STCE Activities

Report 2009

Solar-Terrestrial Centre of Excellence

Activity Report 2009

Table of Contents

PART 1

A. Common Public Outreach and Science Communication

A.1. Objectives

Outreach and science communication is part of the mission of the federal scientific institutes. It is logical that this tradition is integrated in the STCE-project. Two collaborators Dutch and French make this task more concrete: Sophie Raynal and Petra Vanlommel. Their job content centres around communication, education and public outreach: they are EPO officers.

The STCE encompasses sciences from Sun to Earth. Those sciences and the resulting applications converge to Space Weather. Modern life has become dependent on space weather.
The STCE has also the task to communicate this knowledge and related services to other parties: companies, scientists, amateur astronomers, and the general public.
The goal of the WP is to highlight the justification and relevance of a project like the STCE. Through the activities and expertise of the STCE, we have to *raise the awareness* of the existence and consequences of space weather effects. From this point of view, companies with space related activities, companies with interest in navigation and radio-communication, energy plants, aviation… are important targets.
Further objectives are to increase the *visibility* of the STCE as the Belgian expertise in the solar-terrestrial domain and as an important international partner in scientific research and space weather services. The STCE bundles the Sun-Space-Earth expertise and acts as a platform for national and international collaborations. This strategy and our outreach activities allow us to put the STCE as the preferential partner in the Space Weather part of the European Space Situational Awareness program.

A.2. Progress and results

A.2.1. Internal communication

Communication acts on two levels: internal and external. Good Internal communication is one of the necessities to perform well. A website, regular meetings, email contact, (in)formal live contacts, ... can contribute to a good internal communication. The communication cell is present during internal meeting 'Coffee & Science' and actively contributes to the content, see **Error! Reference source not found.**.
The annual STCE meeting was organized on June 08. Work package leaders presented their achievements and progress.

Figure 1: The importance of good communication

The STCE was represented to the committee of directors [**Error! Reference source not found.**] as a dynamic and strategic bundling of know-how. The STCE aims to build Sun-Earth know-how in Belgium and beyond. The strength of the STCE comes from the high level science, the broad set of services and innovative projects. The success is built upon collaboration, internal and external, on national and international level, with scientific institutes, commercial entities and the general public.

A.2.2. Communication towards external entities

The STCE was represented on several meetings relevant for the space weather research, space weather business and non-professional engagements. The EPO cell offered a strong support on the level of external communication for ongoing STCE-projects, e.g. PROBA2. The STCE management and EPO officers are the ambassadors of the STCE for a future involvement in the space weather segment of SSA. It was shown that the STCE has the know-how, the man-power, the infrastructure and the platform for national and international collaboration. The ambition of the STCE is not limited to only SSA, communication about future challenges like PROBA3 are being prepared.

We distinguish between the professional and the non-professional community. The EPO officers have an important role to set up a regular communication channel with the non-professional community, e.g. in the form of educative presentations or through written documents published on the web or in popular journals like *Science Connection*, a federal journal. The information about the involved science is on a regular basis broadcast on the web. Several STCE-members contributed for the content.

A.2.3. The Sixth European Space Weather Week, ESWW6

The Sixth European Space Weather Week took place in Brugge, Belgium, from Monday 16th November to Friday 20th November 2009.

The ROB/Solar-Terrestrial Centre of Excellence (STCE) organized this meeting jointly with the ESA, the SWWT and the COST ES0803 communities. The ROB and the STCE did the local organization. We can build on our expertise of the organization we acquired during the three previous editions. This year's meeting was not in Brussels, but in Brugge.

Figure 2. The ESWW6 announcement poster.

The ESWW6 again adopted the central aim of bringing together diverse communities working on all elements of space weather with a strong focus on user involvement. The keywords of the 2009 meeting were: Science-Models-Aplications-Services-Users, Space Situational Awareness, Impacts on Communication Systems, Health Issues.

Impacts on Communication Systems were the new focus of this year. Health Issues was a challenge for which we aimed for real science and no doubtful relations between medical issues and space weather.

This year's event included a second space weather fair, where users and service providers had the opportunity to interact in an informal working environment. The meeting also included a number of hands-on splinter sessions and explored community development through several dedicated business meetings.

R. Van der Linden and P. Vanlommel were members of the programme committee responsible for the scientific input. The ROB/STCE were the main contributors in the organization of the keynote lecture 'Are we alone?' by Prof. Willy Benz.

M. Hapgood, T. Dudok de Wit and P. Vanlommel took care of the debate '*Space Weather and the Earth's Climate-What are the influences & the effect of an unusually deep solar minimum.*' Dr Stuart Clark, a science journalist and author of a book on the grandfathers of space weather 'The Sun Kings' was the moderator. Prof Mike Lockwood and Prof Kalevi Mursula were the panel members. Prof Henrik Svensmark could unfortunately not come due to illness. The debate was open to the press, the public and the scientific community.

Scientific side events

- Space Weather Tutorial and quiz, [**Error! Reference source not found.**]
- Space Weather Fair
- Contest: The Best of …

Local Organization

- Suitable site selection and set up
- Creation of the poster
- Website: creation and regular update
- Social events: welcome reception, conference dinner, beer tasting, coffee breaks, sandwich lunches
- welcome pack: booklet, USB-stick, relevant touristic material
- Promotion material: invitation for event, fair, keynote, debate
- Sponsoring
- Information desk
- Cosy corner
- Wired and wifi connection
- Daily briefings for participants
- Instantaneous display of photos on HD screen with a software-tool developed by O. Lemaître
- Photographs
- …

Actions towards the Press and Public

- Press release (Eng), published on the website www.sidc.be
- E-Invitation for the debate sent to the press, the public and VIPS.
- E-Invitation for the keynote lecture and the welcome reception for VIPS.

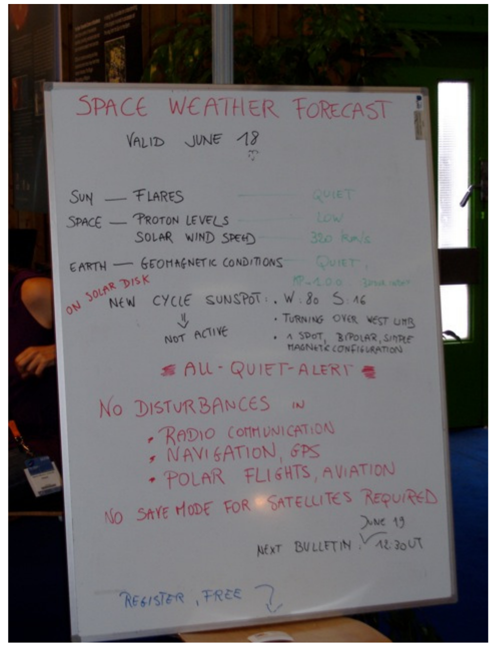
The STCE was presented at the fair by the RWC Belgium and PROBA2. The fair is a hands-on workshop to show products, services to the space weather community. RWC Belgium broadcasts on a daily basis the space weather bulletin. The PROBA2 Science Centre presented the telescopes SWAP and LYRA on-board PROBA2. In a running presentation, the focus was on the data-pipelines and the relevance of PROBA2 data for the space weather forecast centre of the STCE.

A.2.4. Salon du Bourget

The STCE participated as an exhibitor on the 48th International Paris Air Show – Le Bourget, which took place 15-21 June 2009. The STCE represented the involvement of Belgium in space as concerns space weather. The relevant science was represented by 3 general posters focusing on atmospheric modeling, solar radiation, space weather applications. The Regional Warning Centre for space weather presented the PROBA2 scale model as a reference to the scientific instruments SWAP and LYRA. Their relevance for Space Weather was advertised in the form of a daily Space Weather Broadcast, which attracted the attention of many participants. The beauty of space weather, examples of the physical measure of radio black outs, geomagnetic disturbances, solar radiation storms and the consequences on Earth and technological system were the ingredients of a running Space Weather movie. See Figure 3.

A.2.5. Open doors

Figure 3: Visitors of the STCE-stand at Le Bourget got extra information on the Space Weather Forecast and the implications for Space based and Earth based technological systems.



The STCE was presented as a Sun-Earth institute to the general public during the open doors on October 03-04. Several STCE projects were presented by means of posters, oral presentations, movies, scale models of telescopes (Oufti, PROBA2), satellites. The keywords were space weather, space climate, the solar minimum, the ionosphere, UV-radiation, satellite-observations. The short oral presentations about the scientific work of the STCE at the Elisabeth station on Antarctica, the relation between space and human health and the live space weather forecast gave an extra dynamic dimension.

Oral presentations

- 'Le météo spatiale: les prévisions', Frederic Clette
- 'Station de GPS sur Antarctica', Nicolas Bergeot
- 'Human and space', Norma Crosby
- 'Ruimteweer: energie-oprispingen', Dutch and French, Sophie Raynal, Petra Vanlommel

Manned stand

- Scale model and oral explanation 'prototype Oufti-1: a nano-satellite', students from the university of Liège.

Projected presentations

- 'Our Dynamic Sun', P. Vanlommel
- 'PROBA2: preparing for launch' and the possibility for questions about the project and the scale model, D. Berghmans
- 'EIT', D. Berghmans
- 'Het KMI op/L'IRM à Princes Elisabeth Station', Alexander Mangold
- 'The Sun live from the dome', the WDC-team

Posters

- 'The Solar minimum' + oral explanation, C. Marqué and P. Vanlommel

- ‘Solar Activity’ + oral explanation, C. Marqué and P. Vanlommel
- ‘Simba’ –‘TSI’ –‘PICARD’, Steven Dewitte
- Daily written Space Weather forecast

Remote Experiments

- UV-lab@BIRA, David Bolsee
- UV-index forecast@RMI, Hugo De Backer
- Balloon soundings@RMI, Hugo De Backer
- Ozon waarnemingen, De Backer Hugo, R. Van Malderen, N. Van den Broeck

A.2.6. PROBA2

A broad effort was done to communicate about the PROBA2-project.

Communication to the Science Community: PROBA2@esww6fair

The PROBA2 Science Centre was presented at the fair of the **ESWW6**. A presentation about the relevance of the PROBA2 Science Centre for the Regional Warning Centre was integrated in the presentation about the distribution of PROBA2 data. The presentation ran for a complete week for all ESWW6 participants.

Communication to schools

We collaborated with the Vliebergh-Senciecentrum (VSC). VSC is part of the ‘Academisch Vormingscentrum voor Leraren’ of the KULeuven. The centre offers teachers and representatives of educational studies the opportunity to follow continuing-education courses. These courses have the goal to keep up with the development in the field of academic education and scientific research. Another goal is to develop a research critical mind and to bring in new didactical insights into the daily class practice.

The PROBA2 project is called: ‘Ruimteweer waarnemen met Belgische satelliet’. The goal is to capture the attention of teachers. In a second step, we will work together with the interested teachers to develop concrete courses and exercises for students of the third grade ASO, TSO and KSO. Several applications are possible in statistics, mathematics, physics, and geography.

E. D’Huys and P. Vanlommel participated in several meetings on the organization and content of the educative PROBA2@school project.

The PROBA2 introductory course for teachers will be given on March 24, 2010. Teachers will get a written PROBA2 bundle. The teachers are D. Berghmans, E. D’Huys and P. Vanlommel.

meetings

- October 21, KULeuven, Belgium
- June 26, KULeuven, Belgium
- April 03, KULeuven, Belgium
- May 19, Planetarium, Brussels, Belgium

Communication to the general public

A large effort was done to communicate the PROBA2 science towards the general public. We focused mainly on written communication in popular journals.

Press-worthy milestones

A kick-off meeting between Verhaert Space NV and the PROBA2 Science Centre to coordinate the outreach was held on February 17. A full document was used as a reference for future actions.

June 01, 2009: press conference, the shipping

On Jun 01, a press conference concerning the shipping of the satellite to Plesetsk, was organized at Verhaert Space in Kruibeke. The organization was a common effort in which Verhaert took the lead. We produced the press release.

November 02, 2009: champagne breakfast-press event, launch

On Nov 02, the SIDC and the Solar-Terrestrial Centre of Excellence invited the press, scientist and the public to a champagne breakfast at the occasion of the launch of the satellite PROBA2 on November 2, 2009. We proudly presented our instruments SWAP and LYRA. A live link with team members worldwide was set up to receive the latest news of the launch (see Figure 4). In the frame 'the faces behind SWAP and LYRA', several interviews with the scientists were recorded and edited. The interviews ran on a big screen during the breakfast and were put online on the website of the PROBA2 Science Centre: http://proba2.sidc.be.

Figure 4: During the press event, a live link was set up with our colleagues in Dublin. They were having a breakfast party for the general public.

More than 80 people attended the celebration. The press, written, radio and TV, was strongly present. Several amateur astronomers took the chance to come and learn more about PROBA2. We got requests from them for an article in the journal MIRA and a PROBA2-presentation at the annual meeting of the VVS.

Several interviews were done with M. Dominique, D. Berghmans and J.-F. Hochedez and appeared in the written press, on the radio and on television. A press release was written.

January 26, 2010: press conference, the first achievements and images

On Jan 26, 2010 finally, the European Space Agency, ESA and the Royal Observatory of Belgium invited once again the press to present the first achievements and images of the satellite PROBA2. ROB hosted the event. The preparation of this event started before the end of Nov 2009. We focused on three points:

1. PROBA2 is the result of a successful European collaboration with major participation of Belgian industry,
2. The objective of the mission is to test new spacecraft and instrument technology in space,
3. The satellite is equipped with a quartet of new science instruments focusing on solar and space weather observations. For the two 'state of the art' solar telescopes SWAP and LYRA, the scientific responsibility lies in Belgium. The Czech Republic is responsible for the scientific experiments TPMU and DSLP.

We welcomed the Belgian Minister of Science S. Laruelle, and ESA Directors Mr Courtois and Mr Southwood. After the general part, a representative of Verhaert Space illustrated the technical successes. The principal investigators of SWAP and LYRA, B. Berghmans and J-F Hochedez in collaboration with a TPMU/DSLP scientist commented on the first scientific achievements. Here, SWAP has the advantage that it visualizes the dynamic Sun. On Jan 15, 2010, SWAP witnessed an annular eclipse (see Figure 5). Beside nice images, this gives also the possibility to study the black regions (shadow of the moon) in relation with diffracted light.

Figure 5: SWAP witnesses an annular eclipse on Jan 15. The results were presented to the press.

The formal part was concluded with a Questions & Answers session. The written press had several purposive questions. The visual media targeted the people available for interviews (see Figure 6).

Following persons were available:

Mr Courtois ,	ESA Director of Technical and Quality Management
Mr Southwood,	ESA Director of Science and Robotic Exploration
Mr Strauch,	ESA PROBA2 project manager
Mr Teston,	ESA PROBA Programme Manager
Mr Berghmans,	Principal Investigator SWAP, scientist at ROB
Mr Hochedez,	Principal Investigator LYRA, scientist at ROB
Mr Defise,	Principal Investigator SWAP, General Manager CSL
Mr Preud'homme,	Commercial Director Verhaert Space
Mr Schmutz,	Director PMOD/WRC
Ms Wagner,	Belgian Federal Science Policy
Mr Stverak,	Scientist DSLP
Mr Bloomfield	Trinity College Dublin

Media response

Both written press and television broadcasters took the opportunity to target several people. A digital press map was distributed with several animations, background information and the press release.

The media response was enormous:

1. Weerbericht één-television (BE)
2. De Standaard (BE)
3. Le Soir (BE)
4. RTE - Irish TV (IE)
5. Independant (IE)
6. Tagblatt (CH)
7. BBC (UK)
8. TV Oost (BE)
9. TV Bruxelles (BE)
10. SDA/ATS - Swiss news agency (CH)

11. Czech Radio (CZ)
12. Agence Belga - Belgian news agency (BE)
13. United Press International
14. Metrotime (BE)
15. Astronews (DE)
16. Nu (NL)
17. Skynews (Belga) (BE)
18. Nieuws (Belga) (BE)
19. Europa Press (ES)
20. Hirado (HU)
21. National Geographic (JP)
22. Omskinform (RU)
23. RND (RU)
24. Science Daily (US)
25. Physorg.com (US)
26. Alpha Galileo (UK)
27. …

Figure 6: J.F. Hochedez is being interviewed by the visual press on Jan 26 as the Principal Investigator of LYRA.

The corresponding links can be found on http://proba2.sidc.be/index.html/gallery/breve/proba2-press-event-26-january-2010.

ESA-TV made a commercial to promote the ROB contribution to the PROBA2 project. This commercial was intended for broadcasters to be picked up. Frank Deboosere, VRT, weather journal, used a part of it for his weather talk on 'één'. A broadcast like this, reaches a large part of the people in Vlaanderen.

Figure 7: We see the scale model build by the ROB in collaboration with the STCE as it was presented on the Jan 26 press event.

PROBA2 scale model

The ROB-atelier built a scale model of PROBA2 that was shown at the 26 January press event (see Figure 7 and Figure 8). PMOD/WRC and Spacebel expressed their interest to order and pay for a scale model. Practical arrangements are taken in the meanwhile.

General conclusions

The collaboration with ESA and the international partners gave an extra boost to the prestige of the event and accordingly to the ROB and the STCE. The organization went very smooth even if the political environment was difficult. It was quite a challenge to preserve a reasonable balance between all partners and the organization. With the help of several ROB people and the governmental cell 'Event Support', the outcome was very professional.

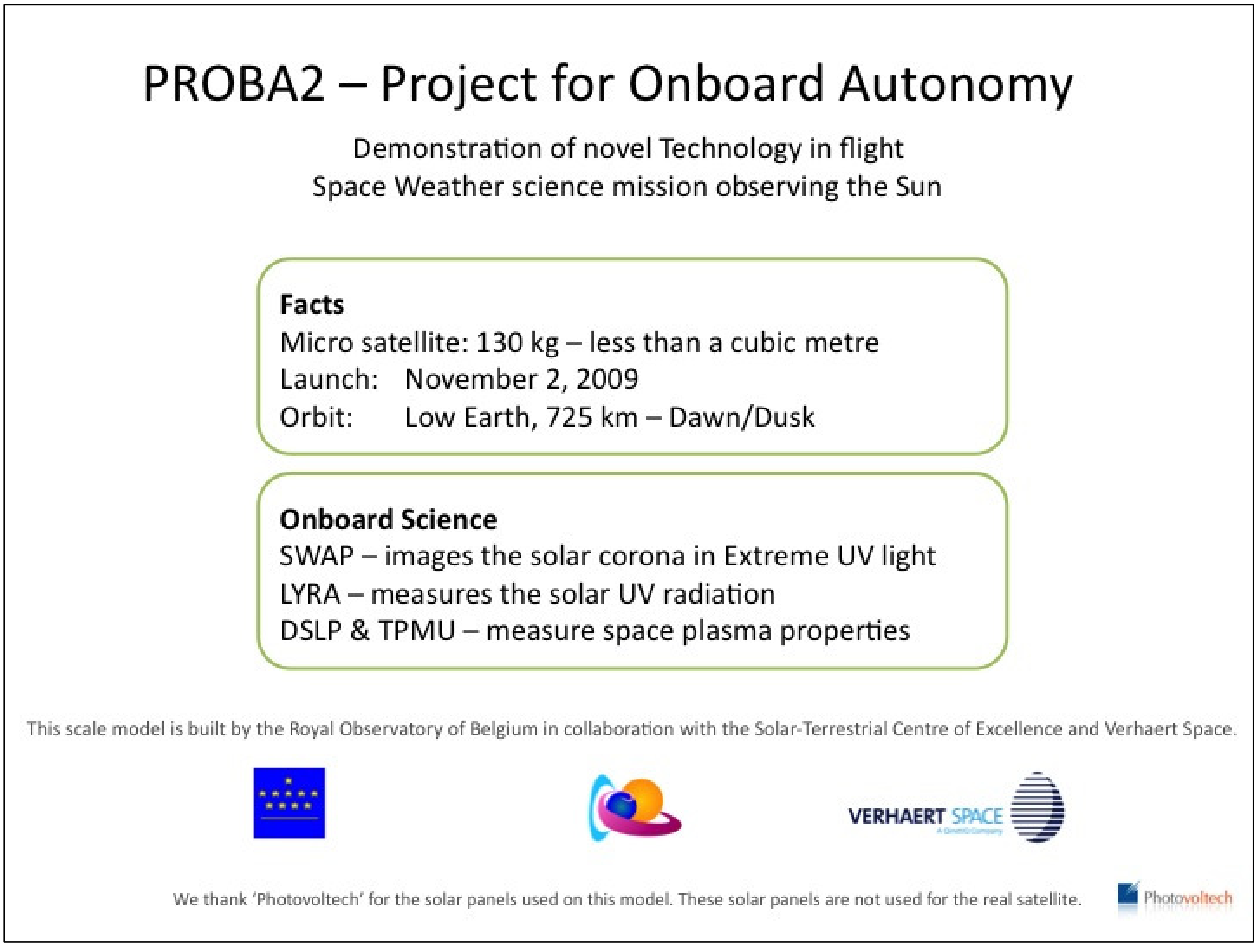


Figure 8: The technical PROBA2 fiche on display with the scale model.

A.2.7. The Sun is NOT dead

In the middle of November 2009, strong commotion was created in the press as reaction on the statement of the astronomer Kees de Jager from the Netherlands that the Sun was dead. We were frequently contacted by the media in this context and finally found it necessary to provide a reacting statement. We explained that the solar minimum of activity was longer then expected and we gave some background information about the absence of a direct link between solar activity and the temperature at the Earth's surface.

This debate was mainly held on internet-sites but got also attention on the radio and television.

Our answer was published on the website **Error! Reference source not found.**.

Zhukov A. N. gave an interview to "Le Monde" newspaper on this prolonged epoch of low solar activity (published on April 17).

A.3. Perspective for next years

In order to get an optimal internal communication, another annual STCE meeting will be organized. The targeted subjects of the 2010 meeting will be lead by the content instead of the division per institute. The focus will lie on interaction. The one-day meeting will start with a plenary session. The afternoon is open for specific topics and workshops.

A large effort will be done again to organize the seventh European Space Weather Week. We will actively help with the organisation of the CESRA-meeting.

The PROBA2 communication will be followed up. In March 2010, we will give a PROBA2 initiation to teachers. This is organized in collaboration with Vliebergh-Sencie, KULeuven. In this frame, we prepared an extended written document about the Sun, solar activity, the link with space weather and PROBA2.

March 19, 2010, another Dream-day is organized. A high-school class visits the STCE and speaks with its employees. The Dream-day helps students in their future study choice.

Several presentation are programmed: Workshop space weather predictions at the KULeuven (March 16, 2010), Volkssterrenwacht Beisbroek (May 05, 2010),VVS annual meeting (May 07, 2010).

The ESWW7 will be held on Nov 15-19, 2010 at the conference site Oud Sint-Jan in Brugge, Belgium. The SIDC/RWC is again represented in the program committee by two members. This committee gives the direction of the content of the ESWW7 and has the task to put up the scientific program. The organisation of the debate, tutorial and the keynote lecture is initiated during the kick-off meeting of Jan 26, 2010. The practical organization is again in the hands of the RWC.

The website is online: http://www.sidc.be/esww7.

A.4. Personnel involved

R. Van der Linden (Project leader), S. Raynal (French-speaking EPO-officer), P. Vanlommel (Dutch-speaking EPO-officer)

Support by E. D'Huys, A. Vander Syppe, O. Boulvin, S. Willems and many others.

PART 2: RESEARCH

A. Energetic events in the Solar Atmosphere

A.1. NEMO Operational Development

Our growing knowledge about susceptibility of modern technological systems to space weather related disturbances has led to a significant rise of the scientific interest to the problem of space weather understanding and forecasting. In turn it resulted in a substantial increase of simultaneously operating satellites devoted to space weather effects, and a corresponding exponential growth in the volume of space weather related data. It is impossible to provide a comprehensive analysis of this huge quantity of data without the development of algorithms and software that are able to automatically identify a segment (or segments) of data that is relevant to a particular physical process or space weather event. The most hazardous space weather events are associated with Coronal Mass Ejections, i.e. natural processes during which an enormous quantity of matter is emitted by the Sun. The easiest way to forecast the arrival of solar wind disturbances is to place a solar wind monitoring spacecraft in the L1 point (e.g. ACE mission). However the forecast based on ACE data gives only about an hour in advance before the solar wind disturbance interaction with the terrestrial magnetosphere starts. In addition L1 measurements are not able to address the problem of solar proton events that are extremely damaging to space based technological systems. The only possibility that can provide both ability of solar proton events prediction and a substantial increase in the forecast time is to predict the CME or other solar wind disturbances on the basis of solar surface observations.

The EUV solar imagers developed with ROB participation and currently operating on SOHO, STEREO and PROBA2 are able to gain exactly this type of data that can be used in the advanced forecast of CME initiation. The methodology to address the problem of CME forecast that has been developed in ROB is based on EIT waves observations, which are associated with CMEs. Dr. Berghmans and Dr. Podladchikova (2005) proposed and developed software algorithms for the automatic identification of EIT waves in EUV solar disk data. This exploited approach led to new mathematical forms of data descriptions and resulted in considerable advance of fundamental scientific knowledge about eruptive solar processes.

A.1.1. Objectives

The main goal this year was to further develop, improve and enhance algorithms for automatic identification of EIT waves in EUV solar corona using the NEMO tool, which led to the Prototype-2 release of the software.

A.1.2. Progress and results

The methodology of the NEMO tool development is based on a spiral model interactive approach (see Figure 9).

The first prototype operational model of this software automatically detecting EIT waves is based on EUV solar images from SOHO (see http://sidc.be/nemo for a detailed description). The main achievement in 2009 for the software exploitation is the construction of the first full database of solar EIT waves observed during 1997-2009. Currently, NEMO is undergoing the Prototype-2 development stage using more advanced EUV solar data coming from the STEREO spacecraft.

