Belgian planetologists.

9.1. ACHIEVEMENTS

9.1.1. Participation in the NASA Pioneer Venus programme

As guest investigators of this planetary programme, scientists of the Institute of Astrophysics of the University of Liège took part in the analysis of the observations of the Orbiting Ultraviolet Spectrometer (OUVS) on the Venus orbiter spacecraft. The δ bands of NO have been observed systematically. The existence and intensity of a "bright spot" near the equator at about 2 a.m. local time provided an important confirmation of the day-to-night Venus thermospheric circulation [1,2]. The measurement of the altitude of the airglow layer served as a basis for the determination of the magnitude of the turbulent transport on the Venus nightside and confirmed the validity of the circulation concept [3,4].

9.1.2. Theoretical study of planetary insolations

The Belgian Institute for Space Aeronomy has carried out studies of different aspects of the solar radiation incident at the top of the atmosphere of the inner and outer planets of the solar system [5,6,7,8 - 9].

In particular, changes in the mean seasonal daily insolations at the top of the Martian atmosphere caused by significant large-scale variations in the eccentricity, obliquity and longitude of the perihelion

[10] and, at the Martian surface, caused by global dust storms characterized by various atmospheric optical thicknesses, have been studied in detail [11]. The results obtained for Pluto [12,13,14] illustrate the sensitivity of Pluto's insolation to changes in obliquity and clearly demonstrate that this insolation might considerably differ between the present-day epoch orbital configuration and alternatives in the past or in the future.

9.2. ONGOING PROGRAMMES

9.2.1. Ultraviolet imaging of giant planets with the Space Telescope

A sizable amount of time has been allocated to this programme in the frame of the "guaranteed observing time" with the Faint Object Camera (FOC) built by ESA for the Hubble Space Telescope (HST). These observations will start within 6 months of the launch of the HST. The scientific objectives of these observations are essentially :

- to obtain far ultraviolet high spatial resolution images of the particle-induced emissions detected by Voyager in the atmospheres of Jupiter, Saturn and Uranus;
- to observe the variability, the intensity and the longitudinal dependence of these emissions and use this information as a basis for new auroral particle acceleration models;
- to study the Saturn's and Uranus' ring and torus environment and their interaction with the high energy particles.

These new observations will amplify and complement the results collected by the Voyager probes during their encounters with the Jovian planets.

9.2.2. Theoretical study of planetary insolations

Presently, a computer programme is elaborated in order to compute the effect of the major rings (A, B and C) on the direct solar radiation at the top of Saturn's atmosphere. A second topic deals with the study of the combined effect of global dust storms and oblateness on the solar radiation on the planet Mars.

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10. FUTURE DEVELOPMENTS

10.1. PLANETARY MISSIONS

10.1.1. ESA Kepler Mars Orbiter Mission

The European Space Agency is considering the possibility of developing a low cost geophysical Mars orbiter with launch possibilities in 1990 or 1992. A spinning spacecraft with its spin axis pointing toward the Earth is foreseen. The excentric polar orbit should have a nearly 24 hrs period. Its scientific goal is to fill in part of the gap left by previous Mariner and Viking missions in the study of the Mars atmosphere, ionosphere and surface.

A Belgian working group with scientists from the Vrije Universiteit Brussel, the University of Liège and the Institute for Space Aeronomy met several times to define the key scientific objectives, concepts and technical feasibility of a visible/UV spectrometer to be eventually proposed as part of the Kepler payload. Various aspects were examined such as :

a) implications of the orbital characteristics of the mission on the condition of observation [1];
b) geometry and range of applicability of occultation measurements of ozone, oxygen and water vapour [2,3] near periapsis;
c) measurement of the visible/UV airglow of the planet's atmosphere and determination of ozone by UV limb radiance sounding [4];
d) interaction between the solar wind and the planetary environment;
e) surface mapping in different spectral bands;
f) imaging capabilities of the instrument [4].

A versatile programmable instrumentt able to meet both the scientific objectives and the specifications of the ESA phase A has been conceived.

10.1.2. Other planetary missions

Besides the Kepler Martian orbiter, no mission has gone through a phase A study. Other ones, however, are presently discussed. The two candidate missions quoted in the Horizon 2000 ESA document are Venture and Cassini.

Venture would be a pure ESA mission consisting of a Venus orbiter with multiple entry probes in order to study the planet for a longer period than previous observations.

The Cassini probe is studied in collaboration between NASA and ESA. The spacecraft would orbit Saturn and release a lander into the atmosphere of Titan. The orbiter will be a Mariner Mark II type spacecraft designed by the Jet Propulsion Laboratory to succeed the present Voyagers. ESA is working on the design of the Titan probe which, after having achieved a 30 min parachute descent into Titan's cold atmosphere will operate on the ground for several hours at the expected temperature of liquid methane. Moreover, the orbiter will also be scheduled to perform a series of encounters with Titan and its atmosphere together with observations of the planet and its rings. This mission will be the first visit to Saturn after the Voyager programme. When the ESA-NASA study will be completed, a call for proposals to the European and American space science groups will be made, to determine which instruments and investigation techniques will actually be used on the orbiter and Titan probe. It is at that time, as was done for Kepler, that the Belgian scientific community will propose specific observation designs. The present planning for the mission envisages a launch date in 1994, a flight time of about 8 years and 4 years of operation. No part of the mission has yet been approved on the American side.

Besides Cassini, no other European planetary probe has been further than preliminary discussions.

Finally, studies of physical processes generated by the magnetosphere of the giant planets will be possible from the Lyman Earth orbiting EUV telescope. This joint ESA/NASA project is presently in the assessment study with a possibility of phase A study in 1986.

10.2. SPACE PLASMA OBSERVATIONS

10.2.1. Cluster

Scientists of the Belgian Institute for Space Aeronomy are interested in participating in the proposed CLUSTER mission whose objectives are to study small-scale structures which are fundamental in determining the behaviour between cosmic plasmas. The Earth's magnetosphere and the region where it interacts with the solar wind form the closest and most accessible environment in which these processes can be studied. The CLUSTER mission will comprise four spacecrafts.

The national participation in CLUSTER would be an interdisciplinary study of these interaction regions and a comparison with the theoretical models developed at the Belgian Institute for Space Aeronomy.

At present, two European industrial consortia are independently performing phase A studies and evaluating alternative mission concepts. The stack of four spacecrafts will be launched by either an Ariane-4 rocket or a Space Shuttle.

10.2.2. Soho

The SOHO mission proposed as part of future ESA projects falls also in the field of interest of the Space Plasma Physics group of the Belgian Institute for Space Aeronomy. Indeed, one of the objectives of the SOHO mission is to study the solar wind, particularly the small-scale physical processes which occur at the Earth's orbit and between the Sun and the Earth.

The Belgian participation in SOHO would be an interdisciplinary study of the small-scale physical processes which occur in the solar wind.

A Phase-A study of the SOHO mission was completed by December 1985.

10.3. LOW-ORBIT EARTH OBSERVATORY

10.3.1. Eureca spacecraft

The European Retrievable Carrier (Eureca) is a spacecraft designed by ESA to be left in orbit by the American space shuttle and be retrieved after a six months mission by another shuttle flight. Its modular design is based on an instrument support structure used during the first Spacelab flight, the European bridge. A similar design has already been tested on the Shuttle Pallet Satellite (SPAS) for a much shorter operation time. Eureca will have large electrical power through the used of solar arrays which will be permanently turned to the Sun, letting one of the spacecraft faces always lit. Therefore, through the occultation technique, this should prevent solar physics experiments and atmospheric studies from interfering with the use of the spacecraft for microgravity. The first Eureca flight will involve, beside a material science payload, several instruments described in this report : the solar total irradiance radiometer, the solar flux spectrometer and the occultation radiometer.

For the second flight, it is intended to propose an instrument associating the Spacelab grille spectrometer with a new occultation visible radiometer based on the ARAMIS design (see 5.2.1). The association of this instrument with other atmospheric remote sensing packages could constitute a complement to the NASA Upper Atmospheric Research Satellite (UARS) and the NASA EOM (Earth's Observation Missions) programme. The orbit altitude and inclination of the Eureca spacecraft should be optimized for atmospheric science. Normal operation include a transfer of Eureca by its own propulsion system from the development orbit up to the operational altitude and, at the end of the operation, a return down to a retrievable orbit, thus allowing even more flexibility.

10.3.2. Space Station and Columbus project

Space Station is a project, presently included in the NASA programme, which aims the realization of a manned base in permanent orbit around the Earth. Such a platform would have a low inclination (28.5 degrees), low altitude (500 to 600 km) orbit to allow easy servicing by the existing space shuttle. It would offer a pressurized environment for scientific research and permit the accomodation for attached payloads. Apart from giving a unique opportunity for scientific applications, SPACE STATION may also be used as a servicing station for assembly and repair of satellites or other payloads and as a transportation node, where vehicles are deployed to other final destinations such as geostationary orbits or planetary missions.

Concurrent with this NASA project, which is at present in early design phase, ESA is studying a similar project, COLUMBUS, which is also in a preparatory phase and for which the following elements are under definition :

- a pressurized module attached to, or integrated with SPACE STATION, taking into account the compatibility of such a module for a free-flying mode;
- free-flying platform either co-orbiting with SPACE STATION and/or in polar orbit, operated as part of the space station system;
- a service vehicle to support the free-flying platforms;
- a resources module to provide the services and resources required for the pressurized module in its free-flying mode;
- ground facilities in Europe to support the orbital operations of the above COLUMBUS elements together with NASA.

From the Belgian side, the community of External Geophysicists and Earth observation scientists could be represented by developments of existing instruments, which have flown either on Spacelab or Eureca and for which the concept of remote sensing has been applied and demonstrated. These experiments would essentially cover the field of solar irradiance monitoring and remote sensing of the stratosphere, mesosphere and thermosphere.

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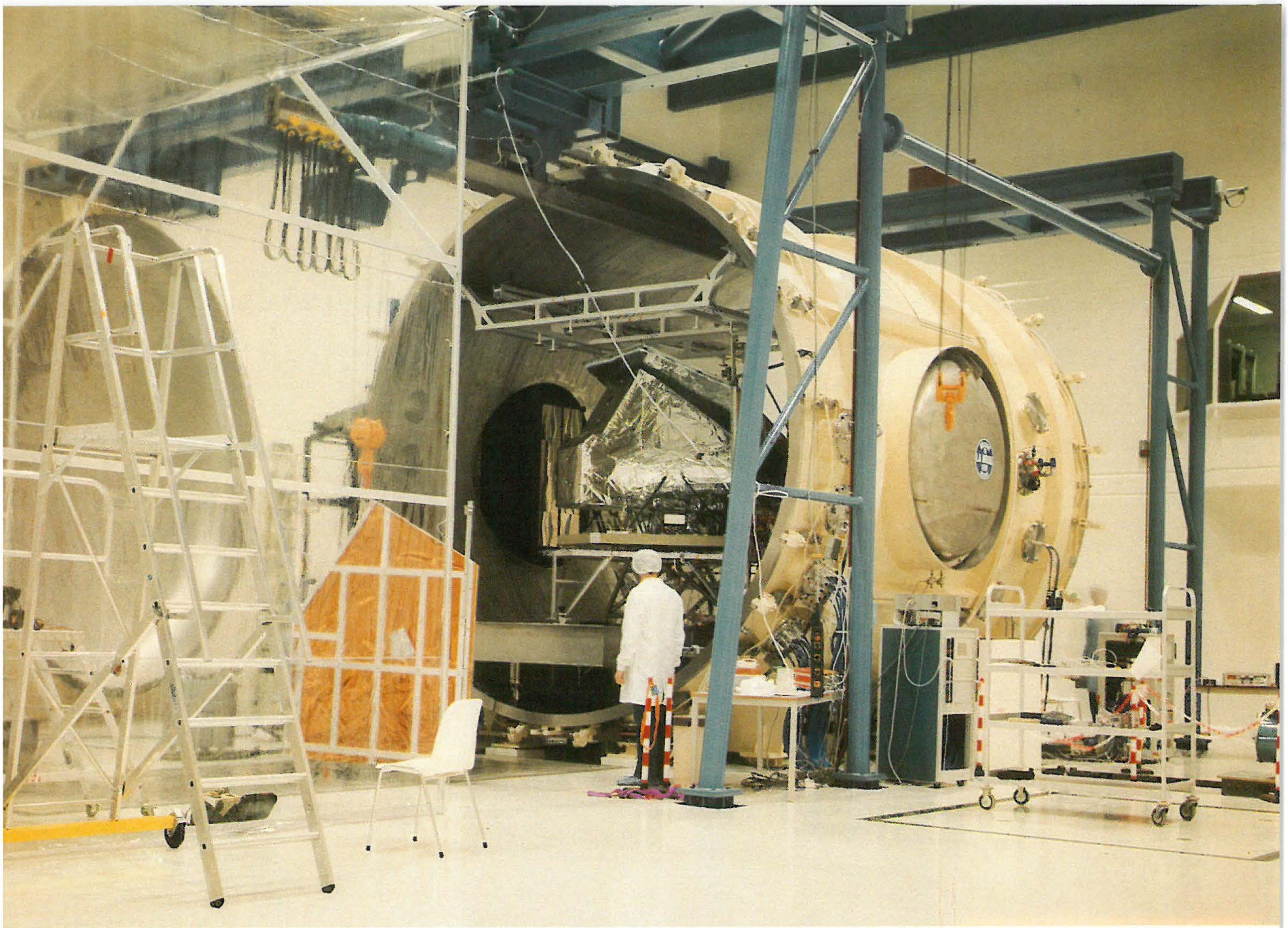
III SPACE ASTRONOMY

The new IALS Vacuum optical Bench



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BISA : BELGIAN INSTITUTE FOR SPACE AERONOMY
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1. INTRODUCTION

From the start, astronomy has been one of the major scientific fields making full use of the new opportunities offered by the development of space science and technology. Since early in the sixties, astronomical research related to space astronomy was performed essentially at the Institute of Astrophysics in Liège and at the Royal Observatory of Belgium.

In this report, we only attempt to cover the main developments of space astronomy in Belgium over a period starting in 1970. So, we just mention for historical purpose the anterior works performed at the Royal Observatory on the Moon's profiles and on the space triangulations using stars as references. For the same reason, we only quote the simulations of cometary plasma by gas release from skylark rockets in the high atmosphere performed by the University of Liège.

In the period of concern, the first important experiment developed in the University of Liège has been the Ultraviolet Bright Star Spectrophotometry (the so-called S2/68 experiment) embarked on the ESRO/TD1 satellite. The first project was followed by several others including more recently e.g. the Faint Object Camera of the Space Telescope, Giotto camera and Hipparcos. All these participations gave rise to a lot of laboratory work, to many publications and to a very active attendance to many commissions and committees at the national, European and international levels. In the same period, the Royal Observatory is essentially concerned by the preparation of the input catalogue of the Hipparcos mission and on a routinely operational basis with the observation of the irregularities of the Earth's rotation using satellite orbit as reference.

Some of the activities now performed in the space astronomy field are more than twenty-five years old, going back to the COPERS period, before the constitution of ESRO. The formation of a space team in the Institute of Astrophysics of Liège dates back to that period. This team, now so-called "IAL Space", has progressively acquired a particular status due to a concentration on space hardware and a development of the size of the team. This tendency has recently materialized by the installation of the IAL Space team in new premises with new space test facilities. This move has not prevented the Institute of Astrophysics of Liège from keeping an important activity in the field, mainly related to space data acquisition, reduction and analysis.

A very important part of space astronomy is continuously performed on a routine and operational basis at the Royal Observatory of Belgium with the tracking of the US Navy navigational satellites for Earth's rotation purposes. To avoid any duplication in this report, the whole work performed in this area has been treated in the "Space Geodesy and Earth's Rotation" section.

2. BELGIAN ACHIEVEMENTS

Belgian astronomers have always been very active in a lot of scientific or technical, international, European and national committees since the inception of space astronomy programmes. It is quite impossible to give an exhaustive detailed list of these participations.

Scientists of the Institute of Astrophysics in Liège have been involved in the definition studies of many ESA missions : LIRTS, Space Schmidt, Magellan/Lyman, etc.

The same group with the Astrophysics Department of the State University of Mons has been involved in the reduction of data of the Ultraviolet Bright Star Spectrophotometer (S2/68 on TD1 satellite) of reduction of spectra from different satellites such as the International Ultraviolet Explorer (ESA/NASA/UK), the Dutch Astronomical Netherlands Satellite, the NASA Copernicus. The University of Mons participated to the Dutch BUSS balloon spectra analysis and to the SMM X-rays mission.

IAL Space has naturally participated to several projects :

- Scanning of the sky in the far ultraviolet (S2/68 instrument on board TD1/ESRO satellite).
  TD1 was launched in 1972 from Vandenberg. The instrument provided data on the ultraviolet flux of more than 30000 bright stars during its 2.5 year lifetime. The instrument has been built in

collaboration with the Royal Observatory of Edinburgh and University College London.

- Halley Multicolour Camera.

  HMC has been embarked on Giotto which probed the Halley comet in March 1986. The aim of the camera was the observation of the inner coma and of the nucleus of the comet.

  HMC provided more than 3000 pictures during the 4 hours of the encounter with Halley. These pictures are analysed by the group of several institutes which collaborated to the instrument development. The leader of the team is the Max Planck Institute in Lindau (Fed. Rep. Germany).

Besides these pure scientific projects, IAL Space has also been engaged in the development of astrophysical instruments as co-contractor or sub-contractor of European consortia. In that particular category, the main projects to be considered are :

- Tests and certification of the Detector Head Unit of the Faint Object Camera.

  The FOC is the European contribution to the NASA Hubble Space Telescope. IAL Space has developed a prototype of the image photon counting detector and has tested in the far UV all prototypes and flight models of the detector unit. This project was executed as co-contractant of British Aerospace.
- Calibration of the Faint Object Camera.

  IAL Space was responsible of the photometric calibration of the FOC. This operation was subcontracted by Dornier System (F.R. Germany).
- Design and construction control of the new IAL vacuum optical bench.

  The optical bench is a table of 12 sq. m based on a 300 ton concrete block. The table is situated in a 5 m diameter and 7 m long thermal vacuum chamber. The new facility is installed in a 600 sq. m clean room. It has been developed with the help of ESA for its future optical payloads and satellites.

3. ONGOING PROGRAMMES

The Royal Observatory of Belgium is the official Belgian representative into the Input Catalogue consortium INCA. He also acts as the official representative in the INCA Steering Committee and in the Executive Committee for the Double and Multiple Stars Catalogue.

The State University of Mons was and still is involved in the analysis of the SMM satellite X-ray data.

IAL Space is also busy with the Hipparcos satellite. The laboratory has designed and manufactured the Optical Ground Support Equipment of Hipparcos. This system represents 10 optoelectronic instruments of extreme sensitivity and accuracy. IAL Space is also involved in the thermal balance and thermal vacuum tests of the different models of the payload. These tests have to be performed in the new optical vacuum facility of the group.

4. FUTURE DEVELOPMENTS

The work associated with the Hipparcos INCA consortium is far from being complete. It will be continued at the Royal Observatory during the next several years. Moreover, it is not excluded that a back-up complementary Hipparcos mission be scheduled in the next decade.

The Astrophysical Institute of the State University of Liège will continue its data reduction and analysis from either the archives of IUE, Exosat, or from future satellites such as the Hubble Space Telescope and the ESA Infrared Space Observatory.

In the immediate future, the scientific activity of IAL Space will be limited to the participation of the analysis of the Giotto HMC images. This institution has been and still is participating to definition studies of new projects within ESA like Magellan/Lyman, an EUV observatory mission, or the development of low-light level imaging detectors.

The Astrophysics Department of the University of Mons is presently concerned with the use of laboratory data coming from ground based experiments (like JET) for further studies of the physics of solar corona and hot regions. Furthermore, it is hoped to make use of the HST facilities for the study of high mass loss evolved stars.

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IV SPACE GEODESY

Tracking station of the TRANET network and Time service, both in support of International Earth observation and Space Geodesy Programmes.

SUB-COMMITTEE FOR SPACE GEODESY

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Acronyms

NGI : National Geographical Institute

RMS : Royal Military School

ROB : Royal Observatory of Belgium

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1. INTRODUCTION

Time determination, Earth rotation and space geodesy are three topics closely related and whose progresses depend on each other : improvement in one field is immediately projected on the others. Moreover they are addressed to the whole Earth and in consequence both the observational materials and the data analysis result through a well established international effort.

During the last 20 years space techniques have forced an improvement of 10^5 in time determination, while the parameters of Earth rotation and geodesy have been improved by a factor 100. The precision is now at the level that geophysical researches, such as monitoring of plate tectonic deformation, are now accessible by space methods.

Belgian groups are taking an active part in those developments. However, in space geodesy and Earth rotation studies more particularly, the Europeans benefit from satellites launched by the USA where, since 1957, the importance and the necessity to support Earth Sciences Studies have been understood. Europe has a long delay in this orientation but a first European Solid Earth mission could be expected in the early nineties.

No special budget has been used to develop the researches and developments in the field of Time determination, Earth rotation and space geodesy. The activities were conducted under the ordinary budget of the Institutions.

2. BELGIAN ACHIEVEMENTS

Since the installation of the Bureau International de l'Heure (1920), the Royal Observatory of Belgium (ROB) is deeply concerned with the measurement of the Earth rotation parameters. Till 1970 such observations were exclusively conducted through astronomical methods : the stars were used as a reference frame.

About 80 stations around the world contributed to this programme and one of the difficulties was to determine the relative coordinates of the participating stations in a reference frame which is free from the deviations of the vertical.

For this reason the European geodesists decided in 1964 to deploy, among other projects, a first space experiment to determine the relative positions of the European sites where the national references were installed.

During this first campaign of space geodesy, the ROB made regular observations from 1966 till 1971.

Several computer programmes for data analysis were designed and the results were published in a European final report [1].

The National Geographical Institute (NGI) also participated in this campaign by installing the tracking station at the ROB.

In 1970, the precision in the determination of the station coordinates became so good that, for the first time, a tracking network succeeded to detect the polar motion.

This performance was reached by the NAVY NAVIGATIONAL SATELLITE SYSTEM (NNSS). This network was then opened for public participation and in 1972, the ROB became the first institution to join the NNSS group [2].

A tracking station was installed at the ROB and data acquisition started in June 1972.

From that date, satellites are tracked on a daily basis at the ROB, while the tracking equipment has been improved on several occasions [3].

The main purposes of these observations are :

- determining the pole position,
- providing the precise positions and velocities of the tracked satellites, called the precise ephemeris (PE).

One position of the pole is determined each 2 days while about 10,000 passes are observed each year.

Several computer analyses were developed [4,5] which lead us, among other results, to detect the apparent variations of the distance between the tracking station and the satellite; they are generated by the second order effect of the ionospheric refraction [6,7,8].

Aiming to unify the European geodetic networks, the ROB participated in the organization of two European campaigns of space geodesy : EDOC-1 (1975) and EDOC-2 (1977). For EDOC-2, data were acquired by 36 stations and jointly with two other institutions (IGN, France; IFAG, RFA) the ROB acted as computing center [4,9,10,11].

Other topics are the development of dedicated softwares for :

(a) determination of satellite orbits based upon the observations obtained in one station;
(b) determination of the coordinates of a ground network based upon a preknowledge of the satellite orbit;
(c) simultaneous determination of the satellite orbit and/of the coordinates of the ground tracking stations [4].

During the same period the ROB took part in the proposals and first studies for a European space programme dedicated to Solid Earth observations. It conducted to the definition of the ESA project called POPSAT, expected to be launched in 1992 [12,13,14].

3. ONGOING PROGRAMMES

At the ROB the actual programme is expected to be maintained till 1994 as the NNSS is expected to be replaced at that time [15]. Also, for the time being, studies still continue aiming to determine the Earth rotation parameters and to test several system improvements, mainly to model or remove the atmospheric drag.

Several systems could be considered as a successor to NNSS; among them, the Global Positioning System (GPS) is a candidate. It will be operational in 1988-1990 and Belgian groups are interested by this new approach of space geodesy. One GPS receiver has been acquired by a Belgian company and it will be at the disposal of three Belgian institutions : the Royal Military School, the NGI and the ROB.

Preliminary programmes were already defined and experimental campaigns have been initiated. The NGI has already conducted a campaign of differential positioning over short distances (max. 50 km). For two of the three groups the main interest of GPS is concerned with the real time or quasi real time positioning.

On the other hand the time transfer via satellites is reaching a better accuracy than via ground transmitters [16].

Since 1972, the ROB has some experience of satellite time transfer via NNSS; the accuracy is of the order of 50 microseconds. The new generation of navigation satellites is giving an accuracy ranging from 10 to 100 nanoseconds.

The ROB is equipped with such a GPS receiver and is experimenting this new type of time transfer for which the main limitation is related to ionospheric perturbations.

4. FUTURE PERSPECTIVES

a. Scientific aspects

Most geophysical parameters of the Earth are derived from the measurement of the time variations of station positions distributed on the surface of the Earth. With the space techniques the precision has been improved progressively to reach, presently, a quality which competes or is even better than most of the terrestrial methods [17].

As an example, current plate tectonic models are reflecting motions deduced from the integration of plate displacements over millions of years.

The comparison of the time evolution of station coordinates, deduced from space methods after a few years of observations, shows motions of the same order of magnitude.

This means that space techniques are reaching the precision required for studies, in a reasonable time scale, of problems related to regional and global plate tectonics.

Of course this requires [14] the establishment :

(a) of an Earth reference system defined by a set of ground stations whose time evolution in position is continuously monitored and regularly determined;
(b) of an inertial reference system in which the Newtonian equations, describing the motion of the satellite, are written;
(c) the knowledge of the relations between the terrestrial and the inertial reference systems.

For all geodynamical studies of the Earth these are a pre-requisite and imply researches for :

(a) the determination of station motions located at the surface of the Earth;
(b) the monitoring of the polar motion;
(c) the control of fluctuations of the Earth rotation around its spin axis;
(d) the motion of the geocenter;
(e) the modeling of the Earth's interior, aiming to estimate accurately the astronomical nutations of the Earth.

The level of accuracy must be of the order of few centimeters in position or 0"001 in orientation.

In 1983, the accuracy of absolute point positioning from radio satellite tracking was around 50 centimeters [17]; recent experiments with a drag free satellite (NOVA), from the TRANSIT series, demonstrated that with a good monitoring of the atmospheric drag, the precision increases by 50% [15]. A new improvement can be expected as soon as a tailored gravity field will be used to process the data of such a satellite.

The experience gained during the last years and the simulation using a dedicated satellite show that the required accuracy is attainable.

Precise space and ground positioning will provide primary information for numerous studies in geophysics and will answer fundamental questions such as :

- are the continental plate motions episodical or not ?
- how are plate motions and deformations related to seismic activity ? (It is one of the most critical questions of the decade).
- what is the magnitude of the relative motions inside a plate ? (vertical and horizontal deformations will inform on the viscosity of the mantle).
- are the jumps detected in the polar motion related to pre-seismic activities ? (If yes it would be an excellent indicator for earthquake prediction).

b. Flight opportunities

From the observations obtained by a set of ground stations, the orbit of a satellite and the Earth rotation parameters are determined by adjusting several parameters related to the geometrical characteristics of the orbit, some unknowns related to the modelisation of the atmospheric perturbation and local parameters.