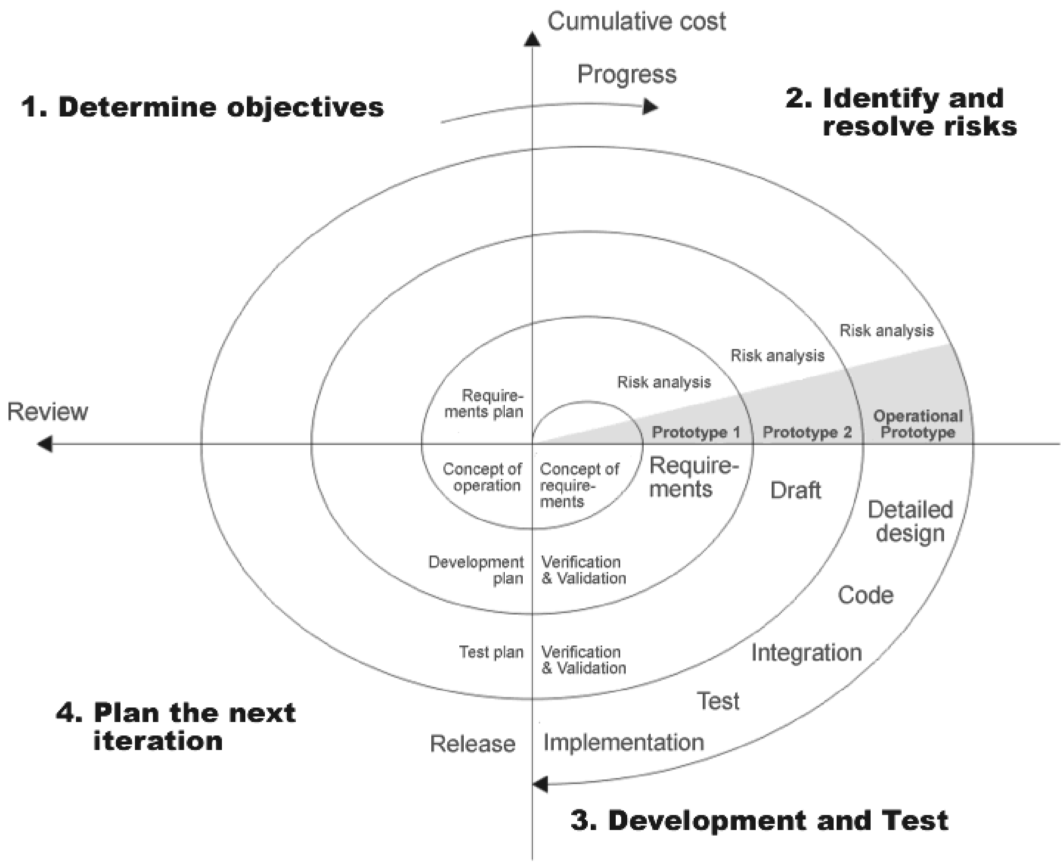


Figure 9: Spiral model of the software development adopted for NEMO tool, developed for automatic identification of EIT waves in EUV solar disk data.

Table 1 presents a detailed description of ROB and external scientists who contributed significantly to NEMO developments.

Name	Affiliation	Function	Output
		Software Development	
David Berghmans, Andrei Zhukov, Elena Podladchikova	ROB/STCE	scientist/analyst	Concept of Requirements. Development. Prototype 1
Ronald Van der Linden	ROB/STCE	Scientist	Concept for Real-Time EIT wave Alerts
Bogdan Nicula	ROB/STCE	Analyst	Concept of Operations for Prototype 2
Aleksandr Vuets, Pavel Leontiev	ROB visitors	Engineer	Development. Prototype 2 (1 peer review paper)

Table 1. NEMO Operational developments in 2009.

Prototype-2 of NEMO significantly differs from the initial software design and consists of a series of advanced techniques such as volume definition of events obtained from the STEREO spacecraft and ε - circle clusterization of dimming areas.

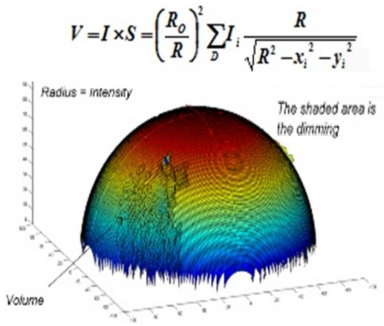


Figure 10. Transition to the complex characteristics of dimmings, the volume, which includes area and intensity

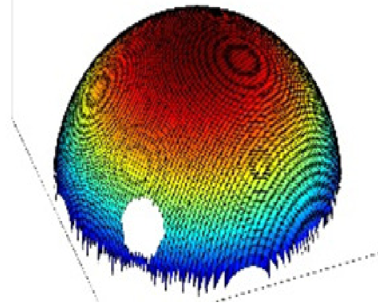


Figure 11. ε - circle clusterization. Region boundaries are determined according to the fact, that the surface is a hemisphere.

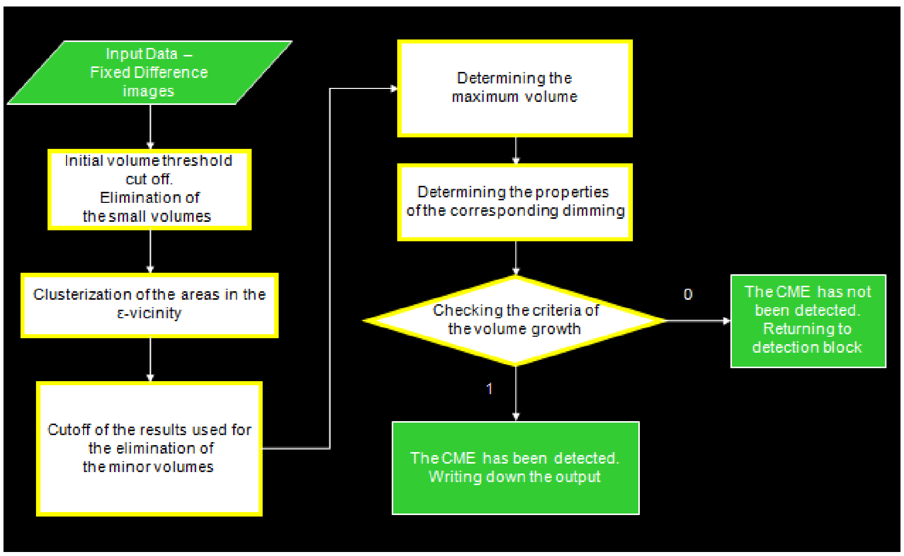


Figure 12: Prototype -2 of NEMO software. White boxes are new subroutines.

A.1.3. Perspective for next years

Table 2 presents the plan for Prototype-2 NEMO development in 2010.

Name	Affiliation	Function	Output
Software Development			
Aleksandr Vuets, Pavel Leontiev	ROB visitors	Engineers	Prototype 2 tests for STEREO satellite data (+ 1 peer review paper)

Table 2. NEMO Operational development. Planning for 2010.

A.1.4. Personnel involved

Scientific staff: Elena Podladchikova, Ronald Van der Linden, David Berghmans, Andrei Zhukov, Bogdan Nicula

Technical staff: Aleksandr Vuets, Pavel Leontiev

A.2. NEMO Eruptive Event Catalog

The output of the NEMO software forms the input of an Eruptive Event Catalog, released in 2009.

A.2.1. Objectives

The main objective of this subtopic is to present the first systematic catalog of EIT waves produced by the NEMO tool. A 2nd Objective is the construction of a user-friendly website containing events detected in real-time.

A.2.2. Progress and results

Name	Affiliation	Function	Output
Software Catalogs and Operations			
Pavel Lisnichenko	ROB/STCE	Engineer	• Full SOHO catalog: http://sidc.be/nemo/catalog/ • Partial STEREO catalogs: http://sidc.be/nemo/whi/ http://sidc.be/nemo/stereo/
Jimmy Broché	ESI, Brussels ROB Training	Programmer	Real-Time detections Interactive web-site: http://sidc.be/nemo/direct/
Sarah Willems	ROB/STCE	Engineer	Server Operations for Real-Time detection website.

Table 3. NEMO EIT wave automatic detector development and scientific exploitation of results in 2009.

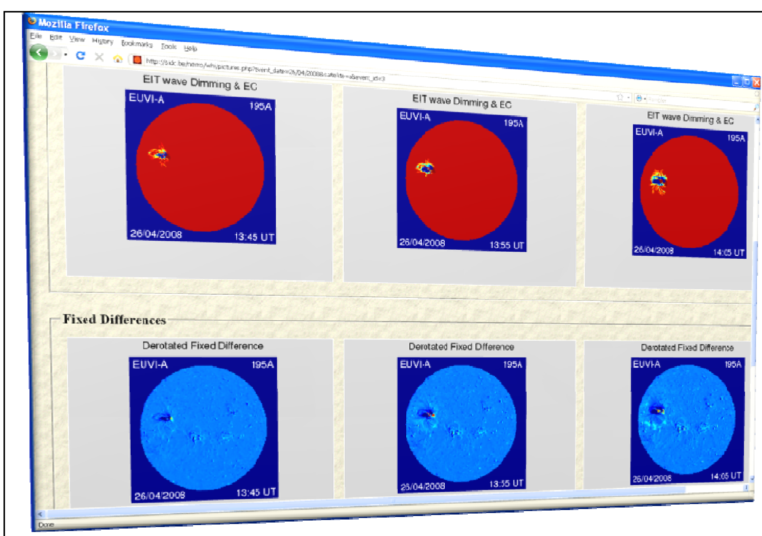


Figure 13 An example of detected Events presented in the catalog. : (Top) Extracted Dimming, (b) Difference Image.

A.2.3. Perspective for next years

Name	Affiliation	Function	Output
		Software Operations and Catalogs	
Pavel Lisnichenko	ROB/STCE	Engineer	• Partial STEREO catalogs for 4 EUV wavelengths. • Concept of Full STEREO catalog.
2010- 2011 students	-	-	Fully Operational Real-Time EIT waves website. Automatic Emails

A.2.4. Personnel involved

Scientific staff: Elena Podladchikova, Pavel Lisnichenko
Technical staff: Jimmy Broché, Sarah Willems

A.3. Scientific Exploitation of NEMO Catalog

A.3.1. Objectives

The EUV telescopes onboard STEREO have uncovered small-scale eruptive events, tentatively referred to as "mini-CMEs" because they exhibit morphologies similar to large-scale coronal mass ejections (CMEs). Coronal waves and widespread diffuse dimmings followed by the expansion of the coronal waves are the most bright manifestations of large-scale CMEs. The high temporal and spatial resolution of the EUV data allows us to detect and analyze these eruptive events, to resolve their fine structure. The objective of this work is to show that the observed "mini-waves" have a strong similarity to the large-scale "EIT' waves.

A.3.2. Progress and results

We analyzed a micro-event observed on 2007 October 17 by the Sun Earth Connection Coronal and Heliospheric Investigation EUV Imager (EUVI) in 171 Å (Fe IX) with a 2.5 minute cadence.

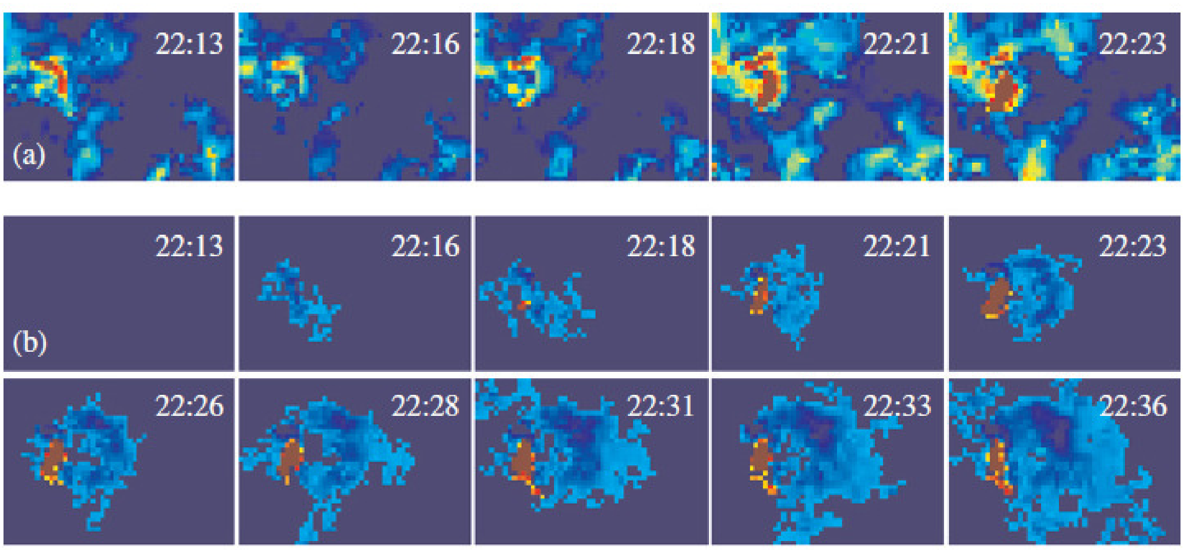


Figure 14: Three different views of the 2007 October 17 SECCHI/EUVI-A micro-eruption: (a) Direct image, (b) Difference Image.

The mini-CME differs from its large-scale counterparts by having smaller geometrical size, a shorter life-time, and reduced intensity of coronal wave and dimmings. The small-scale coronal wave develops from micro-flaring sites and propagates up to a distance of 40,000 km in a wide angular sector of the quiet Sun over 20 minutes. The area of the small-scale dimming is two orders of magnitude smaller than for large-scale events. The average speed of the small-scale coronal wave studied is 14 km/s. Our observations give strong indications that small-scale EUV coronal waves associated with the micro-eruptions propagate in the form of slow mode waves almost perpendicular to the background magnetic field.

A.3.3. Perspective for next years

Name	Affiliation	Function	Output
Scientific Exploitation of Catalogs			
Elena Podladchikova, Ronald Van der Linden	ROB/STCE	scientist	Scientific exploitation of NEMO Events (1 peer review paper)
Leon Ofman	NASA/USA STCE Visitor	scientist	Case Studies of NEMO Events 3D MHD simulations
Monique Pick	Observatoire de Paris STCE visitor	scientist	Comparison of NEMO catalog with Nançay radioheliograph Radio Events

Table 4. NEMO EIT wave automatic detector development and scientific exploitation of results in 2009.

We have as main tasks to accomplish in 2010:

- We are going to prepare a peer review paper presenting 3D parameters of EIT waves such as a height, velocity of EIT waves observed by STEREO. For this purpose we are going to use an especially developed technique of 3D parameters reconstruction for diffusive plasma clouds observed on the Sun.
- The comparison of our EIT waves catalogs with the catalogs of CME radiosignatures will be done in collaborations with Meudon Observatory, Nancay and Humain Radioheliograph scientists.
- Joint observational and MHD study will be performed in collaboration with NASA scientists.

A.3.4. Personnel involved

Scientific staff: Elena Podladchikova, Ronald Van der Linden.

B. Solar Atmosphere

B.1. Spectroscopic Diagnostics

The ultimate goal of our investigations of the solar activity is to understand the structure and variability of the solar atmosphere. This has important implications for several unsolved problems of solar physics, in particular coronal heating and the mechanism of solar eruptions – flares and coronal mass ejections (CMEs) – that have a potential influence on the space weather.

B.1.1. Objectives

Spectroscopic UV and EUV observations of the solar transition region and corona, such as the ones provided by SOHO/SUMER and Hinode/EIS, are highly suited to study flows of mass and energy in the solar atmosphere. They provide diagnostics on plasma thermal and nonthermal velocities and are thereby important for studies of coronal heating, solar wind acceleration and eruptive solar phenomena.

B.1.2. Progress and results

The work on this project has been twofold. On the one hand, transition region and coronal line observations in a polar coronal hole by SOHO/SUMER were interpreted in terms of temperature and Alfvén wave velocity. On the other hand, a study of the coronal line profile distortion in dimmings using Hinode/EIS was undertaken to show that they reveal inhomogeneities of outflow velocities.

Temperature and Alfvén wave amplitude above polar coronal holes

One of the theories to explain the acceleration of the fast solar wind from coronal holes relies on high-frequency Alfvén waves that are dissipated through the ion-cyclotron resonance. This process should produce a preferential heating of ions having low charge-to-mass ratios. To study the ion temperature, one can use the line width, which is broadened by thermal Doppler effect, but also by any velocity field in the line of sight (e.g. from Alfvén waves). To separate both contributions, one can use the gradient of the off-limb line widths. This method was applied to the data obtained with SOHO/SUMER, including a recently identified Fe VIII line at 1442.56 Å that confirms the preferential heating of ions with low charge-to-mass ratio (Figure 15, [11]). The most recent atomic data were used for the density diagnostic necessary to derive the Alfvén wave amplitude. It was found that the derived Alfvén wave amplitude is nevertheless lower than values used in numerical models of heating the corona and accelerating the fast solar wind.

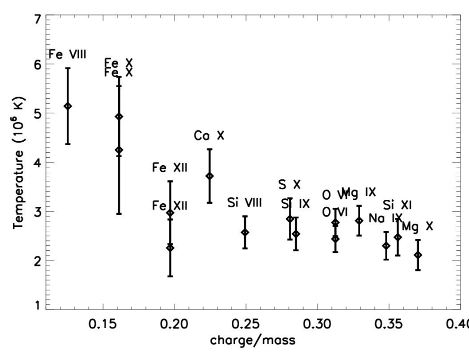


Figure 15: Ion temperatures observed by SUMER around 0.06 solar radii above a polar coronal hole. Ions with low charge-to-mass ratio present a preferential heating.

Line distortion and outflow inhomogeneities in coronal dimmings

Coronal dimmings (regions of temporarily decreased intensity in coronal lines) are the most frequent extreme-ultraviolet (EUV) signature of CMEs. Dimmings are usually interpreted in terms of density decrease. Spectroscopic studies showed that coronal dimmings are associated with large outflows lasting several hours and with larger line widths than in the surrounding area. These wide profiles are usually interpreted as due to the growth of Alfvén wave amplitude in the magnetically open and rarefied region of a dimming. The Fe XII (195.12 Å) line profiles observed by Hinode/EIS in a coronal dimming after an X-class flare on December 13, 2006 were analyzed. It was found that the line profiles in the dimming area are distorted and cannot be described by a single Gaussian function. A two-Gaussian fit of the line profiles allows to conclude that flows in the dimming are inhomogeneous, with the main component at rest and another component more Doppler-shifted than the profile of the single-Gaussian fit [62]. These features cannot be explained solely by the increase of the Alfvén wave amplitude in the dimming area and demonstrate that a spatial and/or temporal inhomogeneity of the outflow velocity should be present.

B.1.3. Perspective for next years

The study of ion-cyclotron resonance and Alfvén wave amplitude will be extended by analysing Hinode/EIS observations above polar coronal holes, closer to the limb and on much wider areas (full raster scans instead of a fixed slit position). The spatial configuration of flows in coronal dimmings will be pursued in a further study. In particular, the spatial distribution of the double-Gaussian line profiles will be investigated. Differential emission measure diagnostics of coronal dimming is planned as well.

B.1.4. Personnel involved

Scientific staff: L. Dolla (spectroscopic diagnostics, STCE)
A. Zhukov (CME and dimming expertise, STCE)

B.2. Disc images and time series

B.2.1. Objectives

The goal is to understand dynamic physical processes in the solar atmosphere on the base of solar disc imaging (in particularly in the EUV) and time series (e.g. solar irradiance).

B.2.2. Progress and results

Three-dimensional (3D) reconstruction of solar coronal structures was performed based on data collected by STEREO/EUVI. The STEREO mission provides us with an unprecedented opportunity to reconstruct the 3D configuration of solar features. The SECCHI/EUVI data from both spacecraft are combined by means of a local correlation tracking (LCT) method. The technique allows an automatic (without user intervention) matching of pixels in both images. This information is then used to triangulate the 3D coordinates of each pixel. The method is used in order to reconstruct and analyze the 3D structure of active regions. In particular, heights of coronal loops observed nearly simultaneously in the 171, 195 and 284 Å EUVI bandpasses are calculated. The properties of loops in the different wavelengths are compared and valuable information regarding their geometry is extracted. It is demonstrated that some loops that look co-spatial in the 171 Å and 195 Å images have in fact different heights (Figure 16) and thus occupy different volumes [25]. The results have important implications for multi-wavelength studies of coronal loops, especially for calculations using filter-ratio techniques.

B.2.3. Perspective for next years

The separation of the two STEREO spacecraft is currently too large to perform this kind of 3D reconstruction, but further analysis of the data taken in 2007 is envisaged. Eventually new methods can be used to treat the more recent data.

B.2.4. Personnel involved

Scientific staff: S. Gissot (LCT expertise, PRODEX)
L. Rodriguez (main work on the 3D reconstruction, PRODEX)
A. Zhukov (physics of coronal loops, STCE)

B.3. Coronagraphic, radio and in situ investigations in the heliosphere

B.3.1. Objectives

The intrinsic dynamic nature of the Sun has its most visible expression in the form of eruptive events. Their study is of high relevance for the STCE, and has a two-fold interest. The first interest is related to space weather in the near-Earth environment, which is driven by the Sun and most directly by the solar wind and the transient solar events carried along with it. The second interest, related to the first, relies on the importance of understanding the fundamental science leading to the origin and development of solar transients. Among them, we can name CMEs, corotating interaction regions (CIRs), flares and EIT waves as the important manifestations of the ever-changing solar atmosphere.

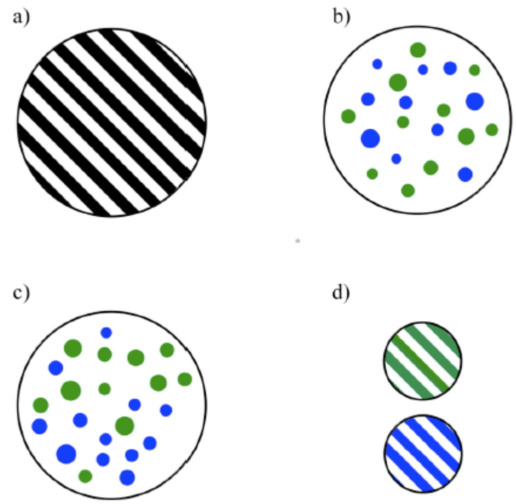


Figure 16: Possible structure of a cross-section of a coronal loop: a) a monolithic loop at a uniform temperature; b) a loop consisting of strands at two different temperatures; c) same as b), but the strands are non-uniformly distributed across the loop cross-section; d) two small monolithic loops at two different temperatures. Only options c) and d) are possible according to the STEREO data [25].

B.3.2. Progress and results

B.3.2.1. EIT waves and dimmings

The physical nature of EIT waves, large-scale bright fronts propagating in the solar corona, still remains a subject of a continuing debate. They are interpreted either as fast magnetosonic waves freely propagating in the corona, or invoking several possibilities linked to the magnetic field restructuring during the CME evolution in the low corona. An EIT wave observed by the SECCHI/EUVI telescopes onboard the STEREO spacecraft on December 8, 2007 was investigated. The wave front had a nearly symmetric shape and exhibited a peculiar velocity profile: after an initial short propagation at a speed around 100 km/s, it nearly stopped for about 30 minutes and then was re-accelerated up to speeds of more than 200 km/s (Figure 17). It is difficult to envisage such a velocity change for a freely propagating coronal wave. It was concluded that this event provides observational evidence that even EIT waves with a symmetric front can be produced by the magnetic field restructuring during the CME eruption [33].

One of the first EIT wave events that were observed by STEREO/SECCHI from widely separated vantage points was also studied. It was found that EIT wave is a bimodal phenomenon. The wave mode represents a wave-like propagating disturbance, probably a fast magnetosonic wave. The convective mode is the lateral bulk mass motion of coronal plasma due to the restructuring of the coronal magnetic field during the CME lift-off. The convective mode also allows us to explain stationary EIT wave fronts that are sometimes reported. Both modes are coupled during the EIT wave propagation in the corona. The bimodal physical nature of EIT waves may explain the inability of existing models to explain all EIT waves in the framework of a single physical mechanism [92].

B.3.2.2. 3D structure of CMEs

The data from SECCHI/COR1 and SECCHI/COR2 coronagraphs onboard STEREO provide us with the unique opportunity to reconstruct the 3D structure of CMEs and their true propagation direction. A study of the CME three-dimensional structure was undertaken. Four reconstruction methods were applied to the observations of three structured CMEs observed by STEREO. A comparison of results obtained from the application of four reconstruction algorithms was presented and discussed [10]. A review of existing techniques for 3D reconstruction of CMEs was prepared in collaboration with a large number of international partners [84]. These efforts are helpful to understand the 3D structure of CMEs, while at the same time they highlight difficulties of stereoscopic reconstruction of structures in optically thin plasma.

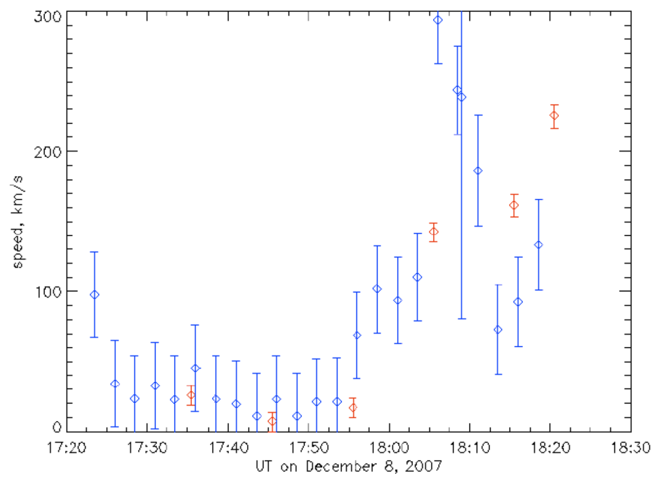


Figure 17: The speed of an EIT wave versus time as observed by SECCHI/EUVI onboard STEREO A on December 8, 2007 in the 171 Å (blue) and 195 Å (red) bandpasses [33].

B.3.2.3. Interplanetary disturbances

In collaboration within the framework of the working group "From the Sun to the Terrestrial Surface: Understanding the Chain" (funded by ISSI, Bern, Switzerland), a joint analysis of solar and interplanetary sources of the severe magnetic storm on May 15, 2005 was performed. The sequence of events, from solar wind measurements at 1 AU and back to the Sun, was analyzed to understand the origin and evolution of this geoeffective ICME. An interpretation alternative to all previous studies of this event was proposed: the ICME is formed by two extremely close consecutive magnetic clouds (MCs) that preserve their identity during their propagation through the interplanetary medium [1].

Another track of research pursued in collaboration with the ISSI team is the analysis of fast frontside full halo CMEs with non-typical geomagnetic response. Three events were selected and the associated solar and heliospheric phenomena as well as their impact on the Earth's magnetosphere were investigated. It was found that the halo CME associated with the strongest geomagnetic disturbance was the one that initiated farther away from the disk centre, while the other two CMEs originated closer to the central meridian but had weaker geomagnetic response. Therefore, these three events do not fit into general statistical trends relating the location of the solar source and the corresponding geoeffectiveness. Possible causes of such a non-typical behavior were identified: non-radial direction of eruption, passage through a leg of an interplanetary flux rope and strong compression at the eastern flank of a propagating ICME during its interaction with the ambient solar wind and possibly with other CMEs [22].

Another important advantage provided by the STEREO data is the ability to combine remote-sensing observations of CMEs with in-situ measurements of their interplanetary counterparts. An investigation was made that demonstrates the identification and matching of CMEs at the Sun with the corresponding ICMEs. The study is based on a forward modeling technique to reconstruct the direction of propagation and angular width of CMEs in three dimensions, thus allowing the simulation of eventual radial propagation up to 1 AU and analysis of their expected impact on a given spacecraft. So far 26 events have been analyzed, and four of them were detected both at the Sun and in situ.

In the framework of the Work Package 3 (Chromosphere and Corona) of the EU FP7 SOTERIA project (SOlar – TERrestrial Investigations and Archives), several chapters were written for the online report "Energy Release through Flares and CMEs, their Evolution and Geospace Impact Parameters for Special

Events”. Current state of knowledge in the field of physics of ICMEs and solar energetic particle events was reviewed. Key problems in predicting the geospace impact of solar eruptive events were discussed [93].

B.3.2.4. Coronal shock waves studied through the observation of solar radio bursts

Coronal shock waves can be either flare-generated freely propagating blast waves, or CME-driven shocks. A multi-wavelength study of large-scale coronal disturbances associated with several slow CME events (with their accompanying flares) was performed. To ensure minimal projection effects on the CME speed measurements, only events related to flares situated close to the solar limb were included in the study. The kinematics of the shock wave signatures, type II radio bursts, was analyzed and compared with the flare evolution and the CME kinematics. It was found that velocities of the shock waves were significantly higher, up to one order of magnitude, than the contemporaneous CME velocities. On the other hand, shock waves were in a close temporal association with the flare energy release that was very impulsive in all events. This suggests that the impulsive increase of the pressure in the flare was the source of the shock wave [77].

B.3.3. Perspective for next years

Investigations of solar eruptive events, their interplanetary counterparts and geomagnetic consequences will be pursued further. In particular, the geoeffectiveness of limb full halo CMEs will be studied. Another important track of research is the possibility to link directly solar and interplanetary observations using STEREO data, including the information obtained by novel Heliospheric Imagers (HI) onboard STEREO. Investigations of transient phenomena in the solar corona associated with CMEs (dimmings, EIT waves) will be continued, in particular using new SDO/AIA data (to be available since May 2010). Investigations of coronal shock waves on the base of radio observations will be continued.

B.3.4. Personnel involved

Scientific staff: S. Gissot (LCT expertise, PRODEX)
J. Magdalenić (work with radio data, BELSPO Action 1)
C. Marqué (work with radio data, STCE)
L. Rodriguez (interplanetary plasma and magnetic field data analysis, PRODEX)
M. West (3D forward modeling of CMEs, PRODEX)
A. Zhukov (solar and interplanetary studies of CMEs, STCE)

C. The Earth's Atmosphere

C.1. Atmospheric Effects on GNSS Applications

When travelling from the GNSS (Global Navigation Satellite System) satellites to the receiving antenna located on the Earth, the radio-frequency signals emitted by Global Navigation Satellite Systems (such as GPS, GLONASS and Galileo) interact with the Earth's atmosphere. The two atmospheric layers that influence the most the propagation of these GNSS signals are the troposphere and the ionosphere (see Figure 18). The troposphere is the lowermost atmospheric shell and it is the seat of all meteorological phenomena's (clouds, rain, hydrometeors...). It contains approximately 75% of the atmosphere's mass and 99% of its water vapour and aerosols. The ionosphere is stretching from a height of about 50 km to more than 1000 km; it is named so because it is ionised by the Sun's ultra-violet light. The ionosphere is thus a shell of free electrons, electrically charged atoms and molecules that surrounds the Earth. As most of the space weather starts at the Sun, also the Earth's ionosphere is undergoing the effects of space weather.

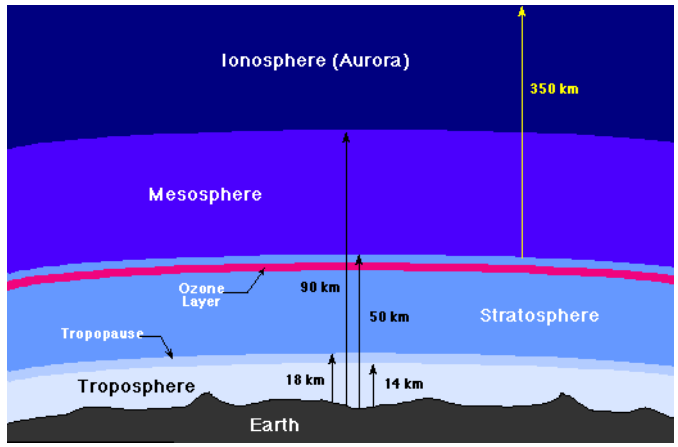


Figure 18: Subdivision of the Earth's atmosphere in different layers

The variation of the electron concentration in space and time is the main parameter that describes the state of the ionosphere. The ionospheric activity strongly depends on solar activity. Indeed, extreme UV and X rays emitted by the Sun are the main source of ionization in the ionosphere. For this reason, Space Weather is the main driver of ionospheric disturbances. In particular, geomagnetic storms are often the cause of strong variability in the ionosphere electron concentration.

The ionosphere Total Electron Content or TEC is another parameter of interest. Indeed, the influence of the ionosphere on GNSS measurements depends on GNSS wave frequency and on TEC. The TEC is the integral of the electron concentration on the GNSS receiver-to-satellite path. It is measured in TEC Units (TECU): 1 TECU=10^{16} electrons m^{-2}.

Both the ionosphere and the troposphere refract the GNSS satellite signals and are error sources for GNSS applications. Tropospheric refraction causes errors of about 2-50 m on GNSS signals, while the errors caused by the ionospheric refraction can reach up to 50-150 m.

C.1.1. Objectives

To assess and mitigate the influence of the Earth's atmosphere on high precision GNSS applications (WP ROB B.2).

GNSS allows computing positions on the Earth with precisions ranging from several meters down to a few mm, depending on the sophistication of the hardware and software used. When high precision GNSS applications are targeted, the Earth's atmosphere becomes a predominant error source.

The effect of the tropospheric refraction on the propagation of GNSS signals can be corrected using several a priori models that satisfy the less demanding GNSS applications, like dm-m level GNSS positioning and navigation. For high-precision applications where mm accuracy is desired, the tropospheric error is parameterised in the final position solution.

As the ionosphere is a dispersive medium, GNSS applications can be corrected for first-order ionospheric effects by combining the different GNSS frequencies. As it will be shown below, during high ionospheric activity, higher-order ionospheric correction terms have to be taken into account for high precision GNSS applications (like e.g. earthquake monitoring).

C.1.2. Progress and results

C.1.2.1. Positioning

The scientists of the STCE have analysed GPS observations gathered during 20 days around the October 2003 geomagnetic storm (which affected the ionosphere above the Northern part of Europe) using the techniques used in GPS-based earthquake monitoring. Earthquake monitoring typically requires positions with a precision better than 1 cm using just a few minutes of GPS observations (kinematic GPS positioning). High-end dual-frequency GPS equipment as well as scientific data analysis software were used for the test. The first-order ionospheric effects were eliminated by taking advantage of the dual-frequency GPS data. The influence of the troposphere was corrected by introducing tropospheric corrections obtained from a previously performed state-of-the-art GPS-based estimation. Then, each 5 minutes, a GPS position was computed and the error on the GPS-based kinematic positions was compared with the intensity of the ionospheric activity.

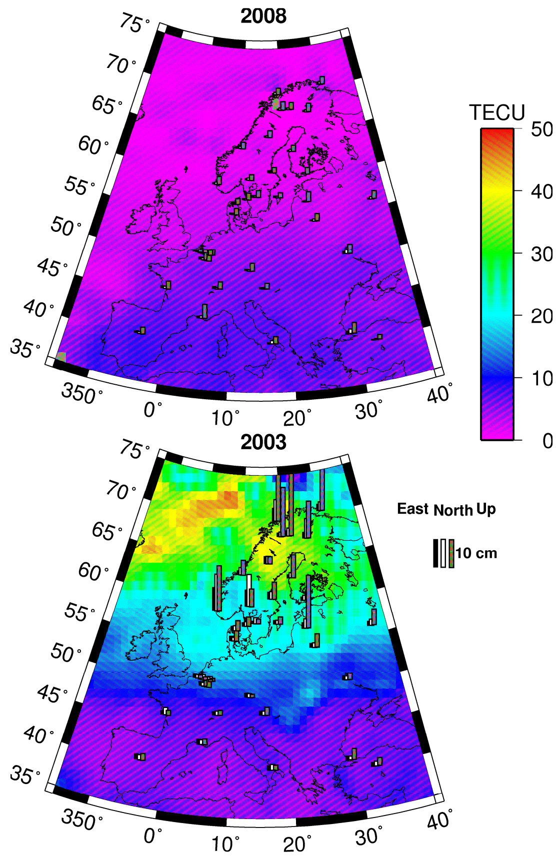


Figure 19: TEC maps and maximum repeatability of the estimated positions (East, North and Up components) in 2008 (normal ionospheric activity, top) and in 2003 (ionospheric storm, bottom).

This intensity was quantified by generating TEC maps for the considered zone. The Total Electron Content (TEC) is a good indicator of the state of the ionosphere. It is the integrated electron density inside a cylinder column of unit base area along a certain direction between Earth ground and satellite altitude. To determine the TEC in the ionosphere from GPS data, the assumption is made that all the electrons are concentrated in the ionosphere. TEC is measured in TECU units with 1 TECU = 10^{16} e^{-}/m^{2}. The comparison of the intensity of the ionospheric activity and the error on the GPS-based kinematic positions showed a degradation of the position repeatability during the Halloween ionospheric storm (Figure 19) which was significant for stations in Northern Europe with outliers reaching 12 cm in the horizontal components, and 26 cm in the vertical component.

As ionospheric storms will become more and more frequent with the coming next solar maximum (predicted for 2013), kinematic GPS applications will be more affected. Hence the importance of having external information, such as TEC maps to increase the information about the ionosphere.

C.1.2.2. Time Transfer

➢ Second-order ionospheric effect on long-baseline links

The present stability requirement for the clocks participating to the generation of the International Atomic Time (TAI), which is the basis for our legal time, is at the level of the nanosecond over one day. The comparison of these clocks is done using GPS Time and Frequency Transfer (TFT). The Atomium software has been developed at ROB to investigate the improvement of time transfer by using high-end GPS receivers. It aims at performing time transfer at the picosecond (ps) level and it is based on the GPS Precise Point Positioning (PPP) and Common View (CV) approaches. Similar to high-end GPS positioning, Atomium uses the ionosphere-free combination of GPS dual-frequency measurements to remove first-order ionospheric effects from the computations. In 2008, we computed and quantified the second and third-order ionospheric perturbations on the GPS signals and their influence on time transfer, and included this correction in the new version of the Atomium software. In 2009, STCE scientists showed that on very-long (intercontinental) baselines, second-order ionospheric delays can cause an effect up to about 10 ps in the relative clock solution, or even more for days with higher diurnal variations of the TEC. This traces the difference in time of the local noon TEC at the two stations. Of course, this ionospheric second-order effect on TFT is not visible for nearby stations (European links) where the local noon is synchronous, as it is the differential ionospheric effect between stations that matters in the TFT solution.

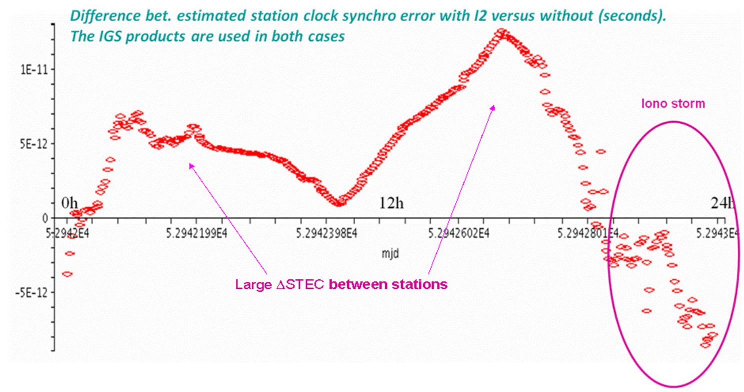


Figure 20: Effect of taking second-order ionospheric delays, or not, into account in the GPS time and frequency transfer for the intercontinental baseline Brussels (BRUS)-Canada (NRC1) link, on the ionosphere-stormy day 30th October 2003. This effect is obtained as the difference between the Atomium clock solutions estimated with and without the second-order ionospheric correction.

Figure 20 illustrates the effect of taking second-order ionospheric delays, or not, into account in the GPS TFT for an intercontinental link. It shows both the effect of the differential local noon maximum in slant-TEC and the effect of the ionospheric storm of Oct. 30, 2003.

➢ *Second-order ionospheric effects during a storm*

Second-order ionospheric corrections use a value of the geomagnetic field at the Ionospheric Piercing Point (IPP) of each GPS signal. Since no real geomagnetic measurements are available at this IPP, Atomium uses the International Geomagnetic field Reference (IGR) model to compute those values. However, the comparison of measurements of the magnetic field with the model during a geomagnetic storm demonstrates that the IGR model does not reproduce the rapid variations (in orientation and magnitude) of the geomagnetic field. The model might miss a factor 100 enhancement. As a consequence, second-order ionospheric effects during a storm cannot be well quantified. For example, the estimation presented in Figure 20, based on the IGR model, shows that the 2^{nd} order effect during the storm reaches up to the order of 10 picoseconds. However, in practice, it might reach up to the order of the nanosecond. But aside geomagnetic storm events, the IGR model can be trusted to estimate the impact of the second-order ionospheric effect on TFT, so that the magnitude of the effect of the differential local noon maximum in STEC as determined in Figure 20 can be trusted.

➢ *Improvement of the tropospheric modeling in Time Transfer solutions*

An improvement of the tropospheric parameter estimation strategy in Atomium reduced the differences between the Atomium and the IGS clock solutions with a factor up to 10. The new strategy estimates the wet part of the troposphere with a 15-minute sampling rate (rather than 2 hour previously) and uses relative constraints of 1mm/15 min between successive estimations. The improvement is illustrated in Figure 21, which presents the clock solution (shown as the differences with respect to the IGS combined solution) and the tropospheric path delays obtained with the two strategies. The Figure also shows the solutions obtained when the troposphere is not estimated but fixed to the ROB or IGS products in the least square analysis.

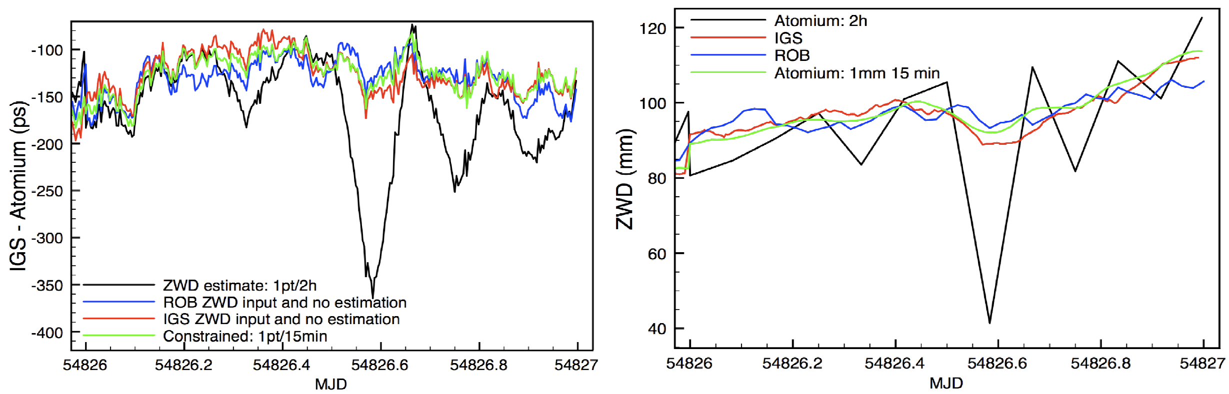


Figure 21. Left: differences between IGS and Atomium clock solutions for TLSE on 1 day for different strategies of ZWD estimations and for a ZWD fixed to ROB or IGS products. Right: ZWD computed from different strategies and software: ROB's ZWD (blue) from the Bernese software, IGS combined ZWD (red), Atomium estimated ZWD without constraints (black) and with constraints (green).

C.1.2.3. Usage of new satellite signals (modernized GPS, GLONASS & Galileo)

Within the next years, existing Global Navigation Satellite Systems like GPS and GLONASS will launch new types of satellites and provide additional signals to deliver better accuracy, reliability and availability of positioning. Moreover, according to a 2007 Russian presidential decree, GLONASS will offer in the near future a full 24-satellite constellation. In 2010, the upcoming GALILEO system plans to launch 3 or 4 test satellites that will be very similar to the final satellites. And finally, in the years 2011-2013, the remaining 26 satellites should be launched. Full Operational Capability of the GALILEO system is expected by end 2013. All these signals have the potential to allow more precise observations of the Earth's atmosphere.

- STCE scientists, together with a consortium led by the Universität der Bundeswehr (München), have replied to the FP7 call FP7-GALILEO-2008-GSA-1 and proposed a project "Scientific Service Support based on GALILEO E5 Receivers: SX5". The Galileo E5 broadband signal features an ultimately low code range noise and the lowest possible multipath errors compared to all other signals of all other GNSS. Precise single-frequency positioning will become feasible using a combination of code range and carrier phase measurements on this high-performance navigation signal using a dedicated ionospheric error mitigation technique. In addition, reprogramming algorithms will also easily allow the monitoring of ionospheric propagation delays with such a single frequency receiver working on Galileo E5.

C.1.3. Perspective for next years

- The focus will now be shifted to the modelling of the atmosphere using GNSS observations (WP ROB B.1). Once this modelling has reached enough maturity, it will be used to investigate the improvements on GNSS-based positioning during periods of high ionospheric activities.

- We will also study the added-value of new radio navigation signals (modernized GPS and GLONASS, and Galileo) for improving the atmospheric corrections for positioning and time transfer. In that framework, we are participating to the FP7 project "Scientific Service Support based on GALILEO E5 Receivers: SX5" (2009-2010).

C.1.4. Personnel involved

Scientific staff: C. Bruyninx (head "GNSS" project)
P. Defraigne (head "Time and time transfer" project)
W. Aerts (Time laboratory and new GNSS signals)
Q. Baire (Development of Atomium)
N. Bergeot (Influence of the ionosphere on GNSS positioning)
J. Legrand
S. Pireaux (Implementation of higher-order ionospheric effects in Atomium)

C.2. Modelling the Earth's Atmosphere using GNSS

C.2.1. Objectives

To improve our knowledge of the spatial and temporal variations in the Earth's atmosphere (troposphere and ionosphere) and its physical processes with emphasis on Europe and Antarctica (WP ROB B.1).

As the GNSS signals traverse the Earth's atmosphere, they contain information on the ionospheric and the tropospheric state. In order to extract this information from the GNSS signals, networks of continuously observing GNSS stations, with well-known positions, are used. For that purpose, members of the ROB "GNSS project" maintain a network of continuously observing GNSS stations and contribute actively to the elaboration and extension of the European GNSS network, known as the EUREF Permanent Network (EPN). In a second step, the GNSS data from these networks are used to compute information on the Earth's ionosphere and troposphere.

C.2.2. Progress and results

C.2.2.1. Development of GNSS Observation Networks

- STCE scientists are in charge of the daily management of the European Permanent GNSS network (EPN), see Figure 22. Within that frame, we maintain and continuously update the EPN Central Bureau (CB) web site (http://epncb.oma.be/, see Figure 23). In 2009, the site received a total of about 2.5 million hits. Moreover, in 2009, 9 new stations have been included in the EPN bringing the total number of EPN stations at 226.
- The quality of the ionospheric and tropospheric monitoring will improve if more satellite signals traversing the Earth's atmosphere will become available. For that purpose, encouraging EPN stations to switch from GPS-only to GPS+GLONASS (Russian counterpart of GPS) or GPS+GLONASS+Galileo (future European navigation system) is one of our top priorities. As a result, almost half of the GNSS receivers track now GLONASS satellites in addition to GPS. Furthermore, over the last year, almost 90% of the new antennas introduced in the EPN have GPS/GLONASS or GPS/GLONASS/Galileo tracking capabilities.
- In order to be able to generate long-term statistics on ionospheric and tropospheric phenomena over Europe, a historical data centre containing all EPN data since 1996 has been installed.
- Together with a number of groups involved in EUREF and WEGENER, we replied to an FP7 call for "Virtual Research Communities" (FP7-SPA.2010.2.1-03). The name of the project is "PLEGG – Platform for European GNSS and other geo-products" and it aims at developing a European e-infrastructure to
    - Warrant optimal access to GNSS and SAR data.

- Provide GNSS derived products for end-user communities
- Foster research to anticipate new GNSS and SAR products

➢ As part of our effort to also modernise the ROB GPS network, several multi-GNSS receivers and antennas have been tested.

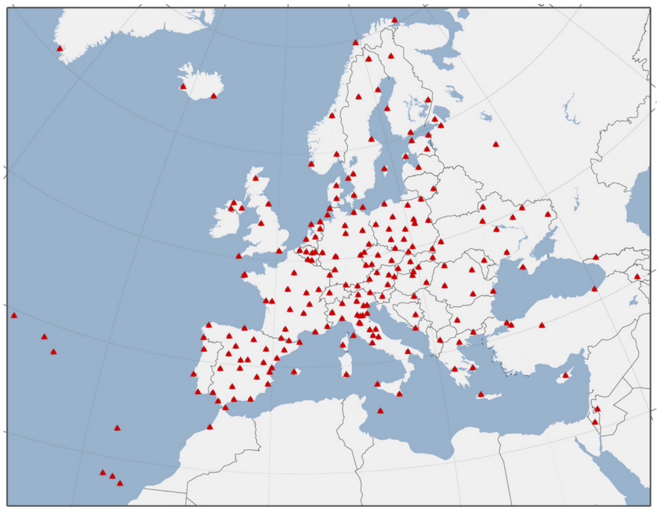


Figure 22: Map of the continuously observing GNSS stations in the EPN (Status: March 2010)

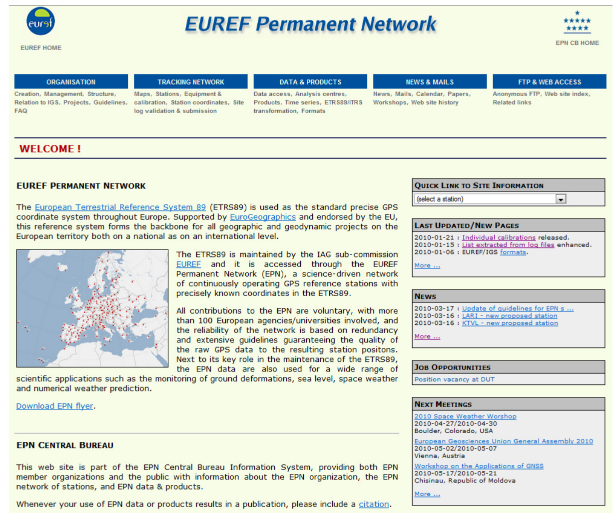


Figure 23: http://epncb.oma.be/ web site of the Central Bureau of the EPN hosted by the ROB

C.2.2.2. GNSS at the Princess Elisabeth base in Antarctica

We contributed to the preparation of the technical design of the GNSS receivers and antennas (one from ROB and one from the University of Luxembourg) that will be installed at the Princess Elisabeth I station in Antarctica, in collaboration with the Royal Military Academy. Once installed, the GNSS equipment will allow monitoring the Earth's atmosphere above the Antarctic region.

Figure 24: GPS antenna installed at the Princess Elisabeth base in Antarctica

➢ Two GNSS receivers (ELIS – see Figure 24- and ULUX) and antennas have been installed at the Princess Elisabeth (PE) base in Antarctica from 10 to 22 February 2009.The data were used to estimate
  - the tropospheric Zenith Path Delay (ZPD) time-series from ELIS and ULUX (3mm mean differences).
  - the hourly TEC above the PE base (differences of 1.5±0.9 TECU with the CODE IGS analysis center TEC maps).

➢ The 2010 GPS mission at the PE base has been prepared with the intent to install a continuously operating GPS receiver.

C.2.2.3. Monitoring of the Earth's troposphere

Precise knowledge of the ionosphere from GNSS measurements cannot be obtained if the tropospheric delays are not properly corrected. This is the reason why some studies of the troposphere modelling in GNSS data must be developed in parallel.

- The development and daily maintenance of the *"EUMETNET EIG GPS water VApor Program II"* (E-GVAP II) analysis centre was continued. This service uses state-of-the-art estimation techniques to provide the meteorological institutes with near real-time (NRT) GNSS-based tropospheric Zenith Path Delays for assimilation in the Numerical Weather Prediction (NWP) models. During the year 2009, about 45 new GNSS sites were progressively added to the processing, bringing the total number of stations included in the service to 210. It was also demonstrated that all requirements for GNSS-meteorology are achieved by our E-GVAP analysis centre.
- The Memorandum of Understanding (MoU) between EUREF and EUMETNET was used to assess the quality of the ROB E-GVAP II analysis centre service. Based on radiosonde and NWP data available from meteorological agencies thanks to the MoU, it was shown that 99% of the NRT tropospheric ZPD estimates delivered by our analysis centre have an accuracy better than the threshold requested for NWP applications.
- The NRT tropospheric ZPD estimates were also compared with the observations from the Onsala (Sweden) Water Vapor Radiometer (data provided by Prof. G. Elgered, Chalmers University, Sweden). The comparison, carried out using data from the first 9 months of 2009, revealed a bias of solely -1.6 mm. This shows the excellent accuracy achieved for the ROB NRT tropospheric ZPD.
- The Belgian dense GPS network was used to monitor the structure, movement and variability of small-scale atmospheric water vapor structures, providing valuable information for Numerical Weather Prediction and nowcasting applications.