Besides the necessity to collect data of high quality, the experiences show that to reach these objectives, several types of problems are to be solved, namely [17] :

- the effect of the unmodelled contribution of the Earth's gravity field;
- the partially non predictible effect of the atmospheric drag;
- if radio signal technique is used, the atmospheric perturbations are difficult to model;
- the ground tracking network must have a world coverage, as homogeneous as possible and in continuous operation.

It means that the space vehicle, its orbit and the tracking network must fullfil a set of requirements that fortunately are now possible to achieve. It is worthwhile to mention [14,18] :

(a) from the past experiences it appears that for the deployment of a continuously operating network the observation technique must have an all weather capability. In consequence a radio tracking method must be used.

(b) the contribution of the unmodelled part of the Earth's gravity field and satellite resonance effects can be limited by the selection of an appropriate altitude, higher than the altitude of most of the satellites presently used for geodesy. A high altitude will also have the advantage to limit or even to remove the atmospheric drag.

(c) the use of a radio method for satellite tracking has the disadvantage to rise the atmospheric perturbations (tropospheric and ionospheric). The last one is automatically resolved as soon as the liaison between satellite and ground is operated with a carrier signal of the order of few gigahertz.

For the geophysical studies one satellite in orbit will fullfil most of the objectives after 5 or 6 years of operation.

The ESA project POPSAT, to be launched in 1992 is a very good opportunity for the projects here described, however it is a little bit too late (2 years) to have a good period coverage with the system presently in use (NNSS) which will be closed in 1994.

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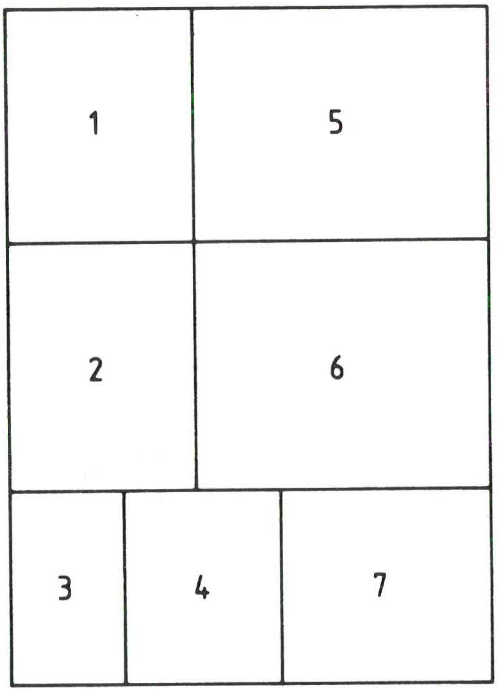
V MATERIALS SCIENCES



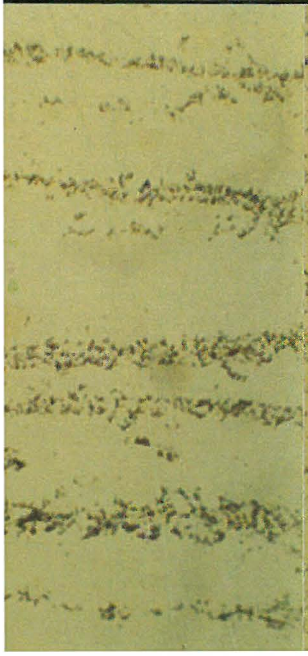
1-2 $Cu-SiO_2$ composite samples melted and solidified on earth (1) and during the microgravity period of the sounding rocket Texus 7 flight (2). The homogeneity of the dispersion is better in the Texus 7 sample.

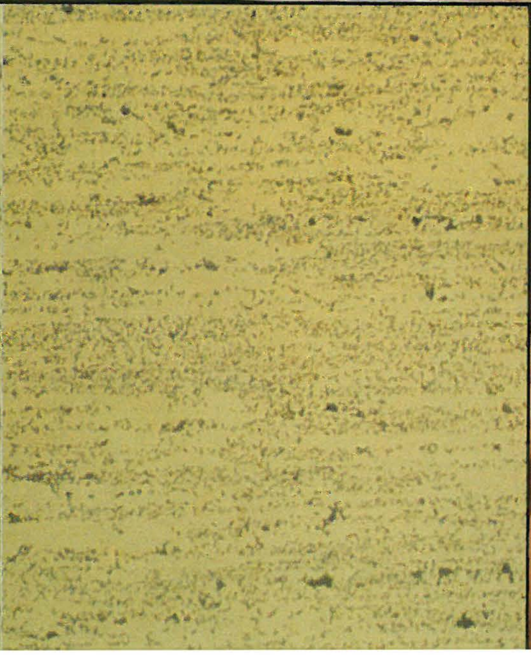
3-4 Microstructure of $Cu-Al_2O_3$ composite melted and solidified on earth (3) and in space (4). A better homogeneity is observed in the sample processed during the D1 Spacelab mission.

5 During KC 135 parabola, the scientific astronaut Dr. R. Furrer is testing the Fluid Physics Module which had to participate to the D1 Spacelab mission in November 1985.

6 During Keplerian parabolic trajectories of the specially adapted KC 135 aircraft of NASA, different experiments on capillarity and wetting are performed. Four free floating experimenters can be seen (Dr. D. Frimout (B), Dr. D. Neuhaus (D), Dr. J. Padday (G.B.) and Dr. J.C. Legros (B).

7 Wetting property experiment performed in a free floating cuvette.





SUB-COMMITTEE FOR MATERIALS SCIENCES

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Acronyms

KUL : Katholieke Universiteit Leuven
RUCA : Rijksuniversitair Centrum Antwerpen
ULB : Université Libre de Bruxelles

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1. INTRODUCTION

Materials Sciences in Space are concerned with the particular problems encountered in crystal growing, in solidification of metals, alloys and glasses in space laboratories. The influence of the reduced gravity on the fluid mechanism processes, on the heat and mass transfer in the liquid phase and on the interaction between liquid phases and interfaces are studied. The perturbations of the volumic forces on the solidification processes (g-jitter), the important role of the capillary forces combined with the wetting properties are an important part of the researches performed under microgravity conditions.

The mechanisms of formation of gas bubbles and the coagulation of small size particles are highly modified by the weightlessness conditions. These phenomena influence the impurity distributions, the structure, the physical and mechanical properties of the materials obtained in space laboratories.

The developments of these studies contribute to a better understanding of the fundamental laws of solid and fluid physics, to the elaboration of scientific laws governing terrestrial technologies and to solve general problems of materials sciences.

The Marangoni convection, induced by surface tension gradients due either to thermal gradients or concentration gradients or both, is related to the properties of the existing free surface between a liquid and a gas phase or between two immiscible liquid phases. The motions generated at the interfaces are propagated into the bulk phase by viscosity.

The influence of Marangoni convection, in systems with crystals growing from melt, on impurity and morphological defect distributions are studied in relation with the development of materials sciences in space. The relations between these distributions and hydrodynamics are central points of most of the studies in this field.

The solidification processes of metals and alloys under microgravity conditions are studied to understand :

- the phenomena of segregation in complex alloys or in composites;
- the formation, the migration and coalescence of gas bubbles and inclusions in melted materials;
- the influence of the shape of solidification fronts during solidification processes on the structural alloys;
- the characteristics of dendritic crystallisation;
- the phenomena of coalescence in monotectics alloys, in immiscible systems, in solidification of eutectics, in composite materials;
- mechanisms of purely diffusive transfer.

In Belgium, the fundamental research activities in this field are performed by two groups : one in the field of metallurgy and composites in the "Katholieke Universiteit Leuven", the other in the field of fluid physics and transport coefficients in the "Université Libre de Bruxelles". Their results are described as well as their ongoing programme and future developments.

A common interest of these two groups is the study of interfacial phenomena and the related fundamental problems.

2. BELGIAN ACHIEVEMENTS

2.1. METALLURGY AND COMPOSITE MATERIALS

The activities in this field are concentrated in the Department of Metallurgy and Materials Engineering, Katholieke Universiteit Leuven [1,6].

2.1.1. Skylab

In the early SKYLAB-experiment "Silver samples melted in space" performed in 1973, the behaviour of a porous material, when melted and resolidified in weightless condition, was studied [2,3].

2.1.2. Texus 6, 7 and 9

A research programme on metallic composite materials started in 1978. The objectives are the identification of forces causing the displacement of particles dispersed in a metallic melt, the study of the role of interfacial phenomena on the preparation and the properties of metallic composites and the investigation whether the space environment can be used to develop new composite materials. During several flights of Texus sounding rockets (Texus 6 in 1982, Texus 7 in 1983 and Texus 9 in 1984) metallic composites with a dispersion of tungsten-, molybdenum-, silicon carbide- or quartz- particles in a copper matrix were studied [4,8,11].

2.1.3. Spacelab 1

During the first Spacelab flight in november 1983 aluminium samples with SiC or Al_2O_3 particles were treated. These experiments showed the possibility of preparing composite materials with a uniform distribution of particles and with homogeneous properties in the weightless condition of space and led to a better scientific description of the behaviour of molten composites both under normal and under reduced gravity levels [4,5,7,9,10,11].

2.2. MARANGONI CONVECTION

The activities in this field are performed in the Chemical Physics Department, Université Libre de Bruxelles.

Long chain alcohol aqueous solutions present a surface tension minimum as a function of temperature. Thermocapillary movements are studied when temperature gradients are imposed on liquid/gas interfaces of such systems [13,14,15,16,17].

2.2.1. Texus 8 (1983)

During this sounding rocket flight, a temperature difference of 20°C was imposed on the interface air/aqueous solution of heptanol (6.10^{-3} m). The temperatures were 45 and 65°C, both higher than the temperature corresponding to the surface tension minimum (T_{min} = 40°C). Movements in the unusual direction, from cold to hot regions were observed at the liquid/gas interface in agreement with $\frac{\partial\sigma}{\partial T} > 0$ measured at equilibrium [18,19,20].

2.2.2. Texus 9 (1984)

The geometry of the cell and the systems were identical as in Texus 8. The imposed temperatures were 35 and 50°C, respectively lower and higher than T_{min}. The expected "opening" of the interface has not been observed. The recorded movements are slow and located in the hot part of the observation volume. The short duration of the Texus experiments (360 s) does not allow to attain a steady state. Differential interferometric measurements indicate that the convection is not oscillatory [20].

2.3. KC 135 PARABOLIC FLIGHTS [21]

a. Flights on 13-14 December 1984

During this mission 40 parabolic trajectories providing µg periods of 30 s were performed.

Various simple and qualitative experiments have been realized related to :

i. antiwetting properties of Teflon coated surfaces used as anti-creeping barriers (coatings by Fluomicron Coatings, Antwerpen) against water, water + dodecylammonium chloride, liquid paraffin;
ii. stability of large flat liquid/gas interfaces;
iii. crystallisation of organic compounds;
iv. possibility to create a flat liquid/gas interface in a volume previously partly filled under normal gravity conditions;
v. cells to be used in the Fluid Physic Module during the D1 mission have been tested;

b. Flights on June 28 and July 1, 1985

During these 40 parabolic trajectories, experiments on wetting and thermocapillary motions have been performed :

i. creation of liquid/gas interfaces by the sliding of a non wetted cover was realized with success;
ii. preliminary studies of the Bénard instability problem have been performed in the perspective of the D2 mission.

- with a flat geometry
- on a sphere

iii. improved experiments were performed for Dr. J. Lichtenbelt to study gaseous bridges created in a liquid phase.

3. ONGOING PROGRAMMES

3.1. METALLURGY AND COMPOSITE MATERIALS

The research in the field of metallic composites will be continued during future Texus and Spacelab flights.

Copper composites were melted and solidified during the D1 Spacelab mission (experiment WL-IHF-09) (flight : end 1985). The evaluation is in progress. Aluminium composites with SiC particles will be studied in two gradient furnaces during the Texus 14 flight (May 1986).

Proposal for a D2 experiment on metallic alloys with a composite coating has been submitted.

3.2. MARANGONI CONVECTION AND TRANSPORT PHENOMENA

i. The study of the behaviour of liquid/gas interfaces of heptanol and of hexanol aqueous solutions were continued during the D1 Spacelab mission (experiment WL-FPM-05) [22]. The evaluation is in progress.

ii. A proposal has been accepted by ESA for an experiment to be performed in Texus 13 flight, in order to complete the information on the temperature when Marangoni convection arises around a surface tension minimum.

iii. The Soret coefficients of 20 different liquid binary mixtures will be measured during the long duration flight of the Eureca 1 platform. This mission is planned for April 1991 experiment SGF 123 [23]. This coefficient measures the proportionality between the imposed temperature gradient and the concentration gradient induced in a binary system. The relaxation time of this phenomenon is very long and these small disturbing convective motions deeply influence the induced concentration distribution. The small residual microgravity during the Eureca mission will allow to eliminate these perturbating motions.

iv. It is planned to study the behaviour of liquid/liquid interfaces in the BDPU (Bubble, Drop, Particle Unit - experiment proposal 21). Preliminary studies will be performed during parabolic flights in March 1986;

v. A proposal has been introduced to ESA in order to study the Bénard instability problem during the D2 mission (1988). This is the continuation of works being performed by the Brussels group for a long time [24].

4. FUTURE PERSPECTIVES

Table 1 gives an overview of some fundamental aspects and technologically interesting materials in the field of microgravity research.

The authors of this report would emphasize that research performed in the field of metallurgy of immiscible alloys, of composite materials and of crystal growth encountered problems due to convection, to thermocapillary convection and to solutal capillary convection. On the other side the teams working on fluid physics and on capillary convection keep in mind the problems encountered in crystal growth, in metallurgy and in the elaboration of composite materials.

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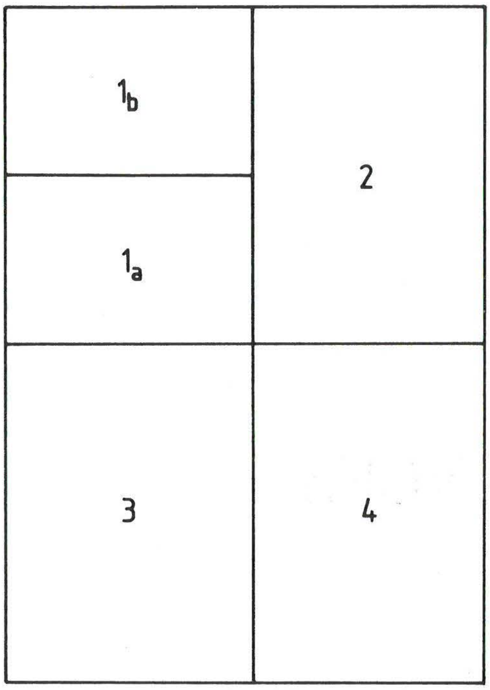
TABLE 1 : Future perspective

	Fundamental aspects	Technologically interesting new materials
WHAT ?	(1) melting and solidification of polyphase alloys (2) emulsions and suspensions : - interfacial phenomena crucible wall/matrix/dispersed phase/ gas phase - segregation phenomena of bubbles, drops or solid particles - fluid motions during and after melting and during solidification (3) electrolytic deposition in weightless conditions (4) capillary convection (5) pure diffusive phenomena	(1) special physical properties (magnetic, semi-conductive, optical, electrical,.). The improvement of mechanical properties can also be of interest. (2) special production techniques : - techniques to homogenize mixtures - shaping by casting, with or without crucible
HOW ?	(1) special gradient furnaces (2) samples with sufficiently large size (3) in situ observations (e.g. X-rays for large dispersoids, holography, interferometry, laser velocimetry) (4) mixing apparatus (5) facilities with a large observation volume, with real time observation and posibilities to react from earth.	(1) appropriate casting apparatus (2) containerless positioning (3) mixing apparatus

TABLE 2 : Microgavity flight opportunities
(except GAS and Middeck Lockers)

		1985	1986	1987	1988	1989	1990	1991
D-1		▼						
SR (TEXUS 13, 14)			▼					
IML-1				▼				
SR (TEXUS,MASER)				▼				
EURECA-1					▼			
SR (TEXUS, MASER (?))					▼			
D-2					▼			
IML-2						▼		
EURECA-2							▼	
IML-3							▼	
D-3								▼
EURECA-3								
COLOMBUS								▬

VI LIFE SCIENCES

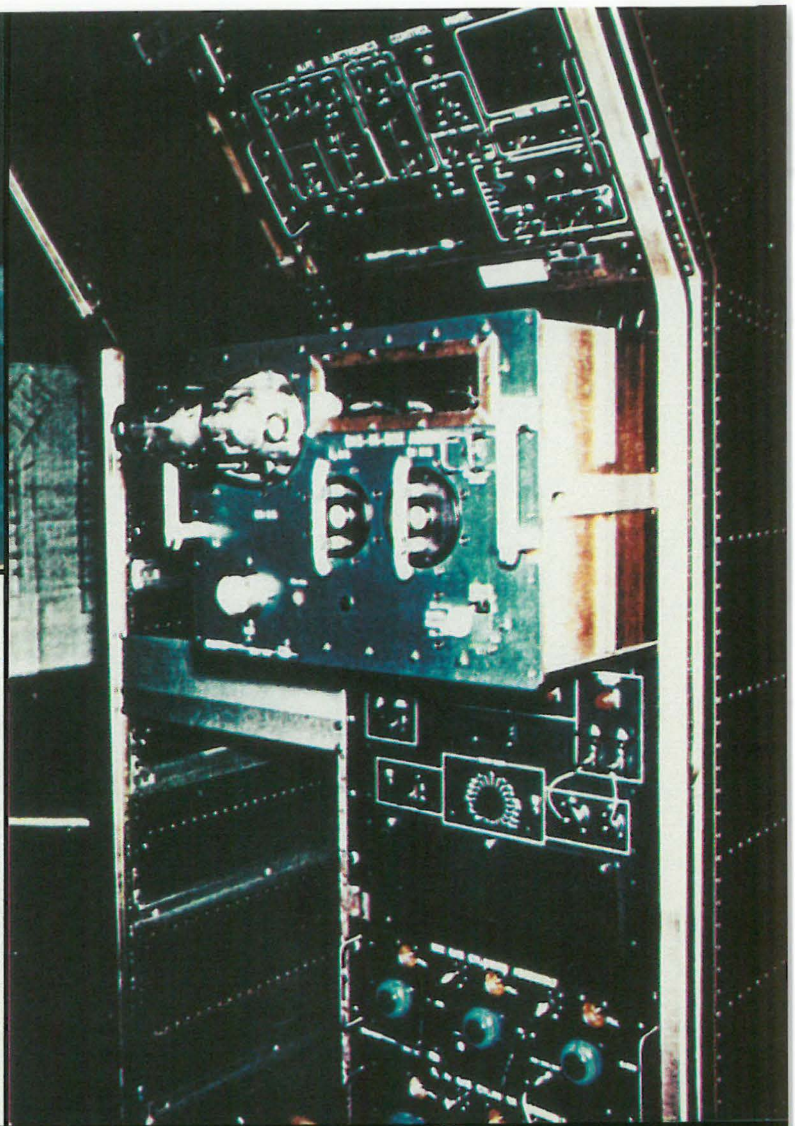


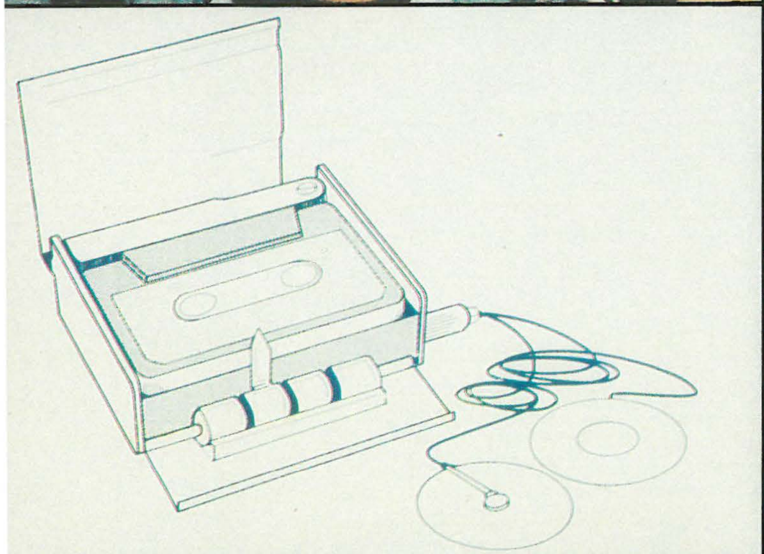
1. Standard Oxford Instruments Medilog recorder (fig. 1a) as the data capture instrument. It is a battery-powered, four-channel cassette tape recorder with a 24 hour endurance, weighting 400 grams, and with dimensions of 130 x 120 x 50 millimeters. It is carried on the person, attached to a belt and together with its electrode leads imposes virtually no restrictions to the wearer, as shown in figure 1b. For EEG's, a small preamplifier is required (10 x 6 x 12 millimeters) which is worn attached to the scalp. The recorded signals were the EEG, EMG and EOG, the latter shown on figure 1b, and a timing and event marker.
Neurophysiology laboratory, Universitaire Instelling Antwerpen.

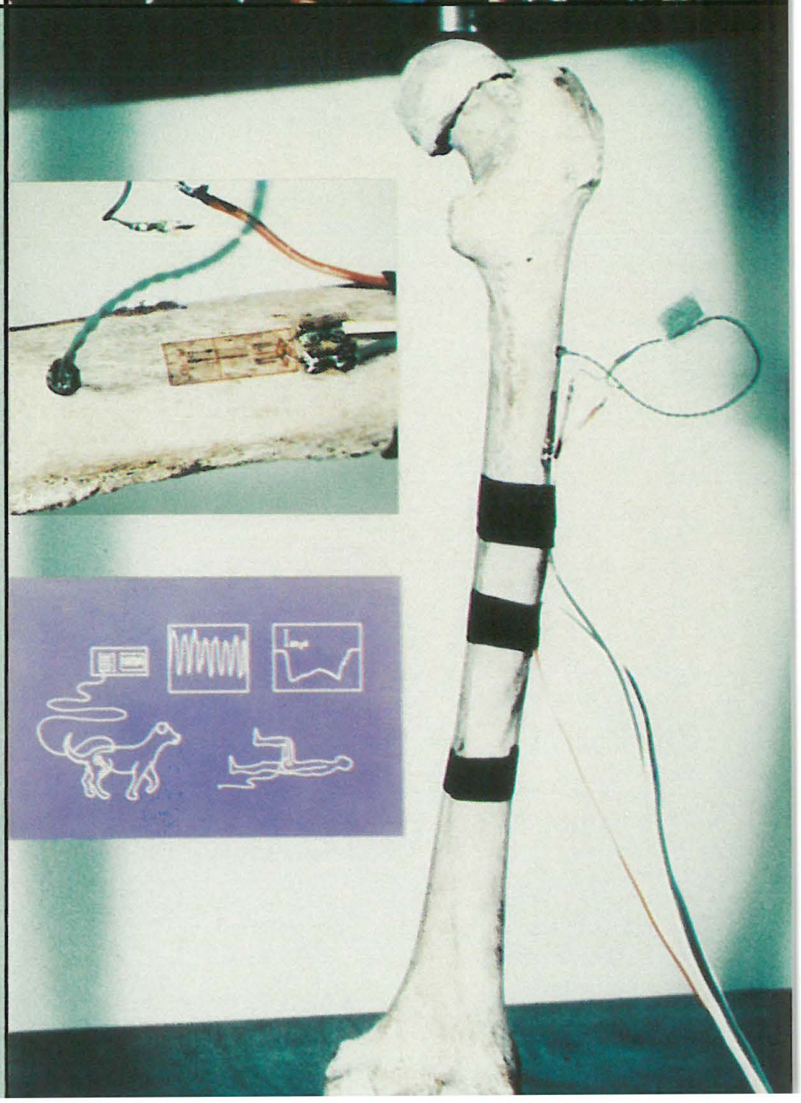
2. Equipment for the experiments on the respiratory system during Spacelab 4 mission. The removable panel contains the mouthpiece where the astronauts breathe.
Institut de Recherche Interdisciplinaire, Université Libre de Bruxelles.

3. 18 day old mouse foetus, Watson's double skeletal staining (Alcian Blue - Red Alizarine 5).
Laboratoire d'Anatomie Fonctionnelle - Université Libre de Bruxelles.

4. Bone strain transducer implanted in the cortex of a human femur in order to compare the response with standard strain gauge during loading test. The small diagrams show the recording of the gait on dog and of a specific exercice on man.
Service d'Orthopédie Traumatologie, Hôpital Erasme. Université Libre de Bruxelles.







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Acronyms

UIA : Universitaire Instelling Antwerpen

ULB : Université Libre de Bruxelles

TABLE OF CONTENTS

1. INTRODUCTION

Since the inception of manned space flight, two problem areas have appeared. The first has to do with man's efficiency and survival in space and is of an essentially applied nature. The second includes problems of a more basic nature of concern to medical scientists such as the biological significance of gravity. The Belgian Life-Science projects feature problems related to both areas of concern.

2. BRAIN PHYSIOLOGY IN MICRO-GRAVITY

by O. QUADENS and Ph. DEQUAE, Neurophysiology laboratory, Department of Medecine, University of Antwerp (UIA), B-2610 WILRIJK.

An experiment aimed at studying the brain activity of the space-traveller has been performed on the Spacelab 1 flight.

Contrary to the traditional assumption according to which the brain becomes activated during wakefulness and inhibited during sleep, experimental evidence has indicated that reactivity is greater during the periods of sleep than during wakefulness. During sleep, the brain stores information for motor adaptation, for memory and for selective attention. The information changes drastically when the gravitational environment changes. Therefore the brain-activity has been recorded in micro-gravity during wakefulness and sleep as well.

2.1. BELGIAN ACHIEVEMENTS

2.1.1. IN SPACE

The Belgian neurophysiological experiment on the SL 1 flight was joined with a British electrocardiographic project (1ES030).

a. Objectives

The primary objective of the experiment was to collect physiological data from a crew member who was not a professional test pilot and who had not experienced years of acclimatisation to abnormal gravitational forces.

Apart from starting to collect baseline data on payload specialists, it had been hoped that some information could be obtained about the control systems operating on the electrical activity of the waking brain (EEG) and on the eye movement activity during sleep (EOG).

Waking

The space traveller has to pass through a variable G state during ascent with no simple transition from 1-G to 0-G. The time from pre-launch disturbances until insertion into orbit is a highly unusual one in physiological terms. The effects of the G-variations on the brain-activity have been recorded for 80 parabolas during 2 hours of parabolic flights.