C.2.2.4. Monitoring of the Earth's Ionosphere

The dense network of GPS receivers distributed over Europe provides an enormous number of radio navigation ray observations, each providing data about the state of the Earth's ionosphere. This immense number of ionospheric observations opens the door for improving the temporal and spatial resolution of TEC maps and ionospheric images. The resulting refined observation of the ionosphere will then allow detection and monitoring of physical processes in the ionosphere.

- The estimation of the daily differential inter-frequency hardware delays (Differential Code Biases, DCB) of the GNSS receivers is a crucial parameter for the TEC estimation. We computed the DCB for EPN stations using the CODE Global Ionospheric maps as *a priori* information. The differences between the estimated DCB from this method and the ones obtained with the Bernese GNSS software present a mean difference of 0.15 ns in 2003 and 0.04 ns in 2008. This corresponds to an error lower than 0.5 TECU on the electron concentration estimation, which is in the error level of the TEC estimation from GNSS data.
- A previously unreported two-step plasma instability process occurring on the day-night terminator gradient of the F-layer ionosphere above Europe on 30th October 2003 was discovered. The process is interpreted as a primary Gradient Drift Instability with subsequent secondary Kelvin-Helmholtz waves. The discovery was made by ingesting EPN GPS receiver station data and data from other European dense national GPS receiver networks into the ionospheric imaging algorithm, MIDAS 2.0. Without the exceptionally high spatial resolution afforded by these networks, the discovery would not have been possible.

C.2.2.5. Usage of new satellite signals (modernized GPS, GLONASS & Galileo)

- The quality of the ionospheric and tropospheric monitoring will improve if more satellites signals traversing the Earth's atmosphere will become available. For that purpose, encouraging EPN stations to switch from GPS-only to GPS+GLONASS (Russian counterpart of GPS) or GPS+GLONASS+Galileo (future European navigation system) is one of our top priorities. As a result, almost half of the GNSS receivers track now GLONASS satellites in addition to GPS. Furthermore, over the last year, almost 90% of the new antennas introduced in the EPN have GPS/GLONASS or GPS/GLONASS/Galileo tracking capabilities.

- The added-value of multi-GNSS (GPS, GLONASS and simulated Galileo data) in addition to GPS-only and dense tracking networks in Belgium, France, Germany, UK and Scandinavia in addition to the EUREF Permanent Network (EPN) for ionospheric tomography was investigated. For that purpose the signal ray concentration traversing the Earth's atmosphere above Europe was studied. The study was made using a tomographic approach: the Earth's atmosphere is divided into voxels.
  First results, with a test grid of 1° in longitude by 1° in latitude by 100 km height during 30 minutes, show that the large EPN network is capable of insuring that 85% of voxels, in a zone extending from -10° to 35° in longitude and from 35° to 70° in latitude from 30 km to 1230 km, are traversed by GPS-only signals (Figure 25). The additional dense receiver networks increase the total number of GPS signals. However the distribution of these additional ray paths creates inhomogeneity in the full set of observations because of the non-uniform distribution of the ground stations.
  Finally, using multi-GNSS observations from the EPN leads to a geometric ray distribution which is more homogeneous in space and time. For our test grid, the percentage of voxels traversed by GNSS rays is 94% (Figure 26). From these results, we can expect to obtain better temporal and spatial resolution for ionospheric imaging.

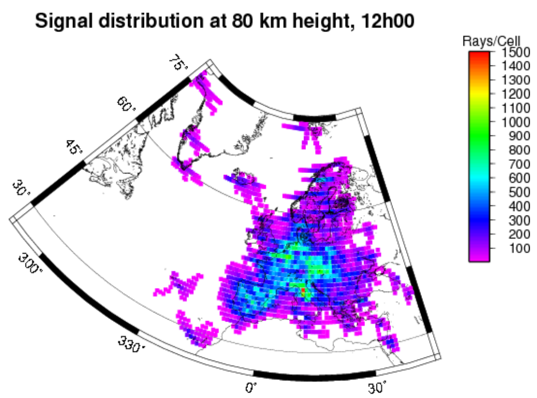


Figure 25: GPS signal distribution with EPN

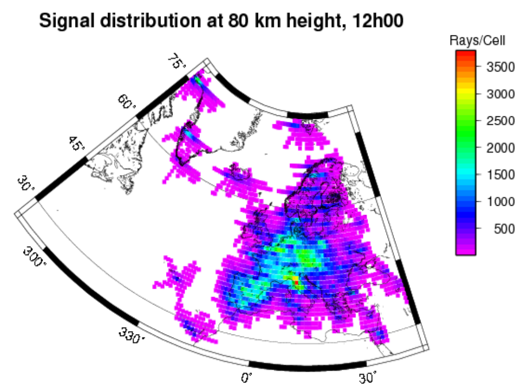


Figure 26 : GPS, GLONASS and Galileo signal distribution with EPN

C.2.3. Perspective for next years

- Upgrade the ROB network of permanent GPS stations to a multi-GNSS network
- Continue to maintain, extend and improve the EUREF Permanent tracking network
- Continue to monitor the troposphere by developing and maintaining the ROB E-GVAP II service and exploit the EUREF-EUMETNET memorandum understanding.
- Continue to exploit the Belgian dense GPS network to improve the knowledge of spatial and temporal variations of the atmosphere.
- Continue to contribute to the GIANT project at the Belgian Antarctic Base
- Investigate methods to improve the temporal and spatial resolution of ionospheric imaging
- Perform research on ionospheric phenomena using ionospheric imaging
- Continue to monitor the European ionosphere concentrating on the improvement of the software, and automation of the generation of TEC maps

C.2.4. Personnel involved

Scientific staff: C. Bruyninx (head "GNSS" project – EPN Central Bureau)
P. Defraigne (head "Time and time transfer" project)
W. Aerts (Time laboratory and new GNSS signals)

N. Bergeot (Monitoring of the ionosphere)
R. Burston (Ionospheric physics)
J.-M. Chevalier (Monitoring of the ionosphere)
J. Legrand (EPN Central Bureau)
E. Pottiaux (Monitoring of the troposphere)
S. Pireaux (Implementation of higher-order ionospheric effects in Atomium)

Technical staff: A. Moyaert (Maintenance and development of GNSS observation networks)
D. Mesmaker (Maintenance and development of GNSS observation networks)

C.3. Monitoring, modeling and forecasting the ionospheric activity

C.3.1. Objectives

The goal of this WP is to develop techniques allowing to monitor, to model and to forecast ionospheric and Space Weather activity "parameters" which have an influence on the performances of technological systems based on radio waves (electron concentration, Total Electron Content (TEC), geomagnetic activity, …).

C.3.2. Progress and results

In 2009, the goals of this WP were:

- To improve TEC reconstruction techniques based on GNSS data.
- To develop an operational technique for real time reconstruction of electron concentration at Dourbes by combining GNSS and ionosonde data
- To develop an operational procedure for real time reconstruction of the ionospheric slab thickness at Dourbes (the slab thickness is a good indicator of the ionosphere dynamics; it can be used in real time as indicator of an up- or ongoing ionospheric storm).
- To further validate the Dourbes K now- and forecasting model on real time data and to implement the necessary corrections/improvements.

C.3.2.1. TEC reconstruction techniques based on GNSS data

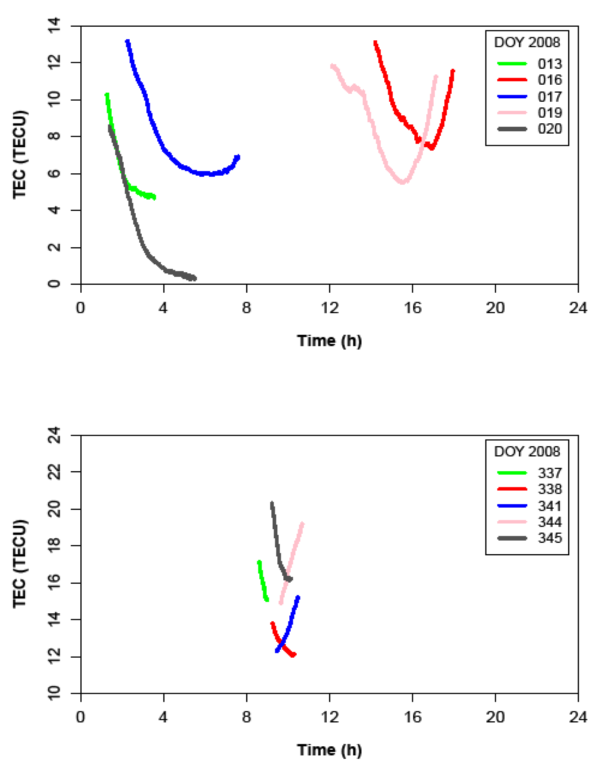


Figure 27 values obtained for Nordwijk (top) and Mizusawa stations (bottom)

The availability of dual frequency GNSS measurements allows reconstructing the slant total electron content (TEC) of the ionosphere. In practice, TEC is computed by using Geometric Free (GF) combinations of code and/or phase measurements. As phase measurements are much more precise than code measurements, TEC is computed by the GF phase combination. The main issue is the resolution of the GF ambiguity. With dual frequency GNSS L1/L2 (GPS or GLONASS) measurements, the ambiguity resolution is usually done by the so-called phase-to-code leveling process. This technique induces a leveling error ranging from 1 to 5 TECU due to code multipath delays but also to variations in differential satellite and receiver code hardware delays. With triple frequency GNSS (modernized GPS and Galileo) new linear combinations of measurements are available, opening opportunities for improved TEC accuracy.

Therefore, we have developed a triple frequency TEC monitoring technique in which the use of Geometric Free (GF) and Ionospheric Free (IF) combinations improves the ambiguity resolution process and consequently the precision of the reconstructed TEC (Spits and Warnant, 2009, ref [11]). The method has been tested on measurements made on E1, E5a and E5b signals emitted by the 2 experimental Galileo satellites, Giove A and Giove B. These measurements were collected in four stations belonging to the Galileo Experimental Sensor Stations (GESS) network.

Figure 27 shows TEC values computed for five different days in Nordwijk and in Mizusawa. During both period (January and December 2008), we obtained low TEC values, which can be explained by the low solar activity.

First (internal) accuracy assessment shows that our triple frequency TEC monitoring technique allows to reconstruct TEC with an error of about 1 TECU which is an important improvement in regards with the dual frequency method. Further improvements in TEC accuracy are expected.

C.3.2.2. Real time reconstruction of the electron concentration profiles at Dourbes

An operational system for monitoring the local ionospheric density distribution has been established at the RMI Geophysics Centre at Dourbes. The purpose of the LIEDR (Local Ionospheric Electron Density Reconstruction) system is to acquire and process data from simultaneous ground-based GNSS TEC and digital ionosonde measurements, and subsequently to deduce the local vertical electron density profile. LIEDR is primarily designed to operate in real time for service applications, and, if sufficient data from solar and geomagnetic observations are available, to provide short-term forecast as well. For research applications and further development of the system, a post-processing mode of operation is also envisaged.

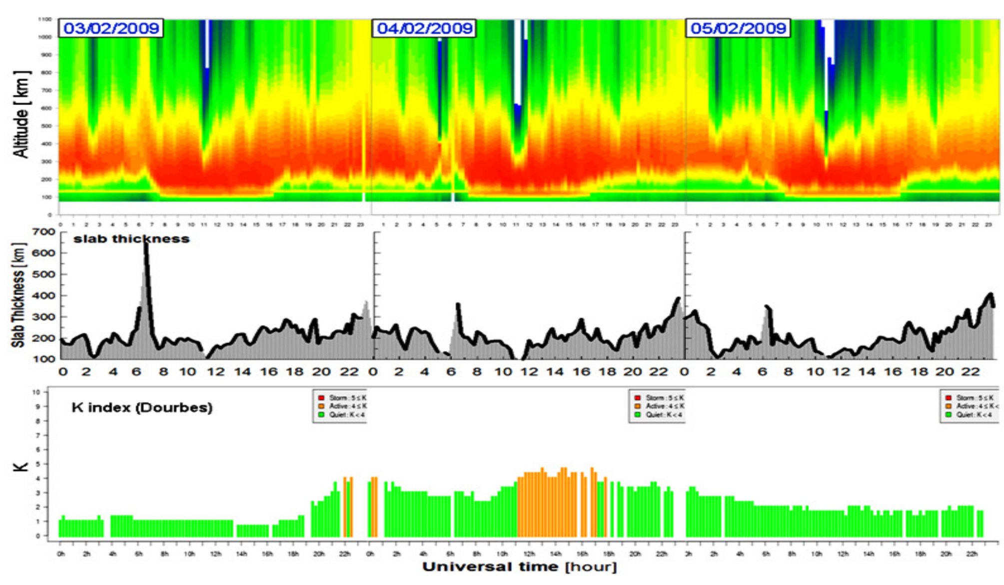


Figure 28. LIEDR real-time interoperability test during a minor storm event, from 13 through 18 February 2009. Top panel: reconstructed electron concentration profile (profilogram). Middle panel: Reconstructed slab thickness. Bottom panel: K index nowcast (Dourbes).

A key module of the LIEDR system is the vertical electron density profile reconstruction that uses simultaneous digital ionosonde and GNSS measurements, together with empirically-obtained values of the O^+/H^+ ion transition level. The ionosonde measurements are used primarily for obtaining the bottom-side profile, since digital ionosondes permit the reliable deduction of profiles from about 60 km up to hmF2. The topside electron density profile is deduced by employing a suitable ionospheric profiler (Chapman, Epstein, or Exponential) and solving a system of transcendental equations (resulting from the use of the above profilers) to obtain the unknown topside ion scale heights, sufficient to construct a unique electron density profile at the site of the measurements.

LIEDR has been tested on actual measurements and is now operational (Figure 28) with the nominal time resolution between two consecutive reconstructions set to 15 minutes.

C.3.2.3. Real time reconstruction of the ionospheric slab thickness at Dourbes

Another key module of the LIEDR operational system is the real-time estimation of the ionospheric slab thickness. The ionospheric slab thickness (τ) is defined as the ratio of the Total Electron Content (TEC) to the maximum ionospheric F2-layer electron density (NmF2). The ionospheric monitoring capabilities of the slab thickness remain largely unexplored, despite the fact that, operationally, it is a very useful parameter as it allows a simple conversion between foF2 and TEC and additionally, it closely relates to other important ionospheric characteristics. From this aspect, various possibilities exist for utilizing the ionospheric slab thickness modelling/monitoring efforts. If available in real time, over a region of interest, the operational slab thickness monitoring can be used for characterizing and eventually predicting the ionospheric density distribution and/or gradients, the extent of ionospheric density anomalies and their propagation characteristics. From this aspect, it is believed that the permanent ionospheric monitoring (incl. slab thickness) can assist various GNSS applications, such as improving the integrity and performance of network real time positioning services, the 'ionospheric threat' identification/estimation in aircraft navigation, etc.

C.3.2.4. Validation of Dourbes K now- and forecasting model

A nowcast and forecast system for monitoring the local geomagnetic activity from ground- and space based measurements has been developed. The "ground" system is based on a fully automated computer procedure for real-time digital magnetogram data processing and determination of the local geomagnetic index K.

The algorithm consists of modules for screening/cleaning of the input data set, establishment of the solar regular variations of the geomagnetic field, and K index calculation using the max-min method. An important part of this algorithm is the strict control of the data input and processing, allowing for an immediate assessment of the quality of output. Such quality control was found to be crucial for the system operation since it helps minimizing the existing possibility of missing an event or sending a false alert to the service users. The ground and space-based nowcast system operability, accuracy and precision have been tested with real-time (raw) measurements from the recent years (2002-2008) and the nowcast K values have been compared with the definitive index values, showing an average RMS error of about 1.0 K unit (Figure 29). Same tests have been performed for the space-based (MAK) model nowcast revealing a similar RMS error. The hybrid empirical model (utilizing both the space-based observations and local ground-based measurements) was estimated with data until 2004 and the error for one-hour-ahead prediction was found to be approximately 0.58 KU. The complete nowcast and forecast system is now operational at the site of the RMI Geophysical Centre in Dourbes (http://swans.meteo.be/geomagnetism).

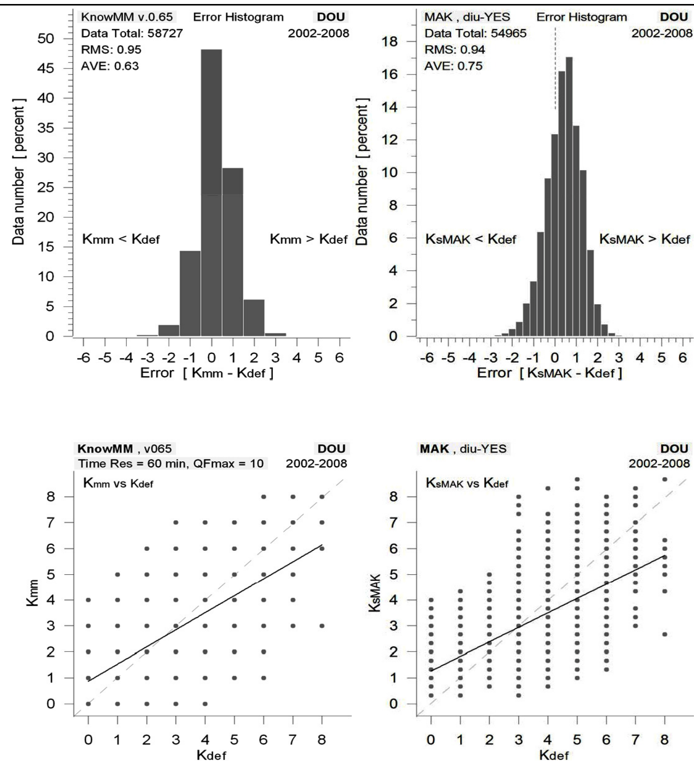


Figure 29 Evaluation results of the K index nowcast production over the period of 2002-2008 from ground (KnowMM, left panels) and space (MAK, right panels) based measurements. Top: Histogram of the residual errors, nowcast K (Kest) minus definitive K (Kdef). Bottom: Scatter plot of nowcast K vs definitive K values.

C.3.3. Perspective for next years

In 2010, the goals of this WP are:

- To analyze the added value of dual frequency GPS (L1/L5) and Galileo (E1/E5a) for TEC reconstruction.
- To further validate the triple frequency Galileo (E1/E5a/E5b) TEC reconstruction technique.
- To develop an improved K nowcast and a more reliable geomagnetic storm alert service (improved quality control).
- To develop a Dst geomagnetic nowcast technique based on ACE data.
- To develop improved Local Ionospheric Electron Density (LIEDR) at Dourbes

C.3.4. Personnel involved

Prof. René WARNANT (Project Leader), Dr. Stanimir STANKOV, Dr. Hugues BRENOT, Ms. Justine SPITS, Mr. Koen STEGEN, Mr. Gilles WAUTELET.

C.4. Radiative transfer

Radiative transfer (RT) codes simulating the propagation of radiation through the atmospheres of different planes serve as cornerstones for satellite remote sensing. They are used in a number of different applications (e.g., atmospheric correction, retrieval of the concentrations of atmospheric constituents from satellite measurements, atmosphere-ocean interactions, modelling of UV fluxes at a planet's surface) and are gradually replacing empirical approaches by providing more accurate and mathematically justified solutions.

The importance of RT codes for the remote sensing science constitutes the major reason for their extensive development. It would be desirable to have a fast and accurate RT code that is capable of simulating different planetary atmospheres to the most possible extent. To achieve this goal, it was decided to combine several RT codes (namely, ASIMUT, LIDORT and VLIDORT) to create an advanced software covering a wide range of atmospheric, spectral and geometrical conditions.

C.4.1. Objectives

The following objectives were set out for the year of 2009:

1. *Conversion of ASIMUT under Unix.* ASIMUT is a modular program for line-by-line RT modelling and retrieval of the concentrations of atmospheric constituents in a non-scattering atmosphere, which was developed by A.C. Vandaele, M. De Mazière and M. Kruglanski at BIRA-IASB in 2006. Before 2009, it was possible to run ASIMUT only under Windows, which was not really convenient for its combination with software written in any other language, e.g., in Fortran, as the combination of programs written in different languages is much easier to implement under Unix than under Windows.
2. *Choice of appropriate advanced codes for simulating aerosol properties.* LIDORT and VLIDORT are advanced linearized RT codes developed by R. Spurr, RT Solutions, USA, which are capable of accounting in an accurate way for scattering and absorption events caused by the presence of aerosols in an atmosphere, but they need to be supplied with already calculated aerosol parameters. Such an approach is not convenient as the user faces the necessity to find a way to calculate these parameters outside the codes.
3. *Combination of ASIMUT with LIDORT/VLIDORT and the aerosol codes.*
4. *Provision of radiative transfer support to other applications of RT in atmospheric forward modelling and inversion.*

C.4.2. Progress and Results

C.4.2.1. The Codes

The main objectives of 2009 have been achieved.

1. The ASIMUT code was successfully converted under Unix. A couple of weeks were required to eliminate differences in programming under Unix and Windows and to link all necessary libraries. Besides its intended use as part of the new software, the Unix version of ASIMUT itself is used for retrievals of several atmospheric constituents from IASI (Infrared Atmospheric Sounding Interferometer) data. Its main advantage compared to the Windows version is a relatively significant gain in run time (approximately by 1/4).
2. Two aerosol processing codes, SPHER and T-MATRIX, developed by M. Mishchenko, NASA Goddard Institute for Space Studies, New York, USA, were chosen for this project. Among all publicly available aerosol simulation software, these two codes seemed to have the best accuracy and performance characteristics. SPHER simulates properties of polydisperse homogeneous spherical particles on the basis of the Lorenz-Mie theory, while T-MATRIX models properties of polydisperse randomly oriented particles of a non-spherical shape (e.g., dust particles of the Martian atmosphere).
3. ASIMUT was successfully combined with four different codes, namely, LIDORT, VLIDORT, SPHER and T-MATRIX, to form advanced software abbreviated as ALVL (**A**SIMUT-**L**IDORT/**VL**IDORT). For the time being, ALVL has the potential to become one of the strongest and versatile RT packages available in the scientific market, as it allows one to model:
   - solar and thermal sources of radiation;
   - satellite and ground-based measurements;

- ➢spectrum range from UV to thermal IR;
- ➢atmospheric polarization;
- ➢absorption and scattering of radiation by atmospheric gases;
- ➢absorption and scattering of radiation by aerosols and clouds (including different models and layers);
- ➢reflection of radiation from the surface (Lambertian and bidirectional reflectance).

ALVL is available to all researchers at BIRA/IASB via the SVN version control system or at http://svn-ae.oma.be/ae_bruker/ASIMUT/branches/ALVL/. Its package also includes a concise manual describing ALVL from both scientific and programming points of view and two sets of example input files. No preliminary knowledge of LIDORT/VLIDORT or SPHER/T-MATRIX is required to run this software, but the user is expected to be familiar with ASIMUT and to know how to build its input files.

A more detailed description of ALVL is provided in the following sections, together with some results of validation.

4. RT support was occasionally provided to scientists at BIRA-IASB who used LIDORT for processing data acquired by SPICAM (Spectroscopy for the Investigations and the Characteristics of the Atmosphere on Mars).

C.4.2.2. Configuration of the created software

ALVL is a combination of five scientific programs and two auxiliary interfaces used to transfer variables from C to Fortran and backwards (Fig. 1). ASIMUT keeps the leading role in the package by controlling input/output and calculating a major number of physical parameters for LIDORT/VLIDORT. While developing ALVL, we followed the principle of minimum interference inside the codes to be able to quickly incorporate updated versions of ASIMUT or LIDORT/VLIDORT in the package. Thus, the interference into ASIMUT itself is minimized to calls to several major LIDORT/VLIDORT-related functions that are stored in a separate directory. Interference in LIDORT and VLIDORT subroutines is more complicated as it was required to block the reading of a number of input parameters that currently come from ASIMUT, but it was still limited to changes in three files. All additional subroutines are stored in separate files.

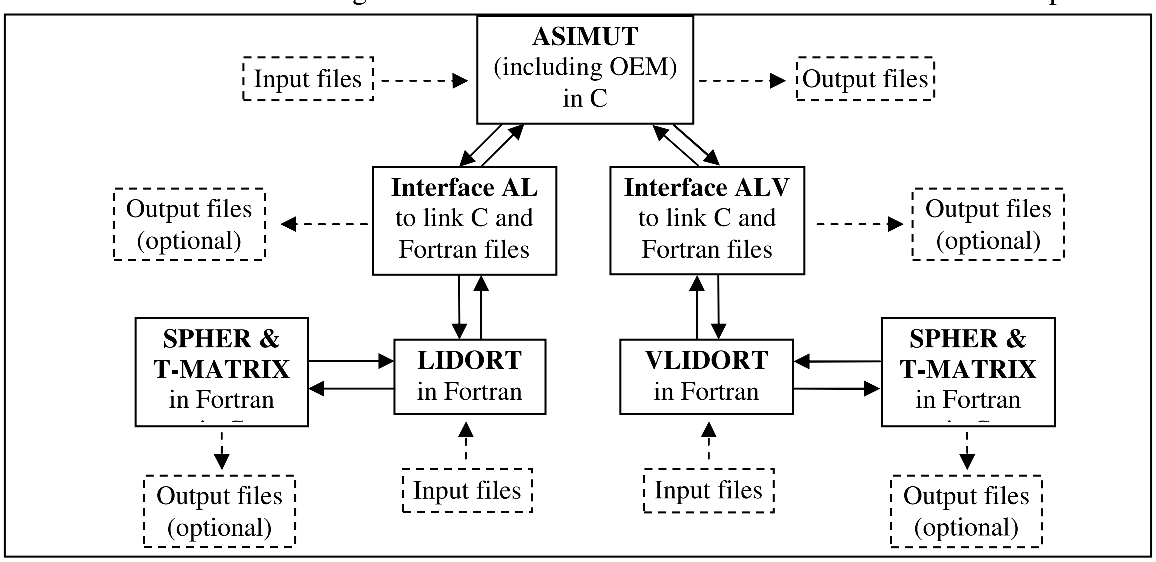


Figure 30. Configuration of ALVL.