Sleep

The eye movements of sleep (Rem) reflect the activity of the brain in the modulation of sensory input and motor output. Moreover, examination of the eye movement frequencies in normal and disordered systems has revealed patterned substrates underlying behavioural performances. The higher oculomotor frequencies are decreased when performance is impaired [18]. They are increased as a function of successful learning. The eye movements of the payload specialist have been recorded during sleep, before, during and after the SL1 flight.

The second objective was to ascertain whether wearing a small tape-recorder and associated electrodes would interfere with the work of a scientist in the Spacelab environment. It was determined at the outset that a basically "off the shelf" commercial recorder would be used, with alterations made only for safety reasons. The maintenance schedule of the recorder during the mission was kept to a minimum because the scientist's time was heavily committed.

b. Scientific return

Fourier analysis of the mean EEG amplitude spectrum in the 4-8 Hz, 8-12 Hz and 12-16 Hz frequency bands indicated increased amplitude in the 4-8 Hz theta band by comparison with pre and post 0-G records.

Increase in the EEG theta activity has been documented in the GEMINI flights and in Soviet cosmonauts in early exposure to space environment indicating that it is a physiological response to the weightless environment.

In the evaluation of the sleep data, two variables were to be taken into account : a 12 hour time-shift for the payload specialist who carried out this experiment and zero gravity. Therefore, several base-line nights were recorded prior to flight. A 12 hour time-shift started for PS1 two weeks prior to launch and a further night was recorded after the shift at - 5 days. After return, sleep was recorded for 2 nights but we must bear in mind that the effects of return to gravity were compounded with the effects of a return to local time.

The Rems increased significantly in number during night 0, but returned to baseline level on night 1. The ratio between the higher and lower eye movement frequencies which indicates the brain neguentropy, though remaining within baseline limits, was higher during night 0 than during night 1. After landing, the number of eye movements increased again during Rem sleep alone but the total number of eye movements remained unchanged as a function of total sleeping time. The fast components outnumbered the slow rolling eye movements and isolated saccades by 2 to 1 as they did on night 0 in Space. They were again equal in number on the following night.

The very disclosure of a pattern in the Rems, which clearly differs between the first and the second night, yet clearly represents a similar pattern across the nights in-flight and post-flight, is indeed challenging. It indicates that gradients in gravitational forces must be considered as a specific stressor that can help explain certain key questions of brain function.

2.1.2. ONGOING PROGRAMMES : GROUND SIMULATION STUDIES

Given the limited flight opportunities, simulation of reduced and increased gravitational states are a valid contribution to solving the brain homeostatic determinants.

Therefore computer simulation studies of Rem regulatory mechanisms have been undertaken using the biomedical data from Spacelab 1. Although a real need for Spacelab environment in the intended studies is recognized, an adequate ground based micro-G programme is essential. Because of the interdependence of the vestibular and cortical brain-systems, a proper analysis approach is under investigation.

2.2. FUTURE PERSPECTIVES

Experiments are aimed at complementing the data from Spacelab 1 with a Medilog tape-recorder, similar to the one which was used on Spacelab 1.

Besides its specific contribution to scientific knowledge, we learned from the Spacelab 1 electrophysiological project ES030 that, what the British and Belgian experiments had in common, was their equipment needs. The flight approved equipment was not designed for one specific experiment but was defined for topics of interest determined by technical categories. It consisted of an electrophysiological tape-recorder suited for multi-user multi-disciplinary measurements which were space qualified within the area of physiological research. This is an important fact to be kept in mind for all future life-sciences experiments for space and time are restricted in the spacecraft environment.

3. THE RESPIRATORY SYSTEM IN MICRO-GRAVITY

by M. PAIVA, Institut de Recherche Interdisciplinaire, Campus Erasme, Université Libre de Bruxelles, B-1070 BRUSSELS.

Experiments performed in centrifuges and tilting the subjects have shown that the lung is exquisitely sensitive to gravity which causes regional differences of ventilation, blood flow, gas exchange, alveolar size, intrapleural pressure and parenchymal stress. The main scientific objectives of our research of the respiratory system in micro-gravity are the study of : I. Gravity dependence of the distribution of ventilation; II. Gravity dependence of chest wall shape and motion; III. Lung blood flow, capillary volume and liquid content. So far, the only published studies of the effects of weightlessness on the distribution of ventilation and blood flow in the lung are those reported by Michels and West (1978) and carried out on board a Lear jet aircraft during weightless periods lasting up to 27 seconds.

3.1. BELGIAN ACHIEVEMENTS

The first studies ever to be performed on the respiratory system during long periods of micro-gravity are scheduled for the Spacelab 4 mission of December 1989. The experiments will be performed with the equipment SL-4 E 198 shown in the figure, developed by J. West, J. Guy and K. Prisk of the University of California, San Diego. One of the tests (MBG) consists of 15 breaths of a N_2 free gas mixture and of the recording of N_2 concentration. The analysis of this test will be performed according to a new method (Paiva, 1975) which has been applied recently (Crawford et al, 1985). Briefly, it consists of the comparison of the N_2 concentration profiles of each expiration normalized by the end-expiratory concentration and of the simulation of the same curves with a mathematical model (Paiva, 1975; Paiva and Engel, 1984).

3.2. ONGOING PROGRAMS IN THE STUDY OF THE RESPIRATORY SYSTEM IN MICRO-GRAVITY

Ludwig Engel (University of Sydney) and M. Paiva have already studied the traditional single breath washouts performed on the astronauts who are supposed to take part in the Spacelab 4 mission. The tracings will be compared with those during the flight. The optimisation of the MBG test is currently pursued in collaboration with Dr. Engel. The scientific basis of the project may be found in a recent book (Engel and Paiva, 1985).

3.3. FUTURE PERSPECTIVES

a. Scientific aspects

The main aspects of the three scientific objectives listed in the introduction are the following :

I. The accepted explanation of the inhomogeneous topographic distribution of ventilation is the lung's compression from top to bottom by its own weight. Not only is this thought to lead to gradients in ventilation, but also asynchrony, with the less ventilated (upper) regions emptying later during expiration. Some investigators believe, however, that the weight of the lung itself is less important than the interaction between lung and the chest wall and diaphragm. These workers consider that the chest shape, and relative local excursion of the ribs and diaphragm, are gravity dependent, and determine regional ventilation. Our experiments should provide an answer to these questions.

II. The problem of recruitment of respiratory muscles and subsequent chest wall motion has been a major topic in respiratory physiology for many years. Chest wall motion has been partitioned into that of the ribcage and that of the diaphragm/abdomen. Substantial differences in the pattern of motion between upright and supine positions reflect the different effects of gravity on diaphragmic length and the mechanical coupling between the diaphragm and the ribcage. In orbit, the considerable hydrostatic influence of the mass of the abdominal contents will be removed. Thus the change of shape of the chest wall and different contributions to its motion by the ribcage and the diaphragm/abdomen will clarify the role of gravity in the mechanisms of chest wall mechanics. The measurements will be performed by respiratory impedance plethysmography (respitrace) which can continuously measure changes in the cross-sectional area of the ribcage and of the abdomen. Furthermore, respitrace monitoring during quiet breathing will provide the first opportunity to continuously monitor the respiration of subjects in space without the constraint or distortion of mouthpieces.

III. Any study of changes in lung function at zero-G must take the vascular compartment into account. While the weight of the lung influences ventilation and leads to inhomogeneity, and may be expected to lead to less inhomogeneity in micro-gravity, the congestion of the lung with blood may lead to the opposite effect. It was originally feared that oedema and deteriorating lung function might threaten life. The volume of blood in the pulmonary capillaries and the tissue volume in the lung periphery should therefore be measured early in the mission using the classical rebreathing technique. Measurements, later in the mission, should be used to follow the time course and extent of adaptation.

b. Flight opportunities

We are involved in the following flights : Spacelab 4/SLS-1 mission scheduled for December 1989; Principal Investigator (PI) : J. West. Spacelab 4/SLS-2 mission scheduled 12 to 18 months after SLS-1; PI : J. West. D-2 mission scheduled for 1991 or 1992; PI : M. Paiva, Co-investigators : J. West, H. Guy, K. Prisk (University of California), M. Hughes (University of London), L. Engel (University of Sydney). M. Paiva is also consultant for the proposal : Extended studies of pulmonary function during weightlessness (PI : J. West) which lasts until 1990. These missions constitute all of the planned flights where the respiratory system will be studied. The collaboration between NASA and ESA will avoid duplication of the experiments which may be modified as a function of the results of previous flights.

4. STUDY OF BONE DEMINERALIZATION IN MICRO-GRAVITY

by M. HINSENKAMP, F. BURNY, Department of Orthopaedic Surgery and Traumatology, Erasmus Hospital, Brussels University; R. BOURGEOIS, Royal Military School.

The effect of the local mechanical environment on bone remodelling was observed by Wolff in 1892 and scientifically demonstrated from that time. Microgravity realizes a situation in which the weightbearing bones are relieved from the weight of the body [6]. The only remaining forces acting on bone are the ones required for joint mobilisation or stabilisation almost without restraints.

Indirect techniques such as calcium balance, bone densitometry, etc..., have shown that microgravity produces bone demineralization mainly localised on the weightbearing bones. It is impossible to simulate microgravity on earth to reproduce an equivalent restriction of bone strains. Also the brief period of microgravity allowed by the parabolic flights is not sufficient for muscular reconditioning and proprioceptive control which could also be disturbed by cerebellar re-equilibration.

The study of bone demineralization in microgravity will allow us to realize a dosimetry of the mechanical strains on bone and to determine preventive treatment of bony losses which could endanger the mechanical resistance of the skeleton after prolonged flight (more than 6 months). This is fundamental to the knowledge of bone remodelling and will have multiple clinical applications.

This aim requires two different approaches : I. an etiological study implying the measurements of the modification of bone strains, both quantitatively and qualitatively during one week's flight and II. a phenomenological study requiring the analysis of the modifications of the bone structure itself, which needs at least two or, ideally, three weeks flight.

4.1. BELGIAN ACHIEVEMENTS

4.1.1. ON GROUND PRELIMINARY STUDIES

a. "in vivo" bone strain measurements

Two bone strain transducers were realized. One is designed for short term experimentation and for human tibial implantation. The second is designed for long term implantation in animals. Both transducers were already implanted in humans and animals on earth and have allowed satisfactory measurements [2, 7, 1].

General agreement has been reached with ETCA to realize the conditioning and the interface of the recording instruments for the spaceflights.

b. Study of bone remodelling on simulation model

Up to now rats were the only animals used to study bone alterations in space. We designed a simulation model of disuse osteoporosis using this animal. The best performing techniques to evaluate bone demineralization were selected and improved on this model before being used to analyse bone samples collected after orbiting in microgravity [5, 10, 22].

c. Preventive therapy

Using the same simulation model, the effect of electromagnetic fields on bone metabolism is studied as a possible substitute for mechanical physiological stimuli of 1-G environment [8, 21, 9, 11, 12].

4.1.2. ORGANIZATION OF CONGRESSES

The first International Congress devoted to "The Gravity Relevance in Bone Mineralization Processes" was organized by the Department of Orthopaedic Surgery and Traumatology of the University Hospital Erasme from January 18 to 20, 1984. It was sponsored by ESA as a workshop, with a multidisciplinary participation of 76 international specialists on bone biomechanics and physiology. A large consensus of the biochemical hypotheses appeared.

4.2 ONGOING PROGRAMS IN BONE DEMINERALIZATION IN MICRO-GRAVITY

a. "In vivo" bone strain measurements

The conditioning of the transducers and the interface of the recording instruments for the space flights are on study with ETCA.

b. Study of bone remodelling after space flight

Tarsal and metatarsal bones from 7 rats flew on Cosmos 1667 and from 3 control groups of 7 rats each are presently on study.

c. Study of bone remodelling on simulation model

The on ground studies previously described, mainly regarding the preventive techniques, are developed in more specific aspects.

4.3. FUTURE PERSPECTIVES

a. Scientific aspects

The exploitation of the results after space flights will allow us to establish the mechanical specificity of bone remodelling processes and to restore it artificially in a micro-gravity environment as well as in all pathological condition encounters on earth in which the mechanical equilibrium of bone is disturbed.

Also, the improvement of the transducers required for space measurements (miniaturization, telemetry, etc...) will allow a more systematic use in clinics and a more precise follow-up of fracture consolidation, implant anchorage and functional revalidation.

b. Flight opportunities

Up to now, these opportunities are the critical factor for these projects. A first general assessment is that Life-Science experiments, because of their lack of strategic importance have relatively little possibility of flight. The second specific aspect of this project is that these measurements require large adult animals (rabbits, dogs or monkeys) or humans. Up to 1988, except for the Anthrorack project, no such facilities will be accessible with ESA. For these reasons, despite the fact that bone from rats is not the best model to be correlated with human bone, we continue to study bone samples of rats which flew on Cosmos USSR flights. For larger animals, we are working with CERMA (France) and we are expecting to use the monkey holding unit of this centre which is programmed to fly with NASA.

5. STUDY OF BONE DEVELOPMENT IN MICRO-GRAVITY

by M.A. ROOZE, Laboratoire d'Anatomie Fonctionnelle, Institut Supérieur d'Education Physique et de Kinésithérapie, Université Libre de Bruxelles.

The development of the limb in mammalian and in avian is characterized by morphogenetic events resulting in a well defined and scheduled sequence of apparition of blastemas, precursors of the skeletal pieces. The blastemas will successively undergo into a cartilaginous and osseous differentiation. Any distortion of the program results in abnormalities of the limb skeleton. At birth time all the skeleton patterns are set up. However the foetal bone formed is characterized by a woven aspect. Later on, the bone will be remodelled into an "adult" haversian bone. We do not precisely know the effect of gravity on the development and the structure of bone but it is a common idea since the Wolff's law that the osteogenic activities are influenced by the mechanical environment but also by modification of various epigenetic factors. The reduction of gravity may disturb the ontogenesis leading to limb differentiation and bone modelling. However the possible micro-gravity influence needs probably long time exposure to low gravity conditions. In this experiment proposal is included the study of the ability of animals, born in micro-gravity, to recover a normal bone structure after a long exposure to such conditions. It is interesting to mention that in such conditions the muscle development is perhaps impaired and the main observed effects directly related to the micro-gravity conditions. For this aim we propose 3 experimental procedures :

a) exposure of pregnant and newborn mice to micro-gravity;
b) exposure of avian eggs to micro-gravity;
c) exposure of limb bud cultures to micro-gravity.

The first experiment needs the use of a mice holding unit and has the advantages of a mammalian in vivo experiment. The extrapolation of the results to man is easier. The second experiment is easier because of the absence of maternal environment, of a reduced glut due to the use of eggs and allows a small overall dimensions container. The last procedure is probably more complicated but is not absolutely needed. It allows however direct action on the differentiating structures. In all cases the eventual teratologic effects may be observed. Collaboration with other scientists allows the use of the other tissues for other studies (heart, vessels, nervous system,...).

5.1. ON GROUND PRELIMINARY STUDIES

This experimental proposal for research has been submitted to ESA. The experiment was considered for the technical feasibility and costing of Biorack. Due to costs, the need for a mice holding unit, and the absence of assistance of the different administrative offices this proposal is still a project despite the fact that we have participated in all the preliminary meetings leading to the presentation of the phase A study of Biorack.

5.2. ONGOING PROGRAMS IN MICRO-GRAVITY

All the technics to be used in this proposal are available and their specific aspects well controlled. No long time micro-gravity conditions being available until yet, no study about this particular aspect has been done.

5.3. FUTURE PERSPECTIVES

The results of such studies will allow us better knowledge of the cartilage and bone differentiation and of the modelling processes. The understanding of these events is important to comprehend the various pathological conditions in which the bone metabolism is envolved.

The flight opportunities are depending on the making of a mice holding unit and mainly on a well defined Life-Science program of experiments and opportunities.

6. SLEEP AND BIOLOGICAL RHYTHMS DURING SPACE FLIGHT CONDITIONS

by J. MENDLEWICZ, M. KERKHOFS, B. LACROIX, P. LINKOWSKI, E. STANUS, Laboratoire de Recherches Psychiatriques, Erasmus Hospital, Brussels University.

The purpose of this project was to analyze the effect of a ten days stay in space on physiological and psychological aspects of circadian rhythms in relation to cardiovascular and metabolic measurements. In this respect, sleep structure and variables, mood changes, as well as core body temperature, urinary electrolytes and melatonin levels are to be investigated. The collection of relevant information about sleep and circadian rhythms in space conditions is essential to the interpretation of data from other experiments, since previous data indicate the presence of interindividual differences in the adaptation to the specific space flight conditions.

6.1. BELGIAN ACHIEVEMENTS

Experiments on human sleep during space flight have been carried out by the group of O. Quadens.

To our knowledge no Belgian study has considered sleep from a circadian rhythm point of view and has analyzed circadian variations in physiological and psychological functions.

6.2. ONGOING PROGRAMS IN THE FIELD OF SLEEP AND CIRCADIAN RHYTHMS IN SPACE

A computer program for on-line sleep analysis has been developed in Fortran and may be adapted to the onboard computer.

6.3. FUTURE PERSPECTIVES

The computer program for on-line sleep analysis may be adapted to the onboard computer. Sleep analysis may be performed if sleep recordings are programmed during the space flight.

7. RHYTMICITY IN SEED GERMINATION

by J.P. VERBELEN, Department of Biology, University of Antwerp, B-2610 WILRIJK.

This experiment in plant physiology proposes to fly a small size container with seeds in order to study the rhythmicity in storage conditions. The question is whether rhythms in dry seeds remain in micro-gravity, the hypothesis being that the origin of rhythms may be linked to terrestrial environment. This project has been submitted for Eureca. It is fully selfsustaining, very resistent to extreme environments and needs no special care.

8. INFLUENCE OF MICRO-GRAVITY ON ISOLATED HEPATOCYTE METABOLISM

by Th. COCHE, E. FEYTMANS, E. DEPIEREUX, Département de Biologie Animale, FNDP, NAMUR.

The objective of the project is to investigate the influence of microgravity conditions on some of the major metabolic pathways of the liver cell. The biological material chosen for these studies is the isolated rat hepatocyte in suspension. Isolated hepatocytes are a valuable tool in metabolic studies and have been well characterized from a functional point of view during the past decade. Furthermore, this experimental model can be readily adapted to conditions prevailing in space-flights.

The functional properties of the cell can be studied conveniently by measuring the incorporation of radiolabelled precursors into cellular metabolites over time. This technique is used routinely to determine the viability of isolated hepatocytes. Important cellular function such as gluconeogenesis, protein synthesis, lipid metabolism, RNA synthesis, etc... can be studied quantitatively by this method. The main problem with this experimental model is that isolated cells kept at 0°C remain viable for approximately 4 hours only. This period should be extended to a few days if cells are to be used in a space laboratory.

ESA has approved the scientific objectives of the project but has stressed the need for preliminary ground-based experimentation to extend cell conservation. We have also discussed the implementation of the experimental protocol in the biorack with ESTEC specialists and no particular problems are apparent at this time.

Fund raising for the project is underway and the preliminary experimentation cell conservation should begin during the first half of 1986. Optimization of the incubation protocol and development and testing of the hardware should proceed over 1987 and 1988. Ground development should be completed by fall 1988 and flight of the experiment is planned for 1989.

9. SUMMARY OF THE RESEARCH ACTIVITIES RELATED TO SPACE OF THE LABORATORY OF EXPERIMENTAL DERMATOLOGY

BY M. LAPIERRE, Institut de Pathologie, B-23/3, Université de Liège, 4000 Sart-Tilman par Liège 1.

The cytoskeleton is deeply involved in the cell shape, organization of internal organelles during mitosis, phagocytosis and cell motility. It might also be involved in the regulation of the cell metabolism. The proposal of this project is to study the modifications of the edification and organization of the cytoskeleton of cells dividing in micro-gravity as compared to the same cells maintained at 1-G. The biosynthesis of one of the main secreted extracellular macromolecules, collagen, will be studied in parallel. It is known that an increased collagen synthesis is induced by submitting mesenchymal cells to mechanical tension. The reality of mechanical "receptors", perhaps related to the cytoskeleton, would be most interesting to investigate in micro-gravity conditions.

9.1. ACHIEVEMENTS, ONGOING PROGRAMS AND FUTURE PERSPECTIVES

Preliminary studies in normal gravimetric conditions are performed in order to characterize the biosynthetic activities of the fibroblasts to be used in space.

a. Scientific aspects

A project entitled "Micro-gravity effects on cytoskeleton and collagen secretion in human fibroblasts of various ages" has been proposed to ESA in collaboration with Prof. J.P. Soleilhavoup (Laboratory of Cellular Biology, Toulouse, France). If accepted, the cytoskeleton organization will be studied by indirect immunofluorescence using monoclonal antibodies to tubulin, vimentin, actin and myosin and the concentration of these various proteins measured by ELISA after 3 and 6 days in space. The collagen synthesis will be estimated using a radiochemical assay. The experiment will be conducted in the BIORACK system. Control experiments will be conducted in the Spacelab in 1-G conditions.

b. Flight opportunities

Spacelab flight of 1987, mission IML-1.

10. GENERAL REMARKS ON EXPERIMENT SELECTION AND FUNDING

From the standpoint of the selection committee, the choice of the discipline to be flown is important. This choice is a function of the degree of development of the proposed discipline and of the theoretical and technical possibilities to undertake it. In other words, the problem must be adjusted to the capacity of the space laboratory as a whole and must have a high probability of success.

In the strategy of the choice, the mobilizing of funds is to be taken into account. In a multi-user project, the ressources are shared. The national grant giving bodies must be aware that in international selection, the funding is an implicit assumption, far more important than expected. So far, the ressources for the experiment which was flown on SL 1 came from the normal FNRS laboratory funds and the shortcomings were covered by the university. However, the results which have thus far been obtained in space should stimulate the feedback between the Life-Sciences projects and the funding for related or different research topics.

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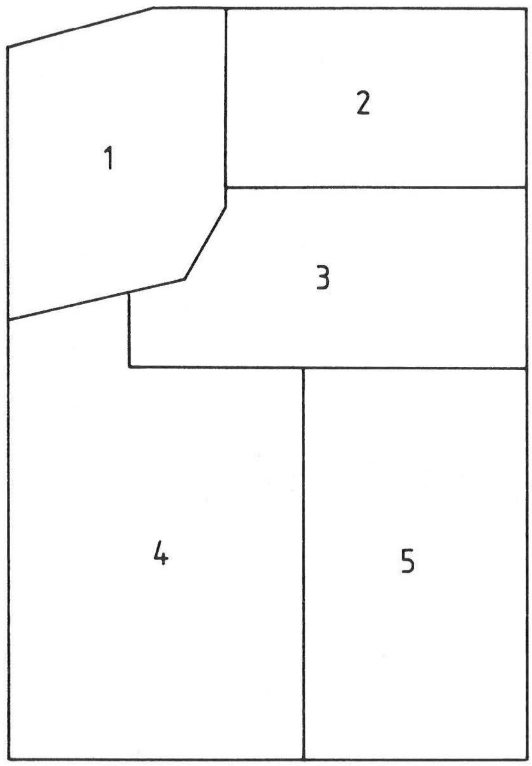
VII REMOTE SENSING



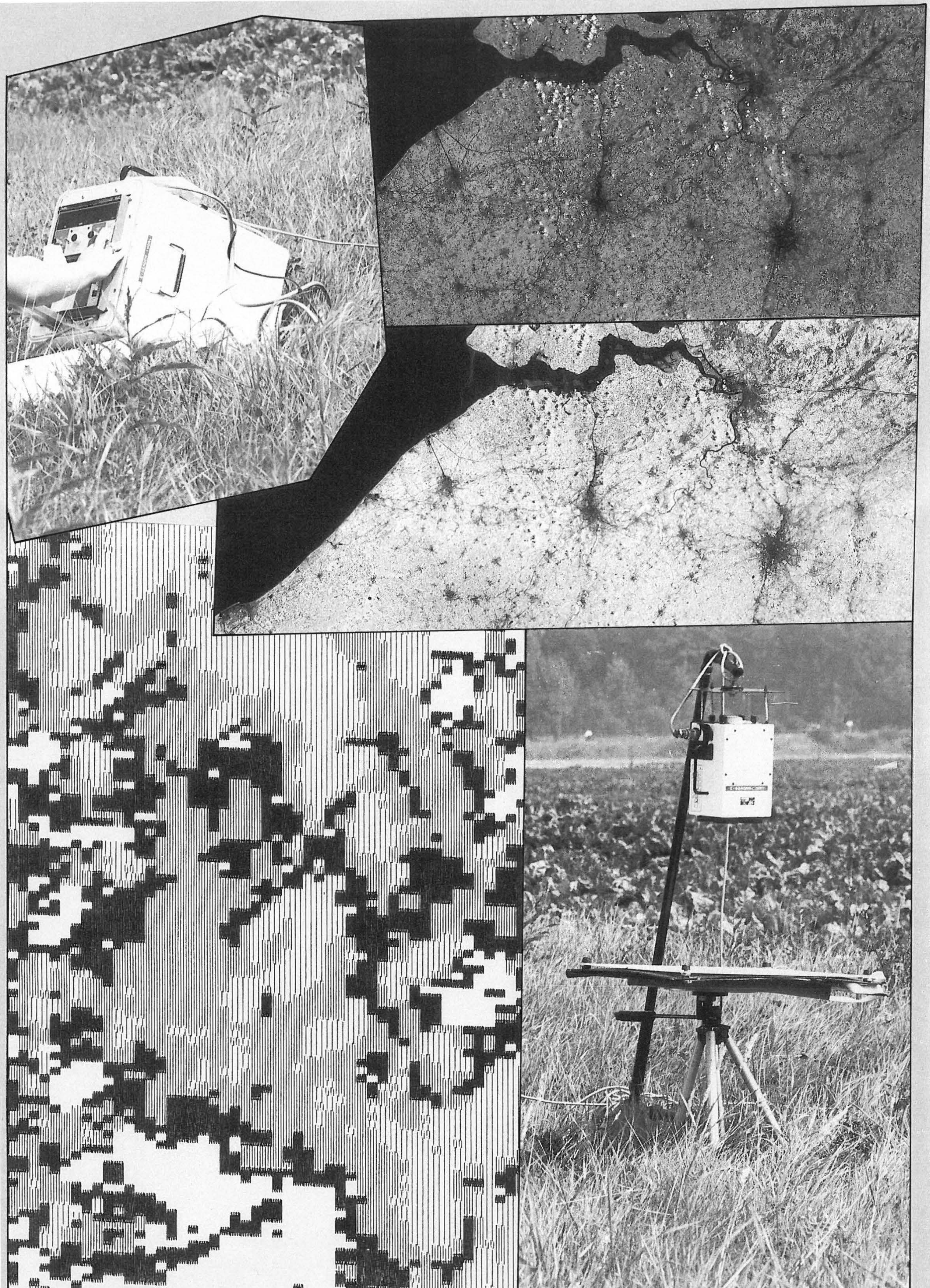
1. Logging of radiometric field data

2. Landsat MSS spectral band 5

3. Landsat MSS spectral band 7

4. Multispectral classification of forest species (Landsat)

5. Measurement of multispectral reflectance for satellite scene calibration.



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Acronyms

FSAG : Faculté des Sciences Agronomiques de l'Etat à Gembloux
KUL : Katholieke Universiteit Leuven
MRAC : Musée Royal d'Afrique Centrale
MVG : Ministerie van Volksgezondheid en Gezin
NGI : Nationaal Geografisch Instituut
RUG : Rijksuniversiteit Gent
UCL : Université Catholique de Louvain
ULg : Université de Liège

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1. INTRODUCTION

The Subcommittee for Remote Sensing was very recently installed in the framework of the activities of the National Committee of Space Research. The subcommittee aims to stimulate cooperation between Belgian laboratories which are actively participating in Remote Sensing research and its applications through national and/or international projects.