The scientific goals fulfilled by each program with respect to ALVL are briefly described in Table 5. The choice between LIDORT and VLIDORT depends on the simulated spectrum (VLIDORT should be used for wavelengths below 2.4 µm and LIDORT for larger wavelengths) and should be made at the time of compilation. The choice between SPHER and T-MATRIX is made by ALVL itself on the basis of input aerosol parameters (spherical or non-spherical particles).

Program	**Author**	**Purpose**
ASIMUT (Unix version)	ASIMUT (Window version) by A.C. Vandaele, M. De Mazière & M. Kruglanski. Converted under Unix by V. Letocart, S. Kochenova & T. Kerzenmacher, BIRA-IASB, Brussels, Belgium	- Control of input and output; - Simulation of instrument properties; - Reading and calculation of the major number of physical parameters required as input to LIDORT/VLIDORT, e.g., geometrical configuration, spectral range, refraction index, gas absorption, temperature profiles, etc.; - Retrieval of different atmospheric constituents with the help of OEM (Optimal Estimation Method) in the thermal IR spectrum.
LIDORT	R. Spurr, RT Solutions, USA	Full scalar radiative transfer in case of scattering and/or thermal emission
VLIDORT		Full vector radiative transfer in case of scattering
SPHER	M. Mishchenko, NASA Goddard Institute for Space Studies, New York, USA	Calculation of aerosol parameters to be input in LIDORT/VLIDORT in case of spherical aerosol particles
T-MATRIX		Calculation of aerosol parameters to be input in LIDORT/VLIDORT in case of non-spherical aerosol particles
Interfaces	S. Kochenova, BIRA-IASB, Brussels, Belgium	Link between ASIMUT and LIDORT/VLIDORT

Table 5: Programs included in ALVL.

C.4.2.3. Example simulations: IASI measurements

This section shows the results of comparison between IASI top-of-atmosphere (TOA) measurements carried out on 22.06.2007 over the Kiruna site, Sweden (67.79°N, 18.38°E), and corresponding ALVL simulations with/without aerosol load in the thermal IR spectrum. The supposed aerosol load is small (the total optical thickness is approximately {0.19; 0.20; 0.24} for cases *a*, *b* and *c*, respectively). There is almost no scattering (the single scattering albedo averaged over the model atmospheric layers is about $\{3.9 \cdot 10^{-4}$; $5.1 \cdot 10^{-4}$; $6.8 \cdot 10^{-4}\}$ for cases *a*, *b* and *c*, respectively), but the effects of aerosol absorption are quite visible, especially in cases *a* and *b*.

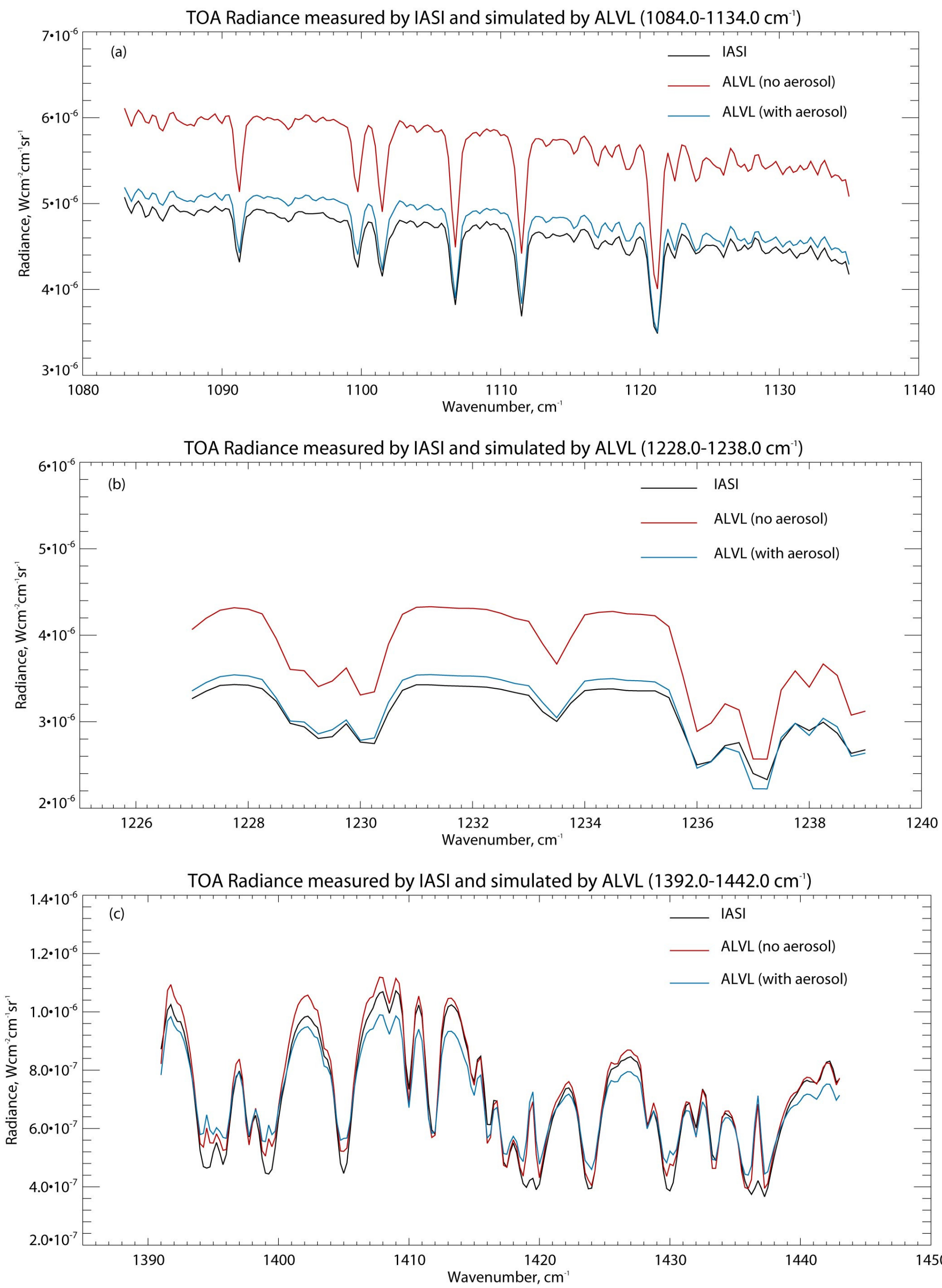


Figure 31. Comparison between IASI measurements and corresponding ALVL simulations.

The above example simulations will be considered part of the ALVL validation effort against experimental measurements.

C.4.2.4. Issues to be resolved in the future

Currently, ALVL is undergoing extensive validation/testing (against other RT software and experimental measurements) and further refinement. Major disadvantages which have not been resolved yet include:

– run time problem (running of an advanced RT at high spectral resolution requires a significant amount of time, which becomes a problem in case of a large number of data which need to be processed);
– run memory problem (ALVL requires a significant amount of memory (sometimes, several MB) during the execution, due to the extensive use of static arrays);
– graphical presentation of the results.

The first two disadvantages are typical for RT codes of such complexity. Theoretically, the time issue can be resolved with the help of parallel execution, which in the case of ALVL will imply the parallel processing of several data files, but this issue has not been investigated in detail yet. The memory issue will be partially resolved by replacing a number of static arrays by dynamic ones. Static arrays were chosen during the development process in order not to deal with memory allocation at that time. The last problem will also be easily resolved in the future. At the moment, the users of ALVL cannot yet benefit from the ASIMUT feature to view input and output parameters in the form of graphic files, as this feature has not been checked thoroughly and was temporarily blocked.

C.4.3. Perspective for next years

In 2010, it is planned:

1. To finish and finalize the refinement and validation of ALVL, to document the results of validation and to include more examples in the ALVL package.

2. To present ALVL at scientific seminars and conferences.

3. To develop collaboration with ULB and to start using ALVL for retrieval of aerosol parameters from IASI data in the thermal IR spectrum.

4. To use ALVL to simulate and process measurements collected by the GOME (Global Ozone Monitoring Experiment) and SPICAM instruments.

5. To provide support to other applications of RT in atmospheric forward modelling and inversion problems (according to the priorities in the course of the year).

C.4.4. Personnel involved

Scientific staff:	M. De Mazière (Project Leader)
	S. Kochenova (creation and validation of ALVL)
	G. Vanhaelewyn (contribution to the validation of ALVL)
	T. Kerzenmacher (coordination of IASI test files for ALVL)
Technical staff:	V. Letocart (coordination of ALVL programming issues)
	N. Kumps (IT support to IASI data retrieval)

D. Earth Environment - Magnetosphere

D.1. Science of the Space environment

D.1.1. Objectives

Science underlies understanding and predicting the space environment. The long term goal of this project is to perform first-class science in various domains related to solar-terrestrial science (solar wind, auroral physics, solar-terrestrial relationships …) in close collaboration with the Institute science staff and other Belgian and international scientific teams. The main objective is to acheave a better understanding and modeling of fundamental plasma physics processes in the solar-terrestrial connection from the Sun to the Earth. Among other components, this includes theoretical investigation of plasma waves, instabilities, and wave-particle interactions, and their applications in the solar atmosphere, solar wind, and terrestrial magnetosphere.

D.1.2. Progress and results

D.1.2.1. Wave phenomena in the solar wind and the magnetosphere

The goal of this work package is to study the role of waves in various regions: in the solar wind, near the magnetopause, in auroral acceleration regions, ...

Waves and instabilities in the solar atmosphere

Small-scale electrostatic instabilities related to the Farley-Buneman instability (FBI) are studied in the partially ionized plasma of the solar chromosphere taking into account the finite magnetization of the ions and Coulomb collisions Error! Reference source not found.Error! Reference source not found.. We obtain the threshold value for the relative velocity between ions and electrons necessary for the instability to develop. It is shown that Coulomb collisions play a destabilizing role in the sense that they enable the instability even in the regions where the ion magnetization is larger than unity. By applying these results to chromospheric conditions, we show that the FBI cannot be responsible for the quasi-steady heating of the solar chromosphere. However, we do not exclude the instability development locally in the presence of strong cross-field currents and/or strong small-scale magnetic fields. In such cases, FBI should produce locally small-scale (~0.1-3 m) density irregularities in the solar chromosphere. These irregularities can cause scintillations of radio waves with similar wave lengths and provide a tool for remote chromospheric sensing.

In the framework of Hall MHD we investigated torsional Alfvén waves guided by the small-scale current threads in the solar corona. We modeled a thread as a magnetic flux tube with twisted magnetic field lines inside the tube and straight magnetic field lines outside the tube. It is shown that the trapped torsional Alfvén waves can propagate in the current thread with sufficient magnetic twist. The waves propagate along the tube's axis and have a localized profile across it. The modes are confined in the region of twisted magnetic field. Our results show that the number of trapped modes depends on the amount of magnetic twist. More twisted the tube, more modes in the system. Also, if the field is not enough twisted, the modes can disappear; so, there is a threshold twist for their appearance. Similarly to the density threads, the current threads guiding the torsional Alfvén waves can be places of enhanced coronal heating due to the wave dissipation.

Wave-particle interactions and particle velocity distributions in the solar wind

The non-thermal features of particle velocity distributions observed in the solar wind, such as particle beams and temperature anisotropies, suggest that the wave-particle interactions can be an important factor regulating the solar wind dynamics. Most attention was previously towards the ion-cyclotron resonant interaction, implying the presence of ion-cyclotron waves in the solar wind. However, recent observations have revealed the predominance of kinetic Alfvén waves (KAWs) in the dissipation range of the solar wind. Having in mind these observational facts we developed the model for the proton beam formation in the fast solar wind by KAWs Error! Reference source not found.Error! Reference source not found.. The basic KAWs properties to increase their parallel electric field and phase velocity with decreasing cross-field wavelengths lies in the core of the acceleration mechanism we propose.

Our scenario for the proton beam formation in the solar wind is illustrated in Figure 32: Our scenario for the proton beam formation in the solar wind (see description in text). At first stage, in the vicinity of the solar wind base (or at some distance from the Sun inside 0.3 AU), a part of the Alfven wave flux develops high cross field wave numbers. Such Alfven waves carry a significant parallel electric potential and trap protons in the certain amplitude-dependent velocity interval around the KAW phase velocity (Vph1 in Figure 32: Our scenario for the proton beam formation in the solar wind (see description in text)). While the normalized wave number continues increasing, the trapped proton fraction is accelerated by the accelerated KAW propagation. In such a way the trapped proton fraction detaches from the main proton component and forms the super-Alfvénic proton beam. The number density and energy content in this beam depends on the energy content in KAWs. In principle, the observed proton beams can be generated by KAWs with quite small magnetic amplitudes, in which case a sequence of KAW wave-trains (e.g. resulting from different parts of Alfvén wave spectrum) can result in the observed non-thermal features of the proton velocity distributions.

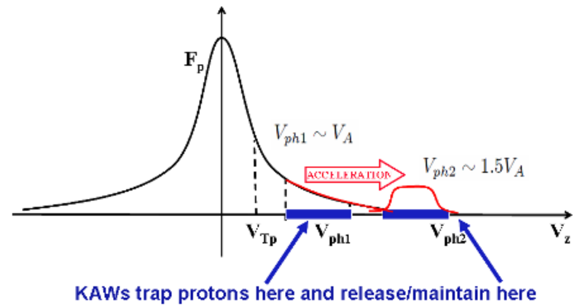


Figure 32: Our scenario for the proton beam formation in the solar wind (see description in text)

Kinetic instabilities, nonlinear interactions, and turbulence of kinetic Alfven waves in the terrestrial magnetosphere

We tackled a complex problem of modeling the plasma state and the wave activity observed by the Cluster satellite during periods of enhanced magnetic activity in the Plasma Sheet Boundary Layer (PSBL). Super-Alfvenic ion beams are often observed simultaneously with an enhanced wave activity in PSBL. We studied a beam-driven fan instability of kinetic Alfven waves at the n=-1 anomalous Doppler effect as a possible source of the enhanced wave activity observed just below the local ion-cyclotron frequency (so-called "fundamental harmonic")

We studied a non-adiabatic acceleration of oxygen ions by the KAW turbulence across the background magnetic field, which can be the source for ion conics in the auroral zones. Our first results have revealed the importance of breaks in the turbulent spectra, where the turbulent energy can be made accessible for the ion energization. Another important property of the ion acceleration by KAW turbulence is that it can be enforced by the field-aligned ion motion in the opposite direction the waves move to, which can lead to the "surfing-on-turbulence" effect. These properties of the proposed energization mechanism are compatible with observed features of KAW turbulence and oxygen ions in the auroral zones.

Large-scale high-amplitude MHD waves observed in the solar corona, solar wind, and in the terrestrial magnetosphere undergo damping that is often faster than would result from the classic collisional dissipation. We study new damping mechanisms for MHD waves produced by their cross-scale nonlinear coupling with the kinetic ion sound and Alfven waves (KSWs and KAWs respectively). The decay of MHD waves into KSWs and KAWs appeared to be faster than the decay into MHD Alfven and sound waves studied in the past. The nonlinearly driven KSWs and KAWs have cross-field wavelengths comparable to the ion gyroradius and are very efficient in wave-particle interactions, producing anisotropic plasma heating and particle acceleration, as is observed in the terrestrial magnetosphere and in the solar corona.

D.1.2.2. Exospheric models for the solar wind and for planets

The goal of this work package is to model the solar wind and its acceleration, and advanced modelling of the polar wind and the exospheres of the planets.

Modelling the solar wind and its acceleration

Kinetic solar wind models have been improved by emphasizing the effect of the interplanetary electric field and the heat conduction. There is a growing interest within the physics community for the kinetic models developed at IASB-BIRA, as attested by the invitations of V. Pierrard to several meetings and workshops like ISSI and Solar Wind 12. Improvements of the solar wind models are planned in the future by investigation of additional effects like the Coulomb collisions for the protons, the kinetic Alfvén waves and the wave turbulence.

Advanced modelling of the polar wind and the exospheres of the planets

V. Pierrard has developed a kinetic exospheric model based on the Kappa velocity distribution function for the exospheres of the giant planets Jupiter and Saturn. Such Kappa velocity distribution functions with an enhanced population of suprathermal particles are indeed often observed in space plasmas and in the space environment of the planets. The suprathermal particles have significant effects on the escape flux, density and temperature profiles of the particles in the exosphere of the giant planets. The polar wind flux becomes several orders larger when suprathermal electrons are considered, so that the planetary ionosphere becomes then a significant source for their inner magnetosphere. Moreover, the number density of the particles decreases slower as a function of the altitude when a Kappa distribution is considered instead of a Maxwellian one. Two dimensional maps of density were calculated for typical values of the temperatures. The exospheric formalism has also been applied to study the escape flux from the exospheres of Io and Titan, respectively moons of Jupiter and Saturn.

D.1.2.3. Study of space weather causes and effects

The goal of this work package is to look at various aspects of space weather research, including the effects of ionizing radiation…

Kinetic models for space weather

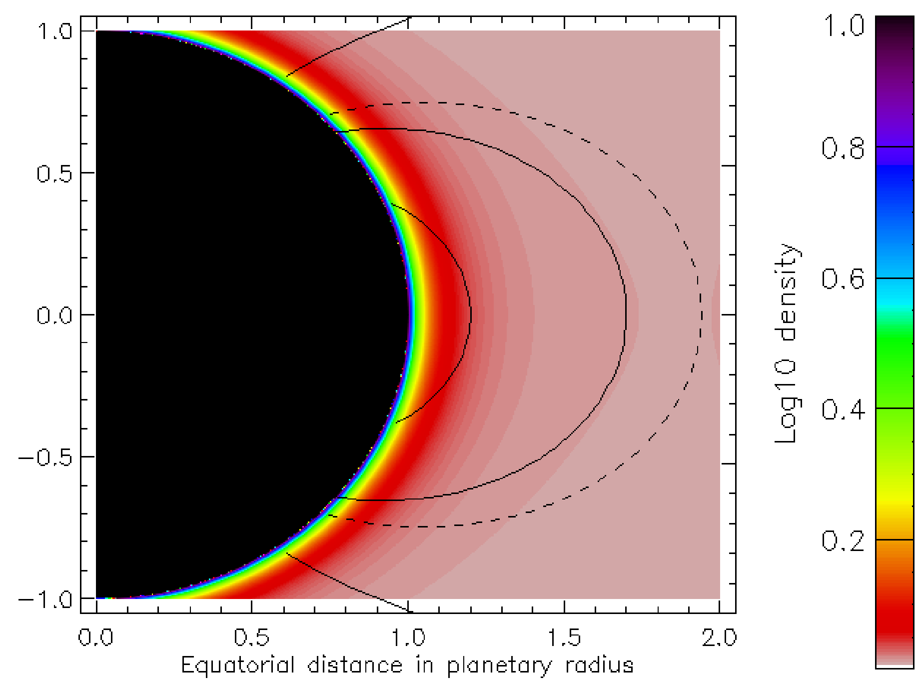


Figure 33: Normalized electron densities in the plasmasphere of Jupiter for a typical Lorentzian velocity distribution with Kappa=4 and a temperature of 4000 K

Various kinetic models for space weather (exosphere, plasmasphere, solar wind…) have been developed at BISA during the last years and were presented in 2009 at different conferences. They led to the publication of a review paper. Moreover, V. Pierrard wrote a book published at the Presses Universitaires de Louvain on the space environment of the Earth to summarize the main physical mechanisms implicated in space plasmas Error! Reference source not found.. This book is dedicated to the students of her lecture on Physics of high atmosphere and space at UCL, as well as for the large public.

Plasmasphere and space radiation studies

The book "*The Earth's Plasmasphere: A CLUSTER and Image perspective*" (editors: Fabien Darrouzet, Johan De Keyser, Viviane Pierrard) has been published by Springer and is commercially available from October 2009. Copies have been distributed to an extensive list of interested scientists. We have sent out book announcements via the SPA and SWEN mailing lists, EGU news, and other channels. It is highlighted on ESA's CLUSTER site (http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=45468). All the papers, the preface and the foreword had already been published online by Space Science Reviews Error! Reference source not found.Error! Reference source not found.. A number of presentations on the subject were given Error! Reference source not found.Error! Reference source not found.Error! Reference source not found..

Concerning space radiation, low altitude energetic electron lifetimes after enhanced magnetic activity have been studied, in close collaboration with UCL. Flux enhancements produced as a consequence of geomagnetic storm occurrence, gradually vanish when the magnetic activity calms down and the fluxes decay to quiet-time levels. SAC-C and DEMETER low altitude observations have been used to estimate the energetic electron lifetimes and compare the decay rates to those observed at high altitude. The effects of the plasmapause position on the radiation belts have also been studied by comparing observations of SAC-C, Cluster and models of plasmapause formation.

D.1.3. Perspective for next years

Solar wind and magnetospheric studies will be extended. The formation and modification of particle velocity distribution functions in the solar wind and terrestrial magnetosphere will be studied by investigating Coulomb collisions, suprathermal populations, nonlinear interactions, instabilities, and turbulence of kinetic Alfven waves.

D.1.4. Personnel involved

Scientific staff: Viviane Pierrard (Project Leader)
Yuriy Voitenko (scientist)

PART 3: APPLICATIONS AND DATA

A. Space Weather

A.1. Solar Activity and Space Weather Operations Centre

A.1.1. Objectives

RWC Belgium is a permanent service centre specializing in solar monitoring and solar activity forecasting. It is run by the SIDC under the auspices of the ISES network. Its solid base is the solar physics research undertaken at the SIDC and our involvement in solar observations from space and ground, giving access to a large volume of solar and heliospheric data that can collectively span operational requirements. Building on insights derived from our scientific studies, the SIDC provides expert and timely information on and assessment of solar dynamics and its likely relevance for human technology.

A.1.2. Progress and results

A.1.2.1. Internal Management

Good Internal communication is one of the necessities to perform well. A website, regular meetings, email contact, (in)formal live contacts, ... can contribute to a good internal communication. The RWC-performance is being guided by the RWCWDC-wiki (http://sol042.oma.be:8000:RWCWDC) and regular internal meetings.

A.1.2.2. External Management

The RWC Belgium was represented on several meetings relevant for the space weather business. R. Van der Linden represented the RWC Belgium in the ISES and FAGS structures, in the present COST activities and in preparatory meetings for the European Space Situational Awareness program. The RWC and the Space Weather performance were presented as part of the STCE review to the committee of directors of the Federal Scientific Institutes.

A.1.2.3. Routine operations

For the RWC activities, a continuous data stream from ground-based spacecraft instruments has to be analysed and interpreted. The daily routine of RWC activities include different tasks:

- *Data distribution*. The RWC acts as a hub for further distribution of solar and geophysical data, mostly in the form of ISES encoded messages.
- *Monitoring solar activity and space weather*. To maintain a high standard in our activities as an RWC, we develop and use software that autonomously detects space weather events. This service is timely and assists the forecaster on duty in his monitoring and alerting task. Examples are CACTus (CME detector), B2X (flare detector), and NEMO (EIT-wave detector). These monitoring activities result in an alert service. Most of the warnings are sent out automatically in several alert-type messages, though some alerts need human intervention.
- *Forecasting solar activity and space weather*. Reports and forecasts of solar activity and space weather conditions are distributed every day (including weekends and holidays) at approximately 12:30 UT in the ‘ursigram’ messages. Weekly summaries are sent out in principle on Mondays, while more extensive monthly summaries of solar and geomagnetic activity are included in the Sunspot Bulletin of the SIDC. The latter also includes medium-term forecasts of the evolution of

the sunspot cycle. This results in the publications [93], **Error! Reference source not found.**, **Error! Reference source not found.**, **Error! Reference source not found.** and [105].

On the technical level, the monitoring, alerting and forecasting services of the RWC contain three main aspects: client database management, production of data/messages and delivery of data/messages. These activities are managed in a semi-autonomous way by the software package *PreviMaster*, which handles the solar data, the forecasts and alerts in conjunction with a database. The interface between the human operator and the *PreviMaster* package to receive the daily forecasts, manually triggered alerts and other subsidiary information, is a secured web-based tool called called *PreviWeb*. Continuous maintenance and upgrade of these two packages, and the SIDC website itself, is an important never-ending task.

Urgency procedures are made available at the website accessible for all forecasters. The trigger was a server failure in a weekend. Two forecasters knowing about the server-set up could manage the forecast to be sent out. With the availability of urgency documentation, every forecaster should be capable of solving failures.

A.1.2.4. Space Weather Forecasting

The quality control of the F10cm-forecast was automatised by linking previmaster to the MySQL-database. The output needs to be made visible on previweb and the general SIDC website.

A new member for the forecast team was welcomed at the beginning of 2009. E. D'Huys received in first instance a training in Space Weather forecasting. Starting from February 2009, she actively participated in the forecasting and was the forecaster for 7 weeks during the year.

As part of the training, E. D'Huys attended the Space Climate School in Saariselkä (Finland) and participated to the annual International Space Environment Service (ISES) meeting in Boulder (25-26 April 2009). Together with the other ISES members present at the meeting, she visited the NOAA Space Weather prediction Centre in Boulder as representative of the RWC (see Figure 34).

Figure 34: Visit of the ISIS members to the NOAA Space Weather Prediction Centre

The space weather briefings are reinitiated and take place during the weekly Science & Coffee. The forecaster on duty gives a resume of the space weather events of the past week. **Error! Reference source not found.**, **Error! Reference source not found.**

A.1.2.5. Solar Weather Browser

The Solar Weather Browser (SWB) is an open-source software tool that allows easily displaying and combining solar images from different observatories together with solar metadata, without the need of data processing. For the forecast team, the SWB offers an easy tool to browse through solar data while performing the forecast and monitoring the sun. The client is readily available for Linux, Mac OS X and Windows at http://sidc.be/SWB.