The Remote Sensing Science and its technology are presently involved in a large number of Earth Disciplines, in a great number of Scientific Goals and this in many countries throughout the world. Therefore, in this first report, preference was given to a preliminary presentation of subcommittee member laboratories together with a brief inventory of their individual remote sensing activities.

It should be noticed that the publications list and some of the descriptions are incomplete due to a lack of timely information out from several laboratories.

2. BELGIAN ACHIEVEMENTS

Presentation of Laboratory Activities.

2.1. EXPLOITATION OF SATELLITE DATA FOR CLIMATOLOGICAL PURPOSES (Université Catholique de Louvain, Institut d'Astronomie et de Géophysique G. Lemaître, Prof. A. Berger)

2.1.1. Ocean-Climate interactions

Sea surface temperature (SST), a parameter which controls the dynamics of ocean-climate interactions, is one of the main information requested by climatologists. Different climate models including adequate SST simulation, have been developed in our Institute. SST satellite derived measurements at a global scale are now required in order to validate these models. Data from the AVHRR carried aboard the GOES, TIROS and the future European ERS-1 satellites will provide useful information for this purpose. Ocean surface wind speed and heat fluxes measured by the SEASAT and ERS-1 satellites will also allow us to test a model that simulates the thermal structure of the ocean upper-layer whose variations influence the climate directly.

2.1.2. Desertification dynamics

One of the worst actual climate-caused social and economic tragedies is the recurrence of the Sahel drought associated with desertification of the Sahara borders. This persistence is hypothesized to be produced by overgrazing which, by decreasing the vegetation density, modifies certain surface parameters such as albedo, temperature, evapotranspiration, sensible and latent heat fluxes etc...

The resulting evolution of the surface energy balance could produce a positive feed-back in the processes of desertification by stabilizing the lower layers of the atmosphere. The purpose here, is to measure the evolution of some of these parameters with satellite data. More precisely, the variation in time of the vegetation cover and of the surface albedo will be measured with the LANDSAT multispectral scanner data (data available from 1972 up to now) while the surface temperature will be obtained from the LANDSAT thematic mapper data. Surface measurements from the future European SPOT satellite will also provide useful information.

2.1.3. Inverse modelling of radiative transfer

Measurements of surface parameters (surface albedo, temperature ...) are of highest importance in climate studies. It is now possible to measure these parameters using satellite data. However, a computationnaly demanding problem, namely, correcting satellite measurements for atmospheric effects (water vapour, aerosols ...) complicates the reduction of remotely sensed data to readily interpretable values.

The purpose here is to determine, with the aid of different shortwave and longwave radiative transfer models already developed in our Institute, simple formulations which should help to eliminate these atmospheric effects on the satellite measurements of surface parameters.

2.1.4. Surface heat flux derivation from satellite observations

A method has been developed to deduce heat fluxes in the atmosphere surface layer from remotely sensed temperature.

By combining remotely sensed day-night temperature differences (obtained from the HCMM satellite) with a one-dimensional boundary-layer model requiring rather few meteorological data, it has been possible to map reasonably estimated values of the sensible and latent heat fluxes over mesoscale areas.

2.1.5. Antarctic ice

The purpose is to combine observations of sea ice extent near the Antarctic coast with observations of the katabatic winds and to simulate both phenomena with a two-dimensional sea-breeze model.

The high-resolution "C-band Synthetic Aperture Radar" of the future European ERS-1 satellite will provide adequate observation data for this simulation.

2.2. LABORATORIUM VOOR TELEDETECTIE (Katholieke Universiteit Leuven, Prof. R. Gombeer)

Research activities

These can be summarized as follows :

a) The development and application of optical and computer aided interpretation methods on various sensor data as collected by satellites from the earth surface.

b) The correlation of field measurements and collateral data with radiometric data recorded from aircraft and from space.

c) The provision of thematic documents, maplike and otherwise, adapted to the specific requirements of agriculture, environmental and land management studies in Belgium and in developing countries.

Current research topic achievements are :

1) Physiography of the Gamp-area in Mali (part I and part II). Sub-project report prepared in the framework of the group agromet monitoring project (GAMP). The Gamp-study aims to demonstrate how Meteosat-data could be used to improve the monitoring of rainfall, evaporation, soil moisture and plant growth in the Sahel (Mali) region. A brief inventory of the lithology, the soils and vegetation distribution has been made over the test-area through the collection of thematic maps.

2) Analysis of radar-data collected over Belgium (test Area Korbeek-Dijle) in the framework of the SAR-580 campaign. Ground data were collected over an agricultural test-area for the study of the correlation between radar reflection and terrain/crop properties. Image electronic analysis of Sar-films (X- and C-bands). Application for land-use studies and crop classification.

3) Analysis of LANDSAT data in support of statistics in agriculture to be collected over Zaïre. Optical interpretation of Landsat colour composites. Development of image interpretation keys. Delineation and assessment of actual land-use patterns for soil management. Preparation of land-use maps over selected areas in the South of Zaïre.

4) Classification of multispectral LANDSAT and RADAR-data (SEASAT, SAR-580) for crop inventories, forest studies and land-use mapping. Development and application of optical and computer aided interpretation methods. Supervised and unsupervised classifications for crop identification and environmental monitoring. Mapping of forest species and land-use patterns over highly parcelled areas. Provision of thematic documents, maplike and otherwise, adapted to the specific requirements of agriculture, environmental and land management studies in Belgium and in developing countries.

5) Collection of spectral signatures of crops and soils by field radiometry. A radiometric campaign is executed on bare soil (field), crops(field). Soils and crop types are distinguished on the basis of their reflectance behaviour. Determinations of plant

cover (LAI), crop stage and biomass. Detection of crop diseases. Correlation of field measurements with radiometric data recorded from space.

6) Soil and vegetation reconnaissance studies in Africa using METEOSAT and LANDSAT-data. Analysis of the multispectral contrasts observed between soil and vegetation units. Applications with vegetation indexes. Preparation of reconnaissance maps useful for more detailed field surveys in developing countries. Study of desertifications, deforestation and seasonal changes : expansion and retraction of lakes, drying of the natural vegetation, evolution and progress of savanna fires.

7) Application of the HCMM-satellite thermal data to land use and urban heat island studies in Belgium. Contribution to the study of anthropogenic heat releases. The thermal inertia of land use classes are calculated from day/night satellite temperature recordings. Mapping of heat islands (industrial locations, cities and villages, Brussels, Antwerp, Ghent) and detection of thermal effluents (Doel). Albedo and surface temperature transects through cities and industrial areas. Surface temperature calibrations.

8) Participation in the PEPS-programme (Programme d'Evaluation Préliminaire SPOT, CNES, SPOT-image).

9) Contractual research in the framework of the Belgian National Remote Sensing Programme (Ministerie voor Wetenschapsbeleid); Crop yield, plant condition and vegetation mapping.

2.3. DEPARTEMENT DE GEOLOGIE ET DE MINERALOGIE (Musée Royal de l'Afrique Centrale, Tervuren, J. LAVREAU)

The "Section de Cartographie et de Photointerprétation, Département de Géologie et de Minéralogie, Musée Royal de l'Afrique Centrale, Tervuren" is presently active in the following fields :

RASTERING

Transformation of one-point data (mostly geological observations) or line-maps (thematic maps) into rasters for further use in multidata processing together with space imagery. Input : keyboard or digitizer. Output : graphic screen, plotter or printer.

TEXTURE

Recognition, enhancement and analysis of geological structures, particularly lineaments. Two lines of investigation :

1. Statistics on lineaments : recognition of directional classes, calculation of parameters for entire zones and for subzones and relationship parameters. Input : digitizer. Output : plotter and/or printer.

2. Design of genetic models : recognition of significant structures (folds, fractures, lineaments) on small scale imagery and integration in tectonic and sedimentary models based on continuum mechanics. Mostly non-automatic procedures.

RADIANCY

Recognition of geological objects and lithological discrimination based on radiancy. Application of image processing techniques to geological mapping.

These fields of activity are presently (1985-1987) applied to following programs :

1. G.A.R.S. - Africa (Geological Applications of Remote Sensing) program of the I.U.G.S. (International Union of Geological Sciences) and the UNESCO.

2. Sedimentary basins development in East- and Central Africa. A program under the auspices of the S.P.P.S.

3. Hydrology : transport of solids. Metallogeny : research of metallotects. Programs initiated by the Department.

ACTIVITY during the last two years : papers published since 1984 :

1. In the field of TEXTURE :

DEHANDSCHUTTER, J. and J. LAVREAU - Integration of lineament analysis in stress analysis and basement tectonics. Mus. roy. Afr. centr., Tervuren (Belg.), Dép. Géol. et Min., Rapp. ann. 1983-1984, 99-108, 1985.

Fracture and lineament analysis on Landsat imagery reveals a remarkable persistancy of these structures over both cratonic areas and mobile zones. Several structural elements as folds and grabens show a constant geometrical relationship to these lineaments. These can be integrated in tectonic models using extensional, oblique-slip and compressional mechanisms acting during basin development.

DEHANDSCHUTTER, J. - Lineaments in the Northern Andes, their significance and relationship to plate tectonics. Abstracts Geowiss. Latein America Koll. Marburg. Schmidt-Effing R., ed., 48, 1984.

The Northern Andes occupy the North-western leading edge of the South American plate. The geologic history in this edge is thought to have evolved schematically through changing triple junction configuration. The leading edge is a triangular shaped mobile zone. This triangle is taken between two arms of the triple junction. It is limited on one side by the Carribean arm and on the other by the Pacific ocean. The rigid interior of the continental shield forms the base of the triangle. The fundamental geologic processes acting on this configuration are examined.

LADMIRANT, H., TREFOIS, Ph. et VANDENVEN, G. - Essai d'interprétation de linéaments sur image Radar (SAR-580) dans la région de Dinant. Bull. Soc. belge Géol., 93, 161-171, 1984.

Numerization and statistical processing of about 3000 lineaments detected on SAR-580 radargraphs (X band, I = 3,2 cm) from the synclinorial Dinant area (Belgium), show a strong similarity between the rose diagrams built on the complex set of geographic lineaments and on a set limited to those lineaments which seem linked to geology. Comparison between the geological map and the results of structural field survey shows that the peaks in the rose diagrams obtained after statistical processing are strongly correlated with the macrostructural elements (bedding, fractures, perpendicular to fold axes, post-folding meridian fractures).

DEHANDSCHUTTER, J. and LAVREAU, J., Lineaments and extensional tectonics : Examples from Shaba (Zaire) and NE Zambia. Bull. Soc. géol. Belg., 94, 209-221, 1985.

Two axes of Phanerozoic rifting (NE and NNW) position along the short diagonals of rhombs limited by ENE and SE lineaments detected on Landsat imagery. NE rifting occurs when ENE lineaments are regionally predominant whereas NNW rifting occurs in regions where SE lineaments are most abundant. All four directions are again recognized in the trend of lineaments which are likely to have been significant in all geodynamic cycles since the Kibaran.
Outstanding features are uplifted areas of folded Precambrian sedimentary series with conspicious S-shaped rhombic pattern. The largest rhomb is situated at the southern tip of the Kibara fold belt in Shaba. Several smaller representatives are found at the northern termination of the Irumide belt of Zambia.
The S-structures are interpreted as sedimentary basins developing between overstepping oblique-slip faults during sinistral slip. They are of the pull-apart basin type. The geometry of the tectonic elements in the Phanerozoic Panafrican and Kibaran is interpreted in terms of extensional and oblique-slip tectonics. Compressive episodes are also recognized in the Kibaran and the Panafrican.

LAVREAU, J. - Age and significance of various sets of lineaments in W. Uganda, S. Sudan and N. Zaire. Int. Basement Tectonics Ass., Publ. nr. 4, 223-228, 1984.

Landsat and airborne imagery reveals three prominent sets of lineaments affecting the basement gneisses of the Archaean "West Nile gneissic complex". Field and thin-section studies show that the lineaments are linked to zones where a pervasive refoliation of the basement cumulates in mylonitization. Geochronology indicates that the different sets of lineaments have been generated during three distinct episodes of the late Precambrian tectonic activity. Faults and fractures of the Western Rift are directionally controlled by these structures.

2. In the field of RADIANCY :

LADMIRANT, H. et WALEFFE, A. - Découverte d'un erg fossile par analyse d'images Landsat (Nord Kasaï, Rép. Zaïre). Bull. Soc. belge Photogram., Télédétect. et Cartogr., sous presse.
The analogic analysis of Landsat images from the North Kasai region has evidenced patterns interpreted as linear dunes colonized by the tropical forest. This fossil erg extends over 250 km in N 60 E direction. The details of the analysis are exposed. Satellite information solely cannot yield a genetic model for these dunes which can nevertheless be dated to the last arid period in Central Africa, i.e. ca. 16000 BP.

LADMIRANT, H. et WALEFFE, A. - Test d'analyse géologique de radargraphies aérospatiales (Adrar des Iforas, Rép. du Mali). Bull. Soc. belge Géol., 93, 179-186, 1984.
The study of two scenes of the Adrar des Iforas from the radar imagery taken in 1981 during the SIR-A experiment has pointed out some peculiar features of the geology of that area; those features have been compared with the existing geological map in view of assessing the possible contribution of space radar imagery to the geological mapping of an arid region. It is concluded that the use of that technique will usefully complete the classical and even the Landsat-based methods of geological mapping by adding new structural and rock-type discriminant criteria.

LADMIRANT, H. et WALEFFE, A. - Corrélations géologiques entre les images aérospatiales et les données de terrain (application au Burundi). Bull. Soc. belge Géol., 93, 213-225, 1984.
In order to test the validity of the analysis of analogic Landsat documents in reconnaissance geological work, the authors compare the information concealed in MSS (band 7, color composites and diachronic imagery) with the geological data obtained from field observations and from airborne photogeological interpretation, in Burundi.

3. Miscellaneous topics :

LADMIRANT, H. - Quelques renseignements de récents congrès de télédétection. Symp. int. : La télédétection facteur de développement Outre-Mer. ARSOM., Bruxelles, sous presse.
The author presents some ideas gathered during recent meetings devoted to remote sensing.

LADMIRANT, H. - Télédétection aérospatiale et géologie dans le cadre de la coopération au développement. Symp. int. : La télédétection facteur de développement Outre-Mer. ARSOM., Bruxelles, sous presse.
After having defined the proper action field of photogeology and remote sensing from space, the author gives a few examples of non- and semi-controlled applications and makes suggestions of interest for developing countries concerning the organization of geological surveys.

LADMIRANT, H. - A propos de deux nouvelles définitions adoptées par la Société internationale de photogrammétrie et de télédétection (ISPRS) à son XVe congrès tenu à Rio de Janeiro en juin 1984. Bull. Soc. belge Photogr., Télédétect. et Cartograph., sous presse.
The author claims that the new definitions adopted for the activity of the Society are misleading and proposes an amendment for them.

2.4. UNIVERSITE DE LIEGE (Laboratoire de Géomorphologie et de Géologie du Quaternaire, A. OZER)

After 1976, our research on photogeology or photogeomorphology was developed by means of satellite imagery. Interpretations of ERTS-imagery of the Southern part of Belgium lead us to describe some new directions of lineaments (mainly N-S and NNW-SSE) unknown until that time. The comparison between aerial pictures and field observations showed us that many lineaments correspond to joints (sometimes, but unusually to faults) in the bed-rock. Research was also followed up within the framework of some thesis (in geomorphology and applied geology at our university), other research on lineaments was carried on in Northern Sardinia with a major neotectonic interest.

Presently, our laboratory takes part in two projects :
- P.E.P.S. (Programme d'évaluation préliminaire SPOT) in collaboration with other Belgian laboratories. Our target is to know the relations between structural features and the geomorphology in Southern Belgium.

Secondly with the national R-D program (S.P.P.S. - TELED/14), we hope to use SPOT datas for experiments on a test-site where the geological structures and some mineral deposits occurences are known.

We are mainly interested in the research of lineaments (faults, joints,...), the mineralisations that these ones may induce and the traces that some special geologic features may let on remote sensed datas. We hope 1) to obtain a numeric codification of well-known and well-mapped geologic features and 2) to integrate these datas to a greater area, with a prospection purpose.

2.5. INSTITUUT VOOR AARDWETENSCHAPPEN (Katholieke Universiteit Leuven, Dienst Kartografie, Prof. Dr. F. Depuydt)

By doing scientific research in Ph.D.-programs and theses, our activities got acuminate in thematic cartography and teledetection. Some topics are :
- aerial photogrammetry and aerial photo-interpretation
- remote sensing :
  * technical specifications of satellite observation and visual interpretation of analogical and digital Landsat-images;
  * geometric correction of Landsat-images with automized interpretation in function of topographical survey, controlled on field towards a few typical Belgian regions;
  * comparison and interpretation of multitemporal Landsat-images.

Since October '85 we are involved in a project on the images of the SPOT 1-satellite. Research is going on, especially on the following topics :

- geometric correction technics;
- a ground survey including gathering of GCP's, as well as a selection of geographical information (GIS);
- study of the planimetric accuracy of the SPOT-image;

- analyse of "mixed pixels" towards different types of landscape (urban, suburban and rural), followed by methods for generalisation to reduce the number of data;
- development and/or adaption of cartographic techniques towards the production of thematic maps at the scale of 1/100.000.

List of publications (concerning Remote Sensing and Photogrammetry

1. Articles

STEENMANS, C., Statistics and Mapping of Land uses by means of Landsat MSS imagery, Proceedings of the Guildford-congress : Integrated approaches in Remote Sensing, 8-11 April 1984, Guildford, p. 143-149.

2. Theses (not published)

VAN HOUTTE, A., Satellietfotografie en kleinschalige kartering, K.U. Leuven, p. 164, 1972.

STEENMANS, C., Planimetrische correctie en fotografische selectie van satellietopnamen ter realisatie van overzichtskaarten, K.U. Leuven, p. 168 + bijlage, 1981.

ROSELLE, F., Generalisatie en kleinschalige kartografie, uitgaande van digitale LANDSAT-gegevens, K.U. Leuven, p. 58, 1982.

ROELS, S., Een vergelijkende studie van multitemporele LANDSAT-beelden en gedigitaliseerde kaartgegevens, K.U. Leuven, p. 108, 1985.

2.6. LABORATORY FOR REGIONAL GEOGRAPHY AND LANDSCAPE STUDIES (Section of Remote Sensing and Image Interpretation, Rijksuniversiteit Gent, Krijgslaan 281, 9000 Gent, Dir. Prof. Dr. L. DAELS and Dr. M. ANTROP, collaborators : Dr. Ph. DE MAYER, Dr. R. GOOSSENS, Lic. M. MARTENS, Lic. Th. ONGENA)

Remote Sensing acitivities

The activities concerning Remote Sensing can be divided into three main groups :

1. Research in image interpretation;
2. Environmental applications;
3. Education and training.

1. Research in image interpretation

The research is focused upon the methodology of the image interpretation with respect to its application in different fields as geography, geology, vegetation studies, landscape ecology, urban planning ...etc. They all need a different and specific methodological approach. Results have been presented in different publications, at congresses and symposia and are judged operational. They are also included in the different courses organized by the Labo for the students of the various disciplines.

A special attention is given to the methods and techniques for the visual interpretation and the direct comparison with the terrain during the field work campaigns. All testing is performed by comparison of image interpretation results and the ground truths in different environments. Most methods are based upon the interpretation of data coming from very different sources, thus having different formats, scales and resolutions; aerial photographs, satellite data, maps, statistics, lab. analysis from ground sampling. Also an emphasis is given upon the dynamic aspects, and hence a multitemporal approach is mostly included.

2. Environmental applications

The developed methods were applied mainly upon the study of different environmental conditions and problems.

a. Landdegradation and hazard studies

Most work deals with desertification processes in different forms, environmental hazard studies, land abandonment and land evaluation in less favoured areas.

Desertification was studied under the various manifestations; sand transportation, salinization of the soil and crust formation. These processes were studied in Egypt, Sudan, Iraq and Algeria.

Hazard studies are closely linked to geomorphological and land-use interpretation. Studies have been carried out mostly in mountainous areas (Cyclades, Argolis, Euboa in Greece and the Pyrenees in France/Spain).

Special attention is given to erosion and mass movements.

b. Geomorphology and pedology

Detailed studies of the moisture content of the soils were carried out on aerial photographs in the Famenne regions and the Polder region of Belgium. Remote sensing and image interpretation for soil studies were performed in Belgium, France, Ireland, Norway, Greece, Malesia, Indonesia, Zaire and Algeria.

c. Archeology and historical ecology

Continuing the tradition of the airphoto-archaeology some detection techniques were developed for the detection of landscape features due to human activities in the (pre)historical past. Methods and models have been elaborated to improve the archaeological prospection as well as the ecological interpretation using the environmental and geographical context. These studies were carried out in collaboration with archaeologists mainly in Belgium and Greece. A new start is now given using data from the second generation satellites (Landsat T.M. and SPOT). The first experiments are carried out in Iraq for the detection of the old irrigation channels.

d. Regional geography and landscape ecology

Land abandonment and landevaluation is studied not only in developing countries but also in less favoured areas in the European community. Studies were carried out in the Provence (France), Cyclades islands, the Peloponnesos and the island of Euboa (Greece). All these areas were subjected, since the end of the 19th century to important changes. To monitor these changes a rapid and frequent monitoring of the landscape is necessary and this can be achieved using Remote Sensing.

e. Land-use inventories and vegetation

These inventories deal with the mapping of different forms of land cover and land use, as well as the statistical analysis of the mapped categories (estimation of areas). Studies were performed in Belgium, Greece, France, Zaïre, Sudan and Egypt.

f. Environmental impact assessment

Besides the almost similar approaches in the studies of desertification and land abandonment, specific research has been done on pollution in industrial, rural and urban areas. Colour infrared aerial photographs were used to evaluate the environmental conditions based upon growing conditions of trees. The interpretation allowed the quantification of the degree of pollution, its mapping and the detection of some pollution sources.

3. Training and education

Education and training in airphoto-interpretation, Remote Sensing and advanced image interpretation is provided for a large number of students at our institute having different scientific backgrounds and at various degrees of specialisation. The duration of the training courses varies between 10h till 120h/year. Students of the following disciplines are trained :

- geography;
- pedology;
- archaeology and history;
- hydrology;
- forestry;
- urban and rural planning.

This training is provided in the framework of the normal academic curriculum and at a post graduate level for students from urban and rural planning and students of Pedology (I.T.C.).

The most advanced specialisation is offered by the possibility of obtaining a doctoral degree.

2.7. LABORATORY FOR REMOTE SENSING AND FOREST MANAGEMENT (Rijksuniversiteit Gent, Prof. Dr. ir. R. Goossens)

Scientific research at the laboratory is performed by two independent teams of research-workers, named respectively CEVA and TELED 06.

CEVA stands for "Centrum voor Vegetatiestudie met Afstandswaarneming", which is Dutch for "Centre for Remote Sensing of Vegetation". The field of study is restricted to vegetation, but can be as varied as forests, nature reserves, agricultural crops and urban green.

CEVA started its research activities in 1976 through a joint sponsorship by a governmental body and private industry.

Government money is supplied through IWONL, Dutch for "Institute for Encouragement of Agricultural and Industrial Research".

The industrial partner is BELFOTOP-EUROSENSE N.V., Belgium's leading remote sensing engineering bureau. The latter has a large survey and processing infrastructure including airplanes, a wide range of sensors, colour photo development labs and image processing systems.

CEVA staff members include academics from Ghent State University, more specifically the Forest Research Institute, and highly qualified personnel from BELFOTOP-EUROSENSE N.V. All have a scientific background in such fields as agriculture, forestry and digital data processing.

TELED 06 has only started in november 1985 under the auspices of the Ministry of Science Policy of Belgium. TELED 06 is a subgroup in the National Research and Development Programme. Research is focused on the use of SPOT satellite data in the study of the natural resources on earth and sea.

TELED 06 staff will have at their disposal in 1987 an infrastructure at a regional level for analogue and digital processing.

Activities in the field of remote sensing

- Monitoring dune vegetation dynamics using color infrared photography (CIR).
  Belfotop-Eurosense N.V. - I.W.O.N.L.
- Inventory and phytosanitary control of wayside trees by means of false color photography.
  Belfotop-Eurosense N.V. - I.W.O.N.L.
- Forest mapping and management data bank using false color orthophotographs.

Belfotop-Eurosense N.V. - I.W.O.N.L.

- Active microwave sensing for vegetation mapping - SAR 580.
  ESA-CEVA.
- Qualitative and quantitative evaluation of forest vegetation using airborne digital multispectral scanner data.
  I.W.O.N.L.-CEVA.
- Remote sensing applications (CIR & MSS) for forest damage assessment (acid rain).
  I.W.O.N.L.-CEVA.
- Digital MSS-classification of land use forms.
  Belfotop-Eurosense N.V. - I.W.O.N.L.
- The use of multispectral remote sensing for biomass estimation and yield prediction of agricultural crops.
  CEVA-Research Centre for Applied Soil Science.
- Soil contamination detection with colour infrared photography.
  Belfotop-Eurosense N.V. - CEVA.
- Potential application of remote sensing to soil moisture estimation and to soil mapping.
  CEVA - Research Centre for Applied Soil Science.
- Design and construction of a remotely piloted model aircraft (RPV) for remote sensing applications.
  CEVA-I.W.O.N.L.
- Forest classification and inventory using SPOT-images.
  National Research and Development Programme of the Ministry of Science Policy of Belgium.
- Agricultural inventory and statistics using satellite imagery (LANDSAT-TM and SPOT).
  CEVA-I.W.O.N.L. - Eurosense Technologies N.V.
- Evaluation of topographic and thematic cartography, using SPOT imagery, applied to inventory and damage assessment of forests.
  Programme d'Evaluation Préliminaire de SPOT (PEPS).
  Belfotop-Eurosense N.V., Walphot Teledetection S.A., EFSR-UCL, National Geographic Institute (NGI), CEVA, Royal Military School.
- Evaluation of monotemporal LANDSAT-TM images for digital forest classification.
  EARTHNET-TELED 06.

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VIII ADDRESSES

VIII. ALPHABETICAL INDEX AND ADDRESSES OF THE MEMBERS OF THE BELGIAN NATIONAL COMMITTEE FOR SPACE RESEARCH AND OF THE SUB-COMMITTEES

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