The daily maintenance of the server that provides the solar input data for this tool is taken care of. The RWC continued the inclusion of our own USET Ha and white-light data into SWB. All the USET data from 2008 are reprocessed to make them available through the SWB. The codes to process the STEREO/SECCHI images are updated, in order to adapt them to a change to the data archive. Similar maintanance activities were carried out through the whole year.

A new e-mail address was launched (SWB@sidc.be) for users to send questions or remarks to.

The Solar Weather Browser was presented in a poster at three meetings: the Space Climate Symposium in Saariselkä (Finland), the Space Weather Workshop in Boulder (Colorado) and the European Space Weather Week in Brugge (Belgium). While the SWB is already well known among the participants of the European Space Weather Week, it was quite new for the attendees of the Space Weather Workshop. Especially representatives of the industry and government agencies showed a lot of interest in this tool.

A.1.2.6. All-quiet-product

We investigated the validity and relevance of our all-quiet-alerts. We send out a survey to all our registered users of this product. The criteria for sending an all-quiet-alert are:

1. the solar X-ray output is expected to remain below C-class level,
2. the Kp index is expected to remain below 5,
3. the high-energy proton fluxes are expected to remain below the event threshold.

It is the forecaster interpreting the space weather data, who triggers to start or end the all-quiet-alert period.

The results of the all-quiet-alert-program was presented by R. Van der Linden at the workshop 'Forecasting the All-Clear', 22-24 April, 2009, UCAR Boulder.

A.1.2.7. PROBA2 and the RWC

PROBA2 is a valuable partner of the RWC in the sense that PROBA2 is the first ESA space weather mission. PROBA2 can provide crucial and timely information about the solar conditions necessary for a good forecast. The relevance of PROBA2 for the space weather prediction centre was stressed on the running presentation **Error! Reference source not found.** shown during the press conference of Nov 2 highlighting the launch of PROBA2 and during the space weather fair at the ESSW6.

Since the commanding of the telescopes SWAP and LYRA and the exploitation of the data are done from the SIDC, we are on the first row to access the data. Special demands focusing on space weather events relevant for the forecast centre are possible.

A.1.2.8. RWC@esww6fair

During the sixth European Space Weather (Nov 16-20), a fair was organized. The fair was intended as a hands-on workshop to show products & services to the space weather community. The SIDC/RWC was present with a stand. On a daily basis, the space weather was broadcast. C. Marqué did the practical arrangements.

A.1.2.9. Science and Coffee

The latest news about the ongoing projects like PROBA2, SDO/EUI, WDC, RWC is shared with all members of the group. The meetings are informal, held on a weekly basis and take half an hour. The attendance is high and ranges from 10 to 20 participants.

A.1.2.10. RWC @ Open doors Space Pole

We list the RWC activities performed during the open doors on October 03-04.

- Running presentation 'Our Dynamic Sun', P. Vanlommel
- Oral presentation 'Ruimteweer: energie-oprispingen', Dutch and French, S. Raynal, P. Vanlommel
- Oral presentation 'Le météo spatiale: les prévisions', F. Clette
- Daily written Space Weather forecast
- Running presentation: 'PROBA2: preparing for launch', D. Berghmans
- Scale model of PROBA2
- Running presentation: 'EIT', D. Berghmans
- Poster presentation: 'The Solar minimum', C. Marqué and P. Vanlommel

➢ Poster presentation: 'Solar Activity', P. Vanlommel

Wikis and Websites

- Internal development wiki: http://sol042.oma.be:8000:RWCWDC
- Internal development wiki: http://pb2sc.oma.be:8000/ESWW/
- Upcoming development ideas for SWB : http://sol042.oma.be:8000/RWCWDC/wiki/SWBmainPage
- http://www.sidc.be/esww6
- http://www.sidc.be/
- http://sidc.be/private/previweb_db/
- http://sidc.be/planning/

A.1.3. Perspective for next years

A.1.3.1. Hardware infrastructure

A revisit to the RWC/WDC hardware infrastructure is planned with particular attention to redundancy.
Two options can be considered:
(1) an architecture with virtual machine inspired on the P2SC system ,or
(2) a fully redundant system of 2 hardware servers running in parallel.
Meanwhile we await the kick-off of ESA's Space Situational Awareness program (SSA) and its associated prototype services before we take strategic decisions on the SIDC RWC/WDC.

A.1.3.2. Solar Weather Browser

Further developments on the server side of the SWB will include moving it to a dedicated server. Also improved logging to facilitate the daily monitoring of the tool and a functionality to reprocess older data, which were already envisioned last year, are still planned.

Data from the PROBA2 satellite will be included into the Solar Weather Browser. The SWB will also be an important contribution to Work Package 6 of the SOTERIA project.

A.1.4. Personnel involved

Scientific staff: R. Van der Linden (Project Leader), D. Berghmans, F. Clette, E. D'Huys, C. Marqué, L. Rodriguez, P. Vanlommel, L. Wauters, A. Zhukov

Technical staff: O. Boulvin, S. Willems, A. Vandersyppe

The daily duty cycle of forecasting and monitoring activities were shared by D. Berghmans, F. Clette, E. D'Huys, C. Marqué, L. Rodriguez, P. Vanlommel, R. Van der Linden, A. Zhukov.

A.2. Space Weather Web Services

Space Weather describes the conditions in space affecting Earth and human activities. It is mainly driven by the solar activity and is associated to phenomena such as geomagnetic storms, the Van Allen radiation belts, ionospheric disturbances, aurora and geomagnetically induced currents at Earth's surface. Several models and data sets have been produced (and are still being produced) by the scientific and engineering community to understand, evaluate and forecast the phenomena and their effects on technological systems. The access to this information is not always straightforward, in particular for a broader public. Web accessible services should educate, inform and provide user-friendly tools to different communities (general public, space engineers and policy makers,…). Our long-term goal is to provide a number of human and machine readable services that expose the scientific and technical expertise that has been and will be acquired on the space environment and its effects.

A.2.1. Objectives

A.2.1.1. .European Space Weather Portal (ESWEP)

The ESWeP portal is an integrated website providing a centralized access point to the space weather community to share their knowledge and results. Initiated under the COST 724 Action the ESWeP is further developed in the framework of the COST ES0803 Action ('*Developing space weather products and services in Europe*'). The portal is hosted at the Belgian Institute for Space Aeronomy. The objective of the project is

- to maintain the Content Management System supporting the portal;
- to develop new functionalities;
- to interact with the European space weather community

A.2.1.2. Space Environment, Effects, and Education System (SPENVIS)

The SPENVIS system is ESA operational software developed, maintained and operated by BIRA-IASB. It consists of a web-based interface for assessing the space environment and its effects on spacecraft systems and crews. The system is used by an international user community for various purposes, e.g. mission analysis and planning, educational support, and running models for scientific applications.

A.2.2. Progress and results

A.2.2.1. European Space Weather Portal (ESWEP)

In addition to maintenance of the portal Content Management System, the following progresses have been achieved in 2009:

- Implementation of a "Space Weather Document Repository" in collaboration with the FP7 SOTERIA project. The repository allows space weather professionals to upload and share their technical documents, reference documents, standards or research papers. The repository is available at URL http://www.spaceweather.eu/en/repository. In addition to the document itself, metada such as author list, title, abstract and topics addressed are stored in the repository. The repository includes currently about 70 documents.
- Implementation of a nowcasting of the plasmapause location based model developed by V. Pierrard (doi: 10.1029/2003GL018919) and forecast of Kp retrieved from SWENET. The nowcast is visible as a preview panel on the portal front page.
- Linking the "Real-time forecasting of well-connected Solar Energetic Proton Events" developed and maintained by Prof. Dr. Marlon Núñez Paz from the University of Malaga through a preview panel on the portal front page.

Figure 35: Screenshot of one ESWEP page showing in the main panel a list of document archived in the SOTERIA Space Weather Document Repository and on left panel the previews of both the plasmapause location nowcasting and the SEP event realtime forecasting

A.2.2.2.. Space Environment, Effects, and Education System (SPENVIS)

The upgrade of the SPENVIS system occurs in the framework of an ESA GSTP contract. In addition to the system maintenance and the user support, the following main progresses have been achieved in 2009:

- Addition to SPENVIS system of the IGE-2006 model (and some alternative versions) for the geostationary electron environment developed by ONERA/DESP (Sicard-Piet et al., doi: 10.1029/2007SW000368). In the user interface, the model is only available when geostationary orbits are defined
- Addition to SPENVIS system of the update to the JPL-91 model for predicting long term solar proton fluences proposed by Rosenqvist et al. (doi: 10.1016/j.asr.2007.08.023).
- Addition to SPENVIS system of the ISO-15390 (and some alternative versions) for evaluating the galactic cosmic ray fluences in the near Earth environment. Inside SPENVIS the model is linked to the computation of Single Event Upset rates.
- Upgrade of the SPENVIS orbit generator in order to simulate trajectories for Martian and Jovian missions.
- Implementation of Jovian trapped particle models based on a code provided by ONERA/DESP. The implementation used the trajectories simulated by the orbit generator and includes as models: Divine and Garrett, GIRE and ONERA/Salammbo.

- Development of a JAVA-based geometry definition tool that allows the generation of GDML files for simple geometries. GDML (*Geometry Description Markup Language*) is a standardized format use to describe geometries in Geant4 applications. Such file is request when using Geant4-based tools such as SSAT (*Sector Shielding Analysis Tool*) and GRAS (*Geant4 Radiation Analysis for Space*).
- Development of a HTML interface to the ECSS space environment standard (ECSS-E-ST-10-04C). The interface is available from the SPENVIS help pages.

All the new development are available in release 4.6.2 (December 2009).

The SPENVIS system is used by a growing community. In 2009, about 1070 people have registed for a SPENVIS account. (35% from Europe and 30% from US). Each month about 300 people access SPENVIS to execute models. The majority is using SPENVIS on an occasional base (few days for a period of about 3 months).

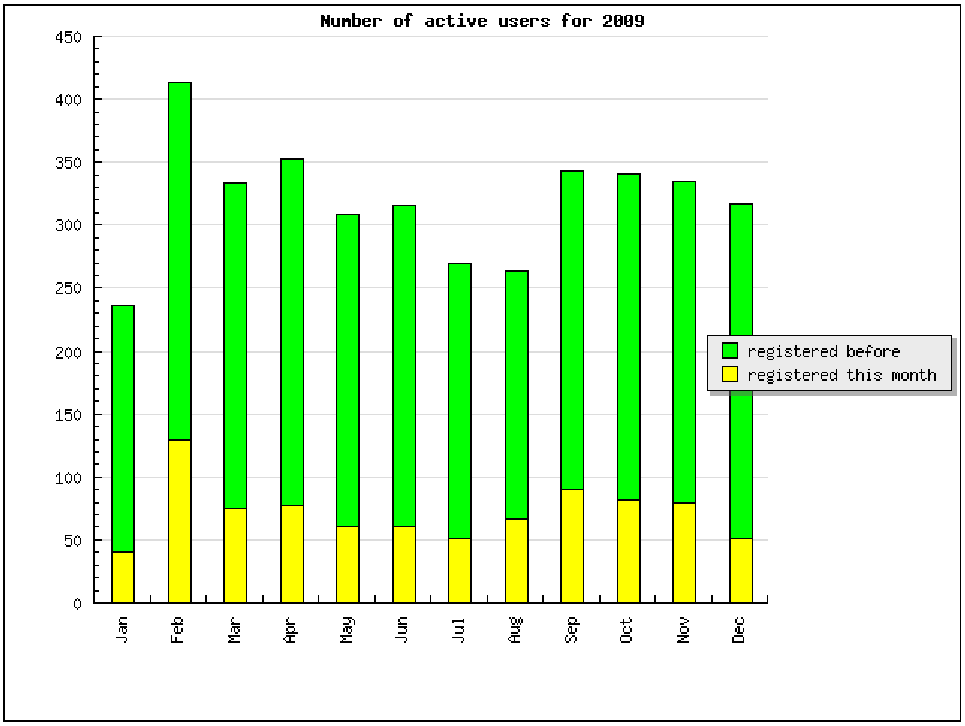


Figure 36: Number of active users of the SPENVIS system for the year 2009.

A.2.3. Perspective for next years

A.2.3.1. European Space Weather Portal (ESWEP)

In the frame of the STCE we want to continue the update and upgrade of the ESWeP web portal. In 2010 the focus will be set on the establishment of establish a formal agreement on how to manage and develop ESWEP. Such a document to be written in collaboration with other partners should consolidate the perdurability of ESWEP.

A.2.3.2. Space Environment, Effects, and Education System (SPENVIS)

In 2010 the focus will be set on the addition of new models in the SPENVIS system, improving the user interface and the development of a specific interface for Geant4-based applications. The development will be governed by the model availability and the user requests. In order to better identify the SPENVIS user requirements and to promote the use of this system, a dedicated workshop will be organised in June 2010.

Other perspectives for the next years are the integration of SPENVIS in the future European Space Situational Awareness Programme and the development of an interface to allow the integration of SPENVIS with space weather Virtual Observatories.

A.2.4. Personnel involved

Scientific staff: Michel Kruglanski (Project Leader), Erwin De Donder (SPENVIS application engineer), Neophytos Messios (SPENVIS application engineer)
Technical staff: Laszlo Hetey (IT development), Stijn Calders (IT support & development)

A.3. SEPEM

A.3.1. Objectives

The STCE/BIRA-IASB is project lead of the ESA Solar Energetic Particle Environment Modelling (SEPEM) project (ESA Contract No. 20162/06/NL/JD). The main objectives of SEPEM have been to create new solar energetic particle engineering models and tools to address current and future needs, as well as simulate past events and future scenarios. With the creation of a standard solar energetic particle dataset SEPEM will provide the user community a new generation of models that will be available on the SEPEM application server that is being developed under the project.
The results of this project activity will be fed into SPENVIS. To guarantee this, some of the SEPEM work has been included as part of our STCE activities and outsourced to Mars Space Ltd.

A.3.2. Progress and results

SEPEM work performed under Mars Space Ltd. in 2009 has included:

- Construction of a MySQL data base (development of a set of download and population tools); includes metadata description.
- Applying processing tools (IDL and php codes) to the data, the result being the construction of a reference dataset.
- Development and construction of the SEPEM application server; includes interface to fluence and flux models developed under the project (their implementation on the SEPEM application server).

A.3.3. Perspective for next years

This punctual work package is done. The SEPEM work is winding down; the project will be finished by end 2010. The outcome of this project, including this work package, will be incorporated in/linked to SPENVIS.

A.3.4. Personnel involved

Scientific staff: M. Kruglanski (Project Leader), N. Crosby

B. Earth Atmosphere

B.1. Development of products and services for the users of real time GNSS applications

B.1.1. Objectives

Nowadays, Global Navigation Satellite Systems are widely used to measure positions in real time with a few cm precision. Such a level of precision can be obtained in "differential mode". In this positioning mode, mobile users make use of so-called "differential" corrections broadcast by reference stations in order to improve their positioning precision. At the present time, the ionospheric effect on GNSS radio signals remains the main factor that limits the accuracy and the reliability of differential positioning. Indeed, GNSS differential applications are based on the assumption that the measurements made by the reference station and by the mobile user are affected in the same way by the different error sources, in particular, by the ionospheric effect. The validity of this assumption depends on the distance between the user and the reference station which is called "baseline": on shorter baselines, ionospheric residual effects are smaller than on larger baselines. In practice, these applications will not be affected by the "absolute" TEC but by gradients in TEC between the reference station and the user. For this reason, local variability in the ionospheric plasma can be the origin of strong degradations in positioning precision. Strong variability in the ionospheric electron concentration (and in TEC) is mainly due to Space Weather events such as geomagnetic storms. GNSS real time users who undergo degradations of their measurement accuracy are not necessarily aware about this problem: this is an important limitation to the reliability of GNSS, in particular, in the frame of so-called "safety-of life" applications such as landings of planes. Therefore, it is important to develop services allowing to monitor GNSS "integrity" with respect to ionospheric threats and to warn GNSS users against such events.

Therefore, the goals of this WP are:

- To develop operational techniques to assess, to model and to forecast Space Weather effects on real time GNSS applications;
- To develop a web site which provides information about Space Weather activity and about Space Weather effects on real time GNSS applications.

B.1.2. Progress and results

In 2009, the goals of this WP were:

- To analyze and characterize TEC gradients which can affect GNSS-based (aircraft) navigation.
- To develop an empirical model to forecast the occurrence of ionospheric disturbances that affect GNSS.
- To further develop SoDIPE-RTK software.
- To implement web pages which contain real time information about:
  - ionospheric activity at Dourbes (TEC, f0F2, electron concentration, slab thickness).
  - geomagnetic activity at Dourbes (Dourbes K now- and forecasting).
  - ionospheric effects on real time positioning with GNSS (qualitative assessment of positioning error using the single station software).

B.1.2.1. TEC gradients which can affect GNSS-based (aircraft) navigation

Ionospheric disturbances are known to have adverse effects on the satellite-based communication and navigation. One particular type of ionospheric effects, observed during major geomagnetic storms and threatening the integrity performance of both ground-based and space-based GNSS augmentation systems, is the sharp increase/decrease in the ionospheric delay that propagates in horizontal direction, thus called for convenience ‘moving ionospheric wall’. Such anomalous ionospheric delay gradients have been extensively investigated for European middle latitudes during the major storm events of 29 October 2003 and 20 November 2003. For the purpose, 30-second GPS data from the Belgian permanent network was used for calculating and analysing the slant ionospheric delay and total electron content values in search of anomalous moving ionospheric walls similar to those reported for the United States. It has been found that such similar ionospheric delay gradients did occur in Europe during these storms, although they were not so pronounced as in the American sector.

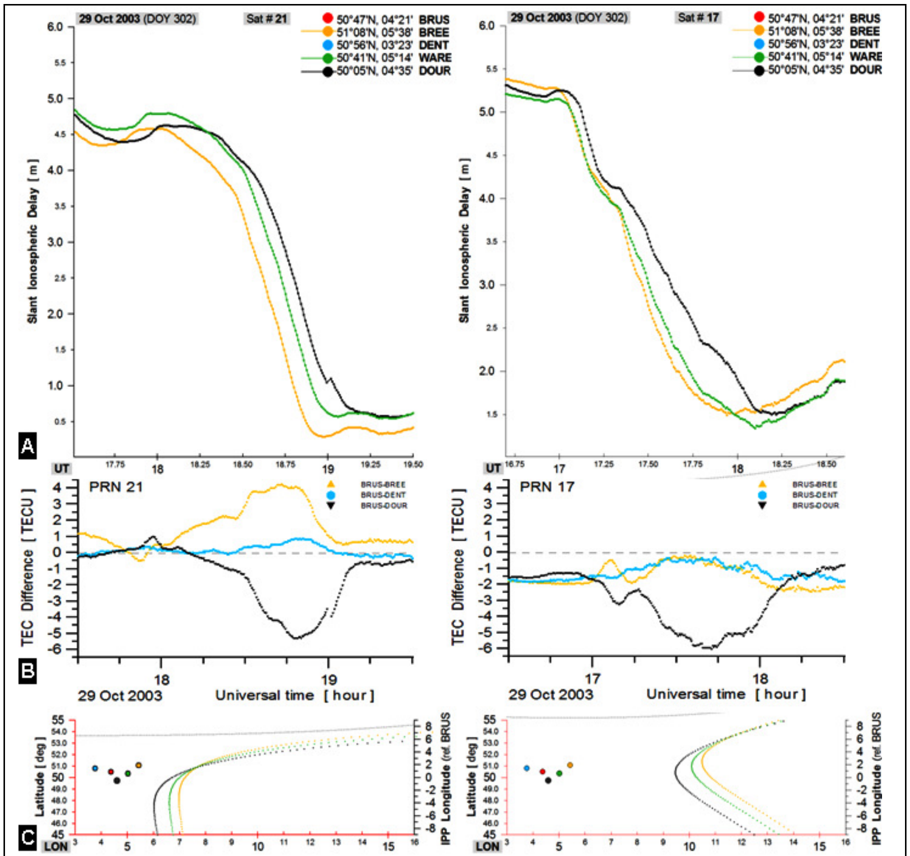


Figure 37: Top panels: Ionospheric delay gradients during the ionospheric storm of 29 October 2003 as measured via GPS satellites PRN#21 (left) and 17 (right). Middle panels: Slant TEC differences between BRUS and three other stations. Bottom panels: The IPP traces (colour corresponding to station) on a geographic longitude vs. latitude map.

For example, presented here is a brief comment on the storm case of 29 October 2003. Taking into account the importance of the IPP (ionospheric piercing point) trace’s location, shape, and orientation, hundreds of slant ionospheric delay profiles have been analysed for this storm day. As expected, only a small number of profiles emerged from the particular period of interest, between 1700 and 2000 UT, that suggest the occurrence of moving ‘ionospheric walls’ (Figure 37, top panels). Figure 37 shows obvious decrease in ionospheric delay (in all satellite-receiver links) thus indicating an ionospheric density depletion that is moving in southward direction. For our analysis of the ionospheric delay profiles, we calculated also the slant TEC differences between the TEC values obtained at the reference station BRUS and the TEC values obtained at the other 3 stations (Figure 37, middle panels). The results, also obtained from measurements along links to satellites #21 and #17, are consistent with the presented results for the ionospheric delays. The latitudinal gradients are clearly seen on the plots for DOUR and BREE. Since the latitudinal difference between BRUS and DENT is negligible, there is no significant difference in their measurements of the TEC. The TEC calculations from the BRUS station fulfil another important role - that of determining the direction of the ionospheric wall movement. By selecting a central station (BRUS) surrounded by other suitably located stations in all possible directions, a star-like formation is set that can help to estimate, to a great level of precision, the direction of the ionospheric gradients propagation. For example one can easily distinguish the almost flat curve representing the BRUS-DENT difference from the oppositely varying BRUS-BREE and BRUS-DOUR differences (Figure 37, middle left panel).

Further research is needed, with available data from other geomagnetic storm events, in order to better understand this interesting phenomenon. In particular, it would be interesting to investigate whether ionospheric effects of such scale/nature are due to concrete ionospheric conditions that developed during these events only or, in general, the local ionosphere conditions in US are more susceptible to such phenomena.

B.1.2.2. Empirical model to forecast the occurrence of ionospheric disturbances affecting GNSS

One can detect small-scale irregularities in the ionosphere by using the so-called “Geometric-Free” (GF) combination of GNSS signals. Since April 1993 this technique allows to compute an ionospheric disturbances index every 15 minutes for GPS station of Brussels (BRUS). The temporal series has been analysed to extract the recurring patterns due to well-known cycles. For instance, we have observed that the ionospheric index follows not only the solar cycle (11 years), but also the season succession and the day/night alternation.

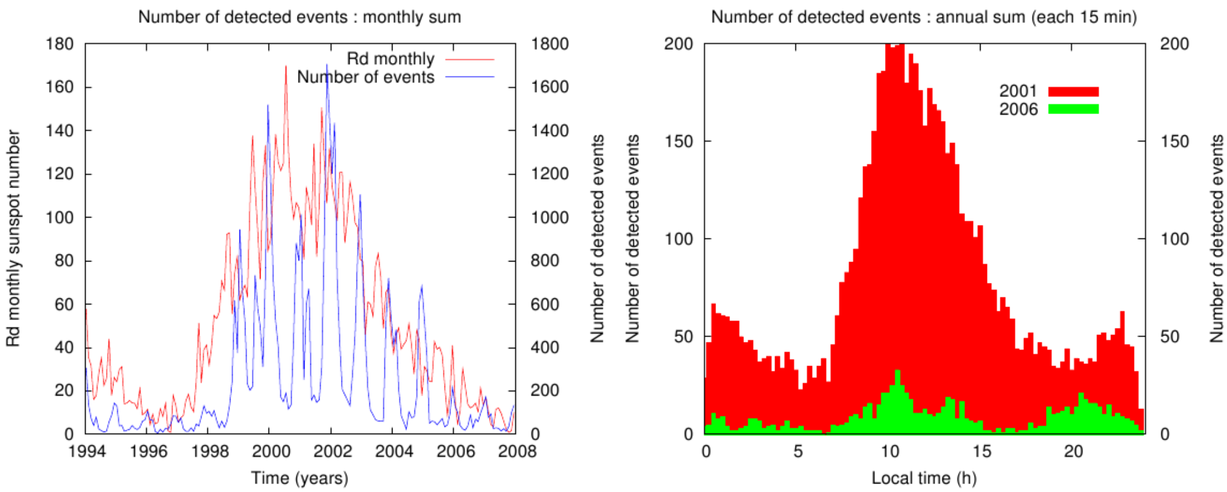


Figure 38: Number of ionospheric events detected over a whole solar cycle (left) and for 2 years (2001 for solar max. and 2006 for solar min.) as a function of local time (right)

The main conclusions of our climatological study of small-scale ionospheric irregularities, which is detailed in (Wautelet et al., 2009, ref [10]), are the following (Figure 36):

1. Irregularities are more numerous during high solar activity periods (e.g. 2000 & 2002) than during low activity ones (e.g. 2006 & 2007).
2. Irregularities are more numerous during autumn and winter months, even during low solar activity periods.
3. Irregularities occur mainly during daytime with a maximum around 10 A.M. (local time) and show a secondary maximum of occurrence during night time (peak time varies with year considered).

The modelling of these recurring patterns can be derived based on the data themselves: autoregressive models can be used to model and forecast the values of the index. The long-term component of ionospheric disturbances prediction model can therefore be written as follows:

Model(Ionospheric index) = f(solar cycle, month, local time)

However, irregularities detected at the station can not always be predicted using such long-term models since their occurrence depends also on space weather conditions, which are not regularly distributed in time. Bulk of space weather phenomena are geomagnetic storms (due to the hit of coronal mass ejection on the Earth's magnetosphere), solar flares and co-rotating interaction regions. Ionospheric irregularities driven by these space weather phenomena induce serious degradation of GNSS user position. Modelling of the occurrence of such phenomena is not possible since they are randomly distributed in time (except the fact that they are more numerous during high solar activity periods). The ionospheric disturbances prediction model can however include this "short-term" component by using the K index forecast in Dourbes station (100 km from Brussels), available 6 hours in advance. The model can therefore be updated to provide forecasts of ionospheric disturbances index 6 hours in advance.

Finally, the ionospheric disturbance prediction model will include both long-term and short-term components:

Model(Ionospheric Index) = f(solar cycle, month, local time) + f(KDourbes)

The final step of the project is to develop a warning system for GNSS users which are affected by these disturbances. Indeed, signal integrity monitoring is in high demand in relative positioning user communities like surveyors, farmers, building industries... The goal is to warn users when the ionospheric disturbance index exceeds a defined threshold and to associate different threat categories with a colour code ranging from green to red.

B.1.2.3. SoDIPE-RTK software

The goal of this work is to assess the effect of the ionosphere on relative positioning, *i.e.* when a user refers its own measurements to another station for which the position is accurately known. For that purpose, RMI has developed the SoDIPE-RTK (*Software for Determining Ionospheric Positioning Error on RTK*) software. Positioning error experienced by a user on the field depends on several causes, like atmospheric effects (troposphere and ionosphere), multipath, orbit error, geometry... SoDIPE-RTK software is designed to "extract" the part of the positioning error which is due only to the ionosphere.

In relative positioning, users form the so-called "double differences" (DD), which are differences between phase measurements relative to 2 receivers (user and reference) and 2 satellites. Therefore, if n satellites are simultaneously observed in both stations at a given epoch, the user is able to form (n-1) independent double differences. These DD are the basic observables for relative positioning since they are mixed together to compute the user's position through a least squares process. As a first step, the software SoDIPE-RTK computes all DD in view for a given epoch and a given baseline. Using the GF phase combination, SoDIPE is able to extract the ionospheric residual term for both L1 and L2 carriers.

As a second step, the software computes the user positioning error only due to the ionosphere by using ionospheric residual terms as input of the least-squares process. Finally, this ionospheric positioning error (further referred to as the "positioning error") is given in topocentric coordinates (North, East, Up) and in terms of distance (ΔD=sqrt(North*North + East*East + Up*Up)).

Figure 39 shows an example of ΔD behaviour during quiet and disturbed conditions (in terms of ionospheric disturbances) for an 11 km baseline. During quiet ionospheric conditions (DOY 103/07) we can observe that, except for the peak around 11 A.M., ΔD rarely exceeds 5 cm, which is the order of magnitude of the typical accuracy of real time relative positioning technique. During a severe geomagnetic storm (DOY 324/03), the positioning error reaches more than 60 cm. More details about the method and results can be found in Lejeune et al., 2010. The cause of the peak around 11 A.M. in DOY 103/07 are the bad geometric conditions encountered during a small time interval, what led to extremely large PDOP at both stations (user and reference), and therefore to large positioning errors. This effect has been taken into account in SoDIPE and the software does not supply any positioning error when bad geometric conditions are observed (Wautelet et al., 2009).

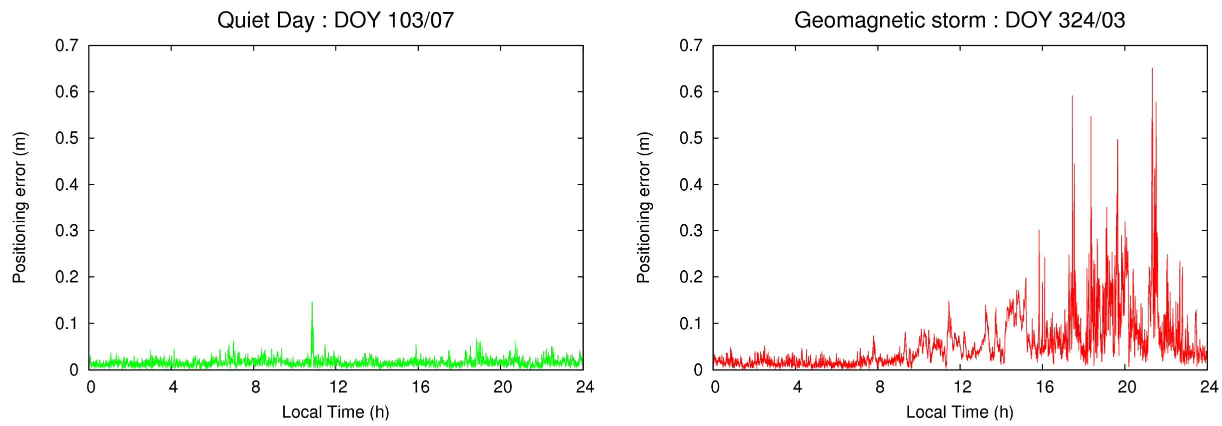


Figure 39 Positioning error only due to the ionosphere for the 11.3 km baseline Brussels (BRUS) – Sint Pieters Leeuw (LEEU) during quiet ionospheric conditions (DOY 103/07) and the occurrence of a powerful geomagnetic storm (DOY 324/03).

SoDIPE has been applied to the whole Belgian dense network (called Active Geodetic Network, or AGN) which is composed of more than 60 GPS stations. Statistics of ΔD have been computed during several quiet days (“nominal conditions”) and two disturbed days (TID and geomagnetic storm): we have shown that baseline length and orientation influences the positioning error. In particular, we have observed that during the occurrence of a Medium-Scale Travelling Ionospheric Disturbance (TID) propagating equatorwards, baselines oriented southwards were more affected by the TID than the ones oriented eastwards. As expected, during quiet conditions, the effect of baseline orientation could not be observed.

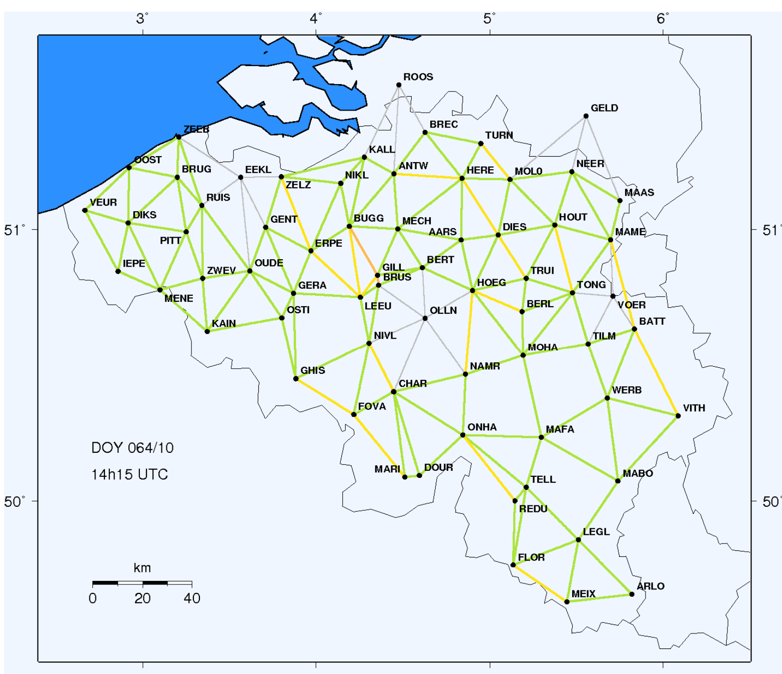


Figure 40: AGN network during the occurrence of a TID for DOY 064/10 at 14h15 UTC. We can see that baselines oriented southeast are generally more affected by the TID than the others.

Finally, we can use ΔD as a good indicator of the effect of the ionosphere on real time precise positioning. Merging this information every 15 minutes in a simple index, we can classify each baseline according a colour code ranging from green (nominal conditions) to red (extreme conditions). The final SoDIPE product is a map representing all AGN baselines in the colour corresponding to the real situation encountered on the field (Figure 38). The main advantage of this method is the computation of useful information for users since positioning error is expressed in meters (user units). However, the main drawback comes from the method itself: at present time, SoDIPE is able to compute data from the previous day only (post-processing mode).

B.1.2.4. Space Weather web site for GNSS users

We started the development of a web site (http://swans.meteo.be) in order to provide users with real time information about:

- ionospheric activity: the local ionospheric activity monitoring is carried out with measurements from the Dourbes ionosonde and GPS TEC stations. The results are immediately displayed on the web for the 3 main products – electron profile concentration, slab thickness, and TEC.
- geomagnetic activity: the local geomagnetic activity monitoring is based on Dourbes magnetogram measurements combined with ACE satellite measurements to estimate the local K index. The nowcast and forecast of the index is displayed immediately and colour scale is utilised for user-friendly reference.
- ionospheric effects on GNSS applications: The RTK (Real Time Kinematic) status mapping provides a quick look at the small-scale ionospheric effects on the precision of relative real time positioning for several GPS stations in Belgium. The service assesses the effect of small-scale ionospheric irregularities by monitoring the high-frequency TEC rate of change at any given station. This assessment results in a (colour) code assigned to each station, code ranging from quiet (green) to extreme (red) and referring to the local ionospheric conditions.

B.1.3. Perspective for next years

In 2010, the goals of this WP are:

- To further validate SoDIPE-RTK software on the Active Geodetic Network under more active ionospheric conditions.
- To develop an empirical model to forecast the occurrence of ionospheric disturbances.
- To further develop the SWANS web site using the output of WP RMI-C1 (improved K and alerts, Dst, LIEDR, improved TEC reconstruction, …)

B.1.4. Personnel involved

Prof. René WARNANT (Project Leader) Dr. Stanimir STANKOV, Mrs. Sandrine LEJEUNE, Mr. Koen STEGEN, Mr. Gilles WAUTELET.

B.2. Synergy between GNSS-based and other SW products

B.2.1. Objectives

To use STCE products (e.g. SIDC records, GNSS-based ionospheric and tropospheric monitoring) monitoring to

- learn more about the interaction and correlation between the Sun and the Earth's atmosphere
- find opportunities to apply these products for other applications
- identify the synergies in the frame of the STCE

B.2.2. Progress and results

B.2.2.1. Correlation between solar parameters and ionospheric TEC values

➢ *Correlation between GPS-based TEC values and sunspot number*

The correlation between between solar parameters and ionospheric TEC values on a global scale has been investigated. A correlation close to 0.8 has been found between the daily sunspot number from the SIDC catalogue and the daily mean global vertical TEC obtained from GPS observations (source: CODE Global Ionospheric Maps) during the last Solar cycle.

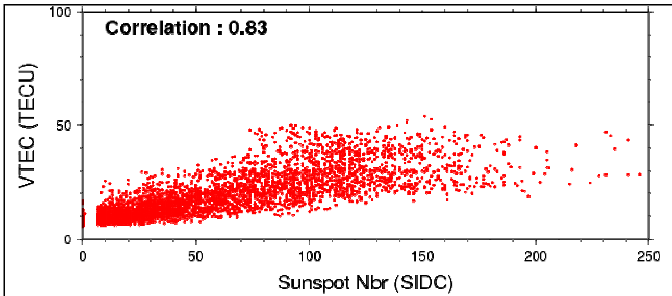


Figure 41: Correlation between the daily Sunspot number from the SIDC catalogue and the daily mean global vertical TEC computed from GPS observations (source: CODE Global Ionospheric Maps) during the period 1995-2009

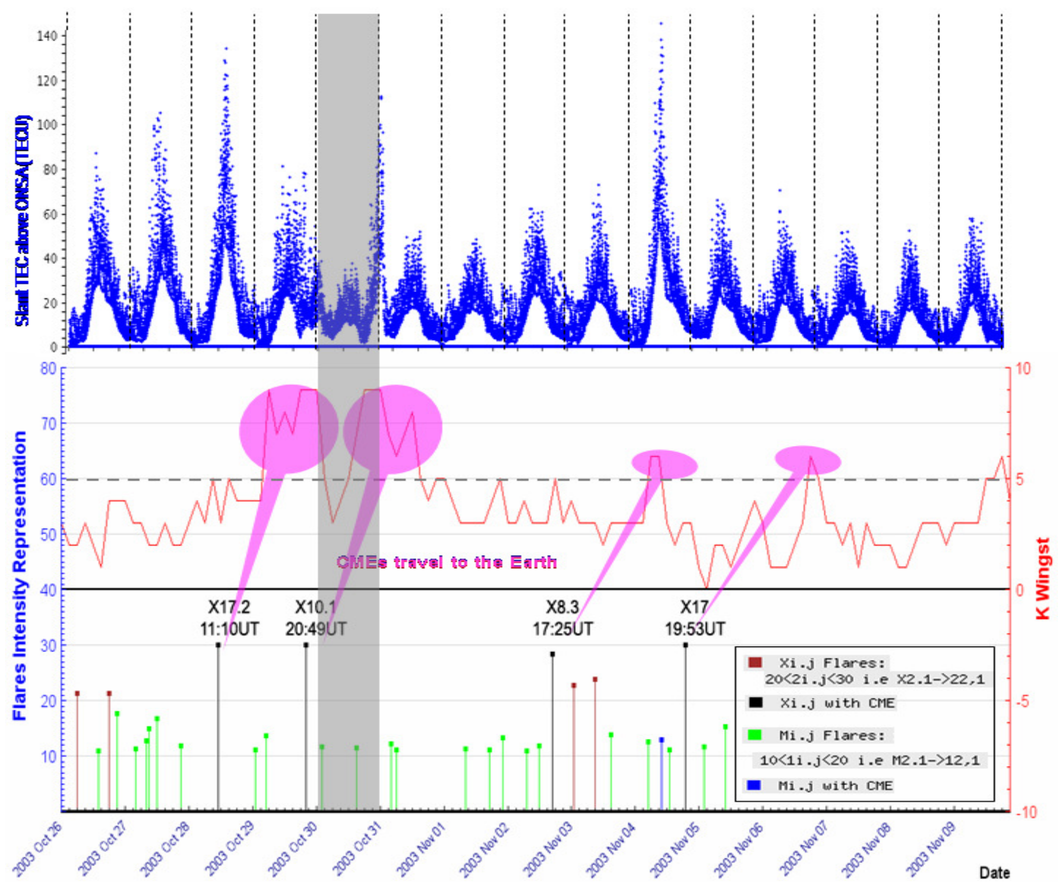


Figure 42: Top: STEC computed with Atomium for the ONSA GPS station; middle: the geomagnetic *K* index from Wingst Observatory; bottom: noticeable solar events (X and M X-ray flares), from 26th October to 9th November 2003. The notation used for solar flares is the following. Labels *i* and *j* are linked to the classification of flares. M flares are represented by a line peaking between 10 and 20 (e.g. M2.5 by a line from 0 to 12.5), while X flares are represented between 20 and 30, at their respective peak-intensity time. Note that X flares bigger than X9.9 saturate the scale and are represented by a line peaking at 30.

➢ *Correlation between GPS-based time transfer perturbations and solar activity*

In order to illustrate how space weather products are relevant to understand ionospheric perturbations in GPS Time and Frequency Transfer (TFT), we analyzed several records from the Solar Influences Data analysis Centre (SIDC), corresponding to periods around the 11th March 2007 (a ionospheric quiet day) and around the 30th October 2003 (an ionospheric stormy day). Figure 42 summarizes relevant M and X solar X-ray flare events around the geomagnetic storm of 30th October 2003. It shows how the X17.2 and X10.1 events triggered geomagnetic storms (monitored by a K-index value higher than 5), leading to perturbations in the slant TEC (number of electrons/m^2 along the signal path) and hence to an impact on TFT (seen in Figure 42, around 0h and after 21h UTC, respectively).

B.2.2.2. Radioscience

The GNSS–based information about the neutral atmosphere and ionosphere of the Earth and the plasma changes induced by solar activity as determined by the STCE actors are valuable information for other partners of the space pole working with radioscience data. Indeed, radioscience experiments use spacecrafts communicating with the Earth through radio signals that travel through the interplanetary medium, the atmosphere of the Earth, and possibly also the atmosphere of other planets (see Figure 43). All these media induce large perturbations on the radio signals and their effect must be corrected for present and future radioscience experiments onboard planetary space missions such as on ExoMars and MarsNEXT (AURORA program).

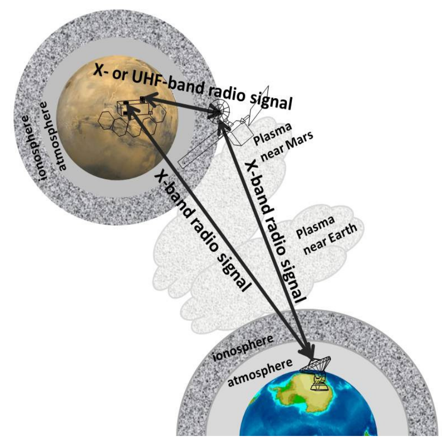


Figure 43: Schematic representation of the atmosphere and plasma effects on radio signals.

The Doppler measurements of the radio signals of these future missions will provide unprecedented information on the interior of the moons or planets through the observation of their orientation and their rotation (precession and nutations, librations, polar motion, and length-of-day variations). An example of the radio link between Mars and the Earth is presented in Figure 44. The lower the signal to noise ratio is, the better the geophysical parameters can be determined. The STCE offers the opportunity to improve the propagation corrections in order to increase the measurement precision, and therewith, to increase the scientific return. GNSS-based corrections for the refraction caused by the neutral atmosphere and the ionosphere of the Earth are and will be used to correct the radioscience signals. The plasma between the planets or moons and the Earth will be taken into account using different solar activity indices. An FP7 proposal entitled "Atmospheric, ionospheric, and interplanetary plasma propagation corrections on Earth-Mars RAdio Link" (Proposal acronym: EMRAL) has been proposed in 2009 under a 'Collaborative Project' funding scheme coordinated by ROB. This proposal is presently under evaluation.

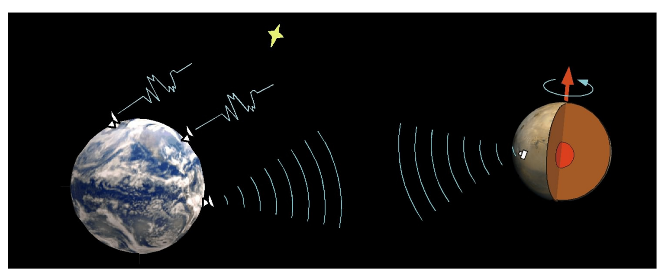


Figure 44: Rotation of Mars can be measured by radio range and Doppler, with the rotation of Earth measured relative to extragalactic radio sources with very-long-baseline interferometer.

In the mean time, solar corona (plasma) effects on the radio-frequency waves propagating between probes around Mars or on the surface of Mars and tracking stations on the Earth have been computed. These computations consist in propagation time delays and phase delays of the radio wave, which only depend on the carrier frequency and on the TEC along the propagation path. Scientists of the STCE have computed the plasma effects for the three different frequency bands (S/X/Ka, i.e. 2.3/8.4/32 GHz) used to track probes in Martian orbit. For this first study, they have used general characteristics of the interplanetary plasma electron density, considering that the coronal and solar wind electron density decreases with distance from the Sun. Such density models have been determined in a series of studies found in the literature but are only rough approximations of the reality. This is especially the case for the solar plasma at distances lower than 4 solar radii. This region must indeed, for the purpose of plasma corrections on the RF waves, be considered as inhomogeneous in reality with respect to the interplanetary plasma at larger distance to the Sun. The scientists of the STCE used the different spherically symmetric radial profiles of the Electron Number Density (END) of the coronal plasma to estimate the TEC along the propagation path. The computations have been performed for different Sun-Mars-Earth configurations, expressed as the Sun-Earth-Probe (SEP) angle. The results for four different models are shown on Figure 45 as a function of the SEP angle values. They show that these different profiles provide a TEC estimation discrepancy of a factor of up to 2 at SEP angles lower than 3° and 5.5° for X and Ka bands, respectively. The propagation effects on the Doppler and ranging measurements are shown in Figure 46. The figure shows that the effects become negligible for ray paths passing far from the Sun, at SEP angles larger than about 8° and 10° for the X and K band, respectively, thus allowing reliable correction of the spherically symmetric contribution of the solar plasma effect of Doppler tracking measurements. The results have been submitted for publication in IEEE. However, the radial profiles of this study do not yet take into account the non-symmetric and time-transient structure of the solar corona and solar wind, which can vary the electron density by a factor of up to 10 with respect to the spherically symmetric predictions. More realistic models of electron density distribution will be used in the future to correct Doppler tracking data dedicated to future high precision geodetic experiments.

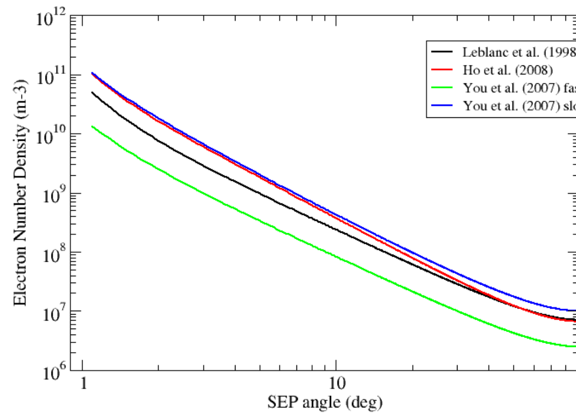


Figure 45: Models of radial profile of the number of electrons per unit volume (or Electron Number Density, END). All these models assume a spherically symmetric radial distribution of the electron density that decreases with increasing distance from the Sun (corresponding to increasing values of the SEP angle).

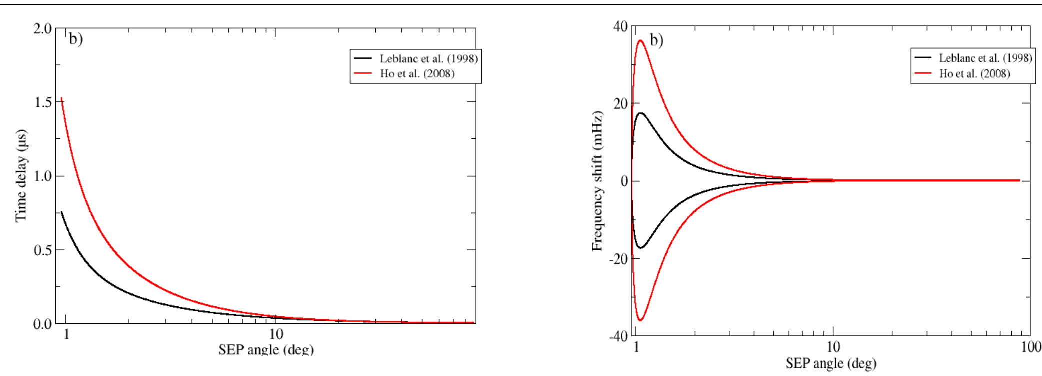


Figure 46: Prediction of the contribution of the interplanetary plasma (a) on the Doppler range-rate (time delay) measurements and (b) on the measured Doppler shift as a function of the SEP angle, using Ho et al.'s and Leblanc et al.'s END radial profiles, for X-band.

B.2.3. Perspective for next years

- Perform studies of the extent of correlation between solar parameters such as sunspot number and 10.7cm wavelength radio flux and ionospheric TEC values on a global and regional scale
- Develop a polar-cap patch identification and tracking algorithm. Polar-cap patches are regions of enhanced plasma concentration, hundreds of kilometres in scale, that appear in the polar regions of the ionosphere. They are of significant practical as well as intrinsic scientific importance, particularly in the Northern hemisphere as they can affect both GPS and high-frequency (HF) radio signals. The combination of ever increasing numbers of trans-polar flights by commercial aircraft and increased reliance by the aviation industry on GPS-based services and their use of HF radio for communication in the Northern polar region means that polar-cap patches have an annually increasing importance. Any ability to identify the current location or predict the future location of polar-cap patches would be of immediate practical use.
- Continue to take advantage of information on the Earth's atmosphere and plasma to correct radio-science signals from spacecrafts exploring the solar system;
- Work on the troposphere of Mars (applying STCE knowledge of the Earth) and its effect on radio signals for the communication between spacecrafts or landers and the Earth;
- Work on solar plasma effects on radioscience data from spacecrafts in our solar system.

B.2.4. Personnel involved

Scientific staff: C. Bruyninx (head "GNSS" project – EPN Central Bureau)
P. Defraigne (head "Time and time transfer" project)
W. Aerts (Time laboratory and new GNSS signals)
N. Bergeot (Monitoring of the ionosphere)
R. Burston (Ionospheric physics)
J.-M. Chevalier (Monitoring of the ionosphere)
J. Legrand (EPN Central Bureau)
E. Pottiaux (Monitoring of the troposphere)
V. Dehant (Radioscience experiment coordinator)
P. Rosenblatt (Radioscience experiment data analysis)
Ö. Karatekin (Planet atmosphere)
M. Mitrovic (Radioscience error budget)
C. Nkono (Plasma effect on radioscience)
E. Podladchikova (Solar activity and plasma model)
L. Rodriguez (Solar activity and plasma model)
A. Zhukov (Solar activity and plasma model)
R. Van der Linden (Solar activity and SIDC)

B.3. Influence of ozone and aerosol on climate and UV radiation

B.3.1. Objectives

The objective is to maintain the long time series of ozone observations (both with balloon soundings and with spectrophotometers)

B.3.2. Progress and results

B.3.2.1. Ozone column

The Royal Meteorological Institute of Belgium has a long tradition in the observation of ozone in the atmosphere. Since 1971 regular (almost daily) observations of the total ozone column at Uccle are available. The observations started with a Dobson instrument. In 1983 and 2001 the observations were expanded with Brewer instruments, which are more state-of-the art. After a long overlapping period, the observations at Uccle with the Dobson instrument ended in June 2009. The instrument will be transferred to Kiev (Ukraine). The time series of the ozone observations at Uccle from the different instruments are combined and can be used to study changes of the ozone layer on different time scales.

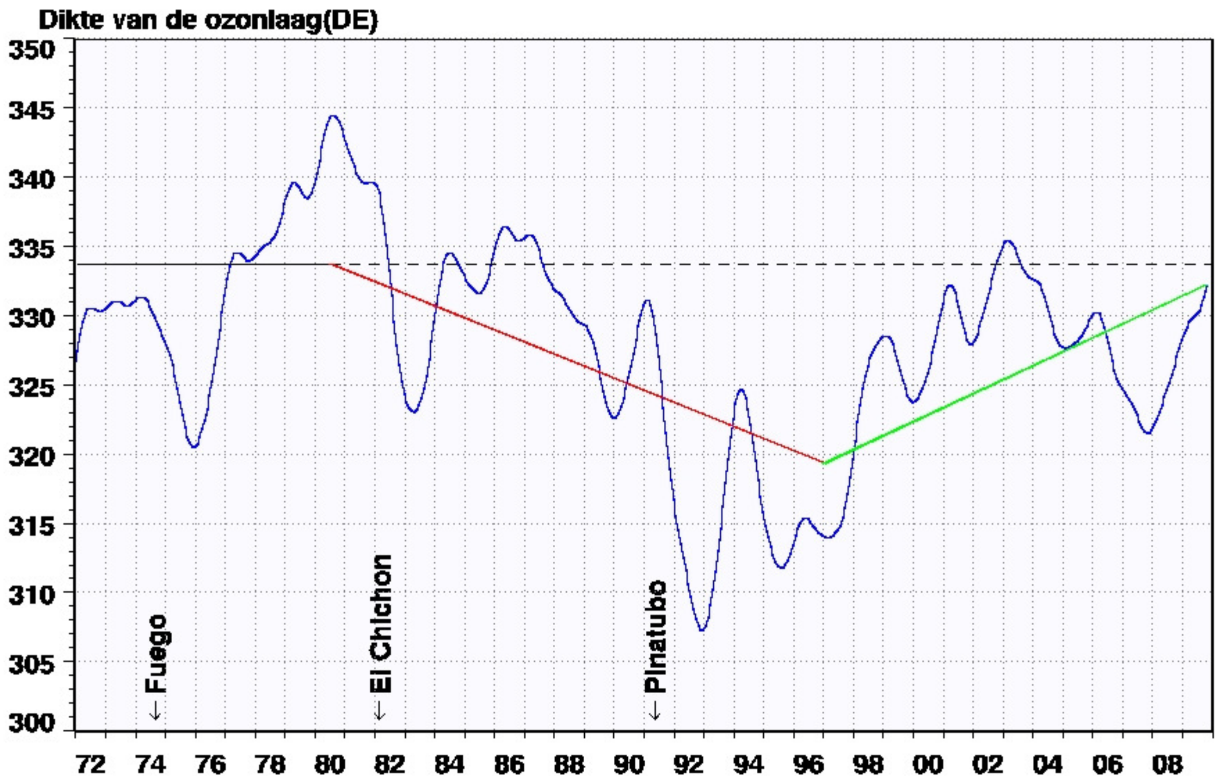


Figure 47: Running means of the ozone column over Uccle, with piecewise linear regression.

Figure 47 shows the running yearly mean values of this time series. Ozone is depleted by Chlorine and Bromine compounds, which entered in the stratosphere (where the so called ozone layer resides) in the early 1980s. Through the regulations of the Montreal protocol their concentration started to decrease in the second half of the 1990s. Therefore the piecewise trend line is drawn through the data. The time series also shows the influence of some large volcanic eruptions.

In order to maintain the quality of the observation the Brewer instruments were calibrated against a travelling world standard instrument in May 2008, and this will take place again in 2010. These calibrations normally take place every two years.

B.3.2.2. Ozone profiles

Besides the ozone column the vertical distribution of ozone is also observed. This is done by radio soundings launched approximately three times a week. During such a sounding, an electrochemical ozone sensor, coupled to a meteorological radio sonde is attached to a balloon. The balloon ascents to about 30-35 km and gives a detailed profile of ozone, temperature, humidity and wind. This time series started in 1969 and belongs to the longest records of ozone profiles in the world, together with Payerne in Switzerland and Hohenpeissenberg in Germany who started around the same period. In 2007 new ground equipment for radio soundings was installed to ensure the continuity of the observations.

The time series of ozone soundings can also be used to derive trends as function of the altitude. Indeed the behaviour of ozone in the stratosphere is totally different from that in the troposphere.

Uccle is an ozone station in the Network for the Detection of Atmospheric Composition Changes (NDACC). All the ozone data are stored in international databases and can be used for studies of changes in the composition of the atmosphere and the relation with climate changes. The routine ozone soundings (about 140-150 per year) of Uccle are also used for the validation of ozone products from satellites (e.g. KMI-IRM is part of the O3M SAF of EUMETSAT for the validation of GOME-2 profiles). ECMWF is planning to integrate also reactive gases in the numerical weather forecast system. In this context, ozone soundings are very useful, either to validate model results, or to assimilate in the system, as they are the only detailed source of profile information in the troposphere. Therefore it is of high priority to continue the long time series of observations.

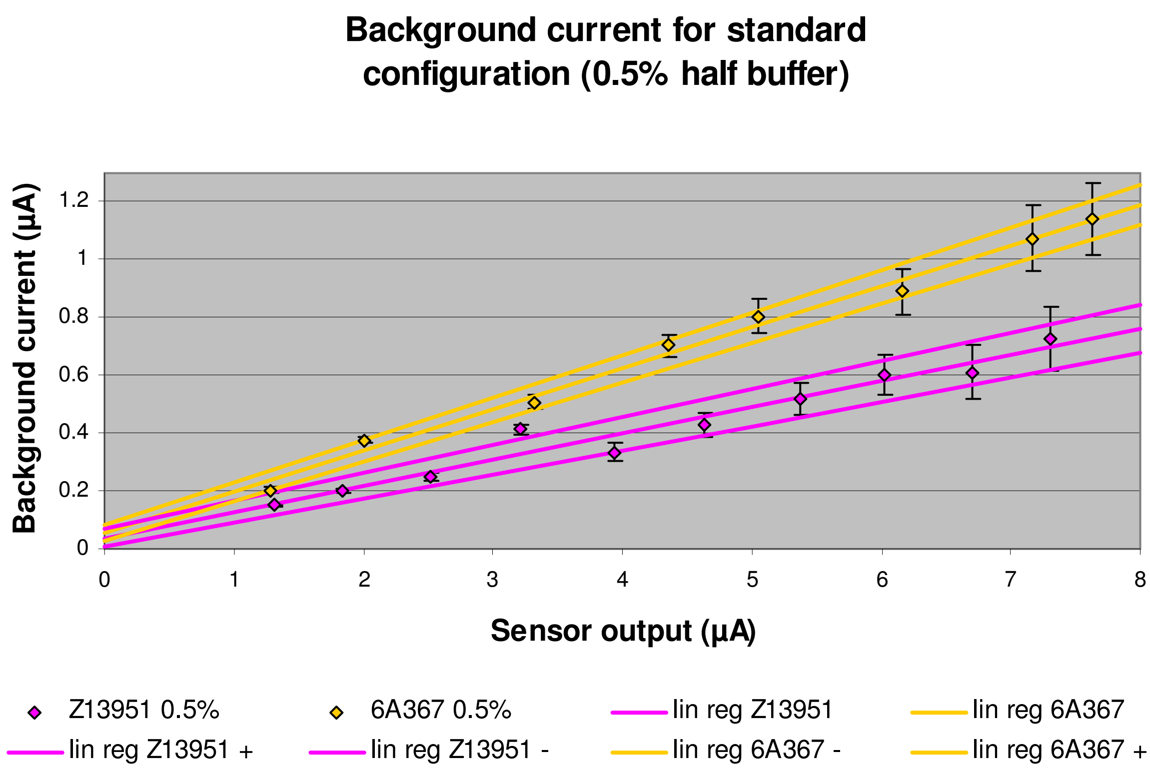


Figure 48 Example of the results of an ozone sounding, giving detailed profiles of ozone, temperature, relative humidity wind speed and wind direction

Although ozone sensors are used at several stations, there are still some uncertainties in its operation. One of these uncertainties is the meaning and the treatment of the background current. To learn more about the behaviour of what was called the background current, some particular experiments were performed. In a laboratory set-up, the ozone sensor was given a known amount of ozone from a calibrated source. The difference between the expected theoretical current and the measured current was calculated for different sensors, and different solution strengths in the electrochemical cells. Figure 48 shows that the difference in current is linearly dependent on the current (or ozone concentration). The slope depends on the solution used, and on the type of sensor (different manufacturers). This was partly done by a trainee of the University of Antwerp (Nick Van den Broeck). Detailed results are available in his report (Nick Van den Broeck, Measurement of the background current of ECC ozone sensors, Universiteit Antwerpen, 2009)

B.3.2.3. Water vapour tendencies

The ozone sounding data contain besides the ozone profiles also profiles of temperature, humidity, wind speed and direction. Water vapour is a key variable for climate research. Humidity changes around the tropopause, where the ozone gradient is large, may reflect an important impact on the climate.

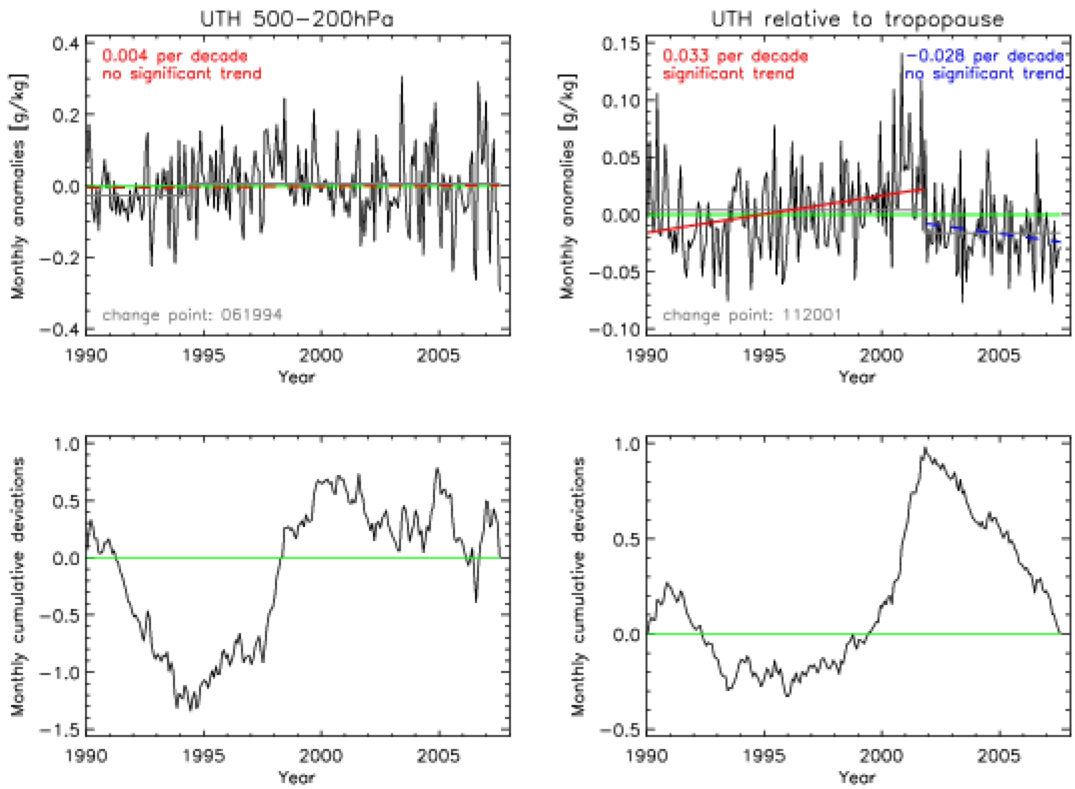


Figure 49 Upper panels: Uccle time series of monthly anomalies of the integrated specific humidity for (left) the upper-tropospheric layers between 500 and 200 hPa and (right) a layer that extends from the tropopause to 3 kilometres below the tropopause. The mean before and after the detected change point are shown in grey. The linear regression lines for (left) the entire time period and (right) the time periods before and after the detected change point are also drawn. Red lines are used for positive trends, blue lines for negative trends. A full line denotes a statistically significant trend, a dashed line a statistically insignificant trend. The statistical significance of the trends is investigated by Spearman's test. Green lines denote the zero anomaly lines. Lower panels: the respective monthly cumulative deviations of the anomalies shown in the upper panels from the mean of the anomalies. Green lines denote the zero lines.

Therefore, we reviewed the humidity data retrieved by a homogeneous subset of the Uccle radiosonde database. As a matter of fact, up to the year 2000, the most prominent feature is a period of negative upper-tropospheric humidity (UTH) anomalies in the early 90s, which is a response to the Pinatubo eruption: volcanic aerosols led to a global cooling of the lower troposphere and reduced the global water vapour concentrations. In the late 90s, the UTH then slowly recovers from the Pinatubo response. However, the most curious finding of this study is the drop in upper-tropospheric humidity in autumn 2001, which makes an end to this significant moistening of the upper troposphere. We argued exhaustively that we do not find any instrumental or environmental cause in our dataset and we ascribe it to natural variability. As this drop is prominently present in the time series of UTH defined relative to the tropopause (with the tropopause as upper limit and a height/temperature relative to the tropopause) and absent in the absolute UTH time series (e.g. between 500 and 200 hPa), see Figure 49, the cause of the UTH decrease is without doubt associated with the variability of the tropopause itself. As a matter of fact, the tropopause itself underwent a lifting and cooling around autumn 2001, with the opposite behaviour before autumn 2001. A similar change in the tropopause properties around autumn 2001 is detected in the time series of other European radiosonde stations. This variability of the tropopause can be of tropospheric and/or stratospheric origin.

However, in the time series of lower-stratospheric temperatures, thickness of geopotential height and ozone amounts, we do not find any change around autumn 2001. On the other hand, in autumn 2001, the tropospheric temperatures rose significantly, so that vertical turbulent motions or convection lead to a considerable stretching out of the free troposphere. As a consequence, the tropopause is also lifted up, cooled down and the upper-tropospheric layers started to freeze-dry in the fall of 2001.

Another interesting point within the framework of STCE is the presence of a solar maximum in the year 2001. As can be seen in Figure 50, during the last solar cycle, the UTH and tropopause variability is very similar to the solar flux variability, so that a role of the solar variability in the autumn 2001 cannot be ruled out. However, the variability of the entire tropopause temperature time series (starting in 1968) seems to be less coupled with the solar cycle.

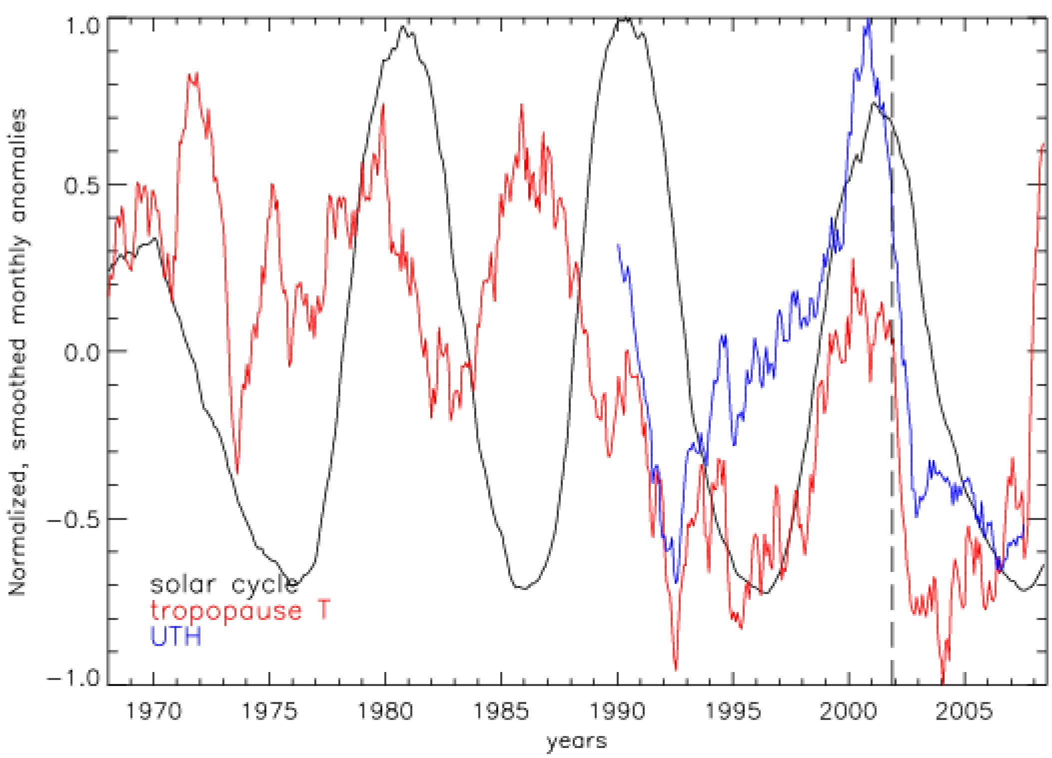


Figure 50. Time series of normalized, 2-yr running means of the monthly anomalies of the 10.7cm solar flux, the Uccle tropopause temperatures and UTH. The autumn 2001 change is marked by a vertical dashed line. We consider 2-yr running means in order to compare the variability at time scales larger than 2 years.

B.3.2.4. Aerosol observations

The direct sun measurements of the Brewer instruments can be used for the retrieval of AOD values at 320nm (Cheymol & De Backer, 2003). Figure 51 shows the time series of measured AODs (from Brewer#016) at Uccle from 1984 to 2009. There is a significant negative trend in AOD for this overall period and it seems that there has been a change in the AOD trend around 1997 (Figure 52). Further research is needed to define the cause of this change.

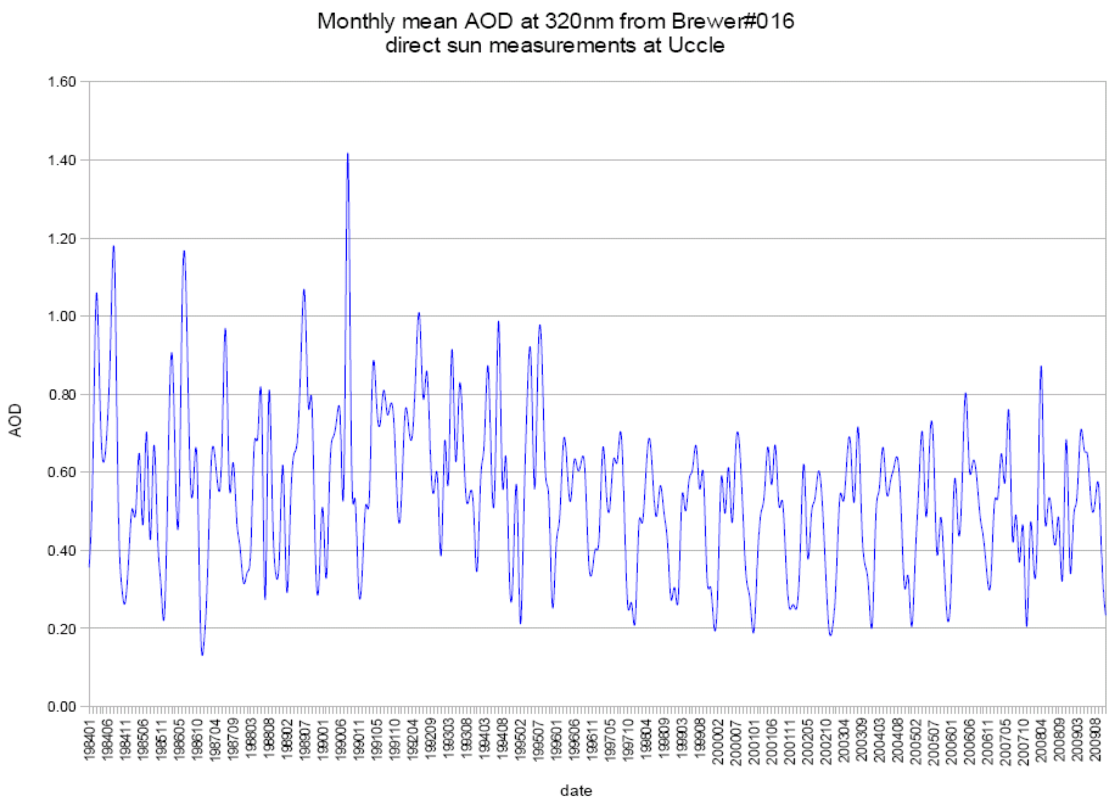


Figure 51: monthly mean AOD at 320 nm at Uccle

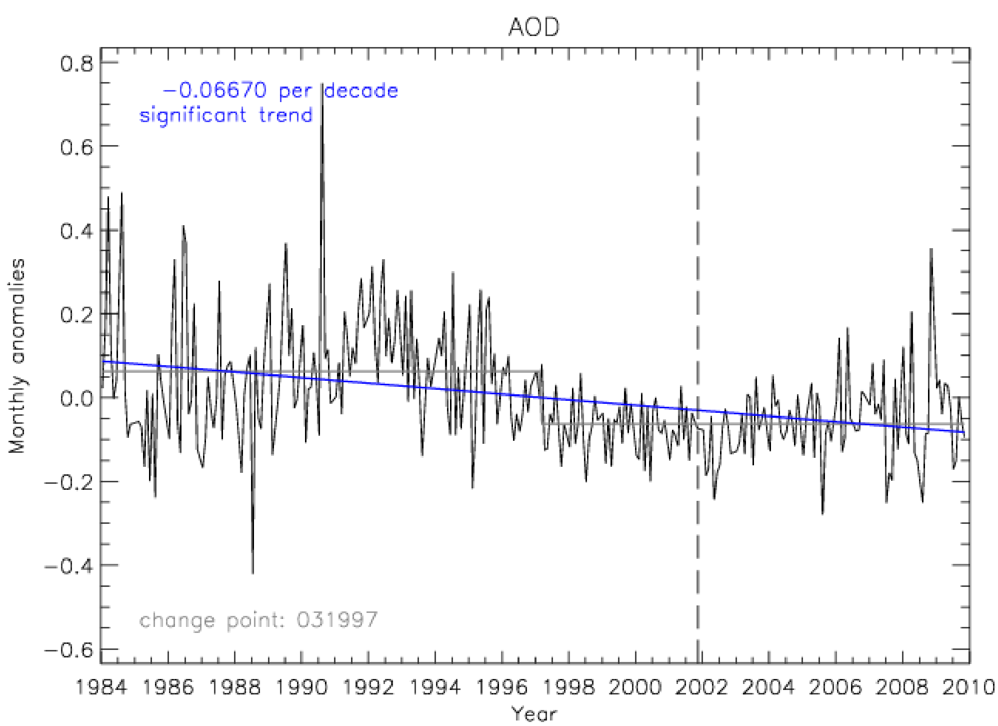


Figure 52: Monthly anomalies of the measured AOD values.

Also, a new method is developed at the RMI which allows AOD retrieval at 340nm from sun scan measurements performed by Brewer#178. The obtained AOD values for 2008 are plotted in Figure 53. The method is to be validated with Cimel measurements and an improved cloud-screening algorithm is to be developed in the near future.

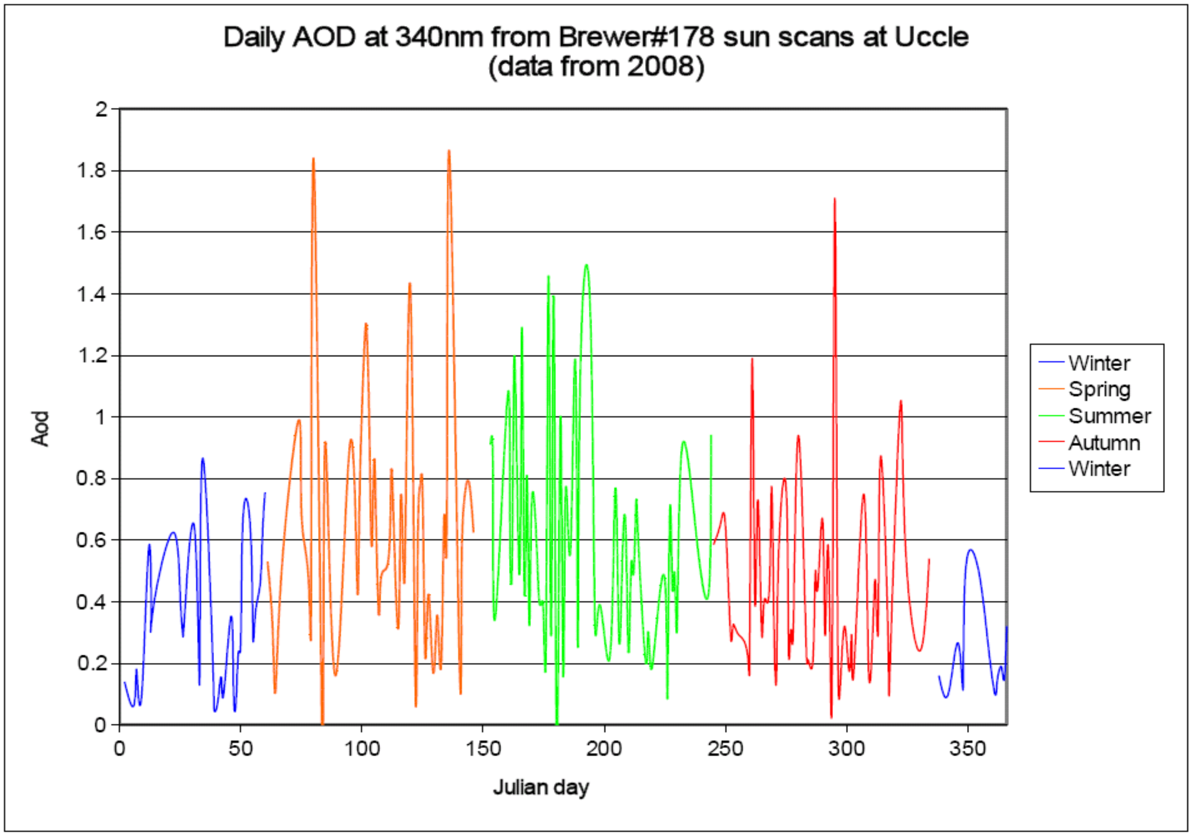


Figure 53: Daily AOD at 340nm at Uccle for 2008

B.3.2.5. UV observation and forecast

The comparison of several ozone-predicting models shows that the model developed by the Deutscher Wetterdienst generates the best results (details in Houillet, N. & De Backer, H., 2007, Comparaison de modèles de prévision de la colonne d'ozone en vue de la prévision de l'index UV - projet réalisé dans le cadre d'un stage d'insertion professionnelle). This model provides us with ozone forecasts for the current day, the next day and the day after. Using these ozone values as input for the operational UV index forecast enables us to extend the range of this forecast from one to three days, thus improving the predictions.

Changes were also made to the aerosol input values. Before March 2009, the operational UV forecast model used a constant aerosol value (0.38) as input, whereas afterwards, a climatological monthly mean AOD value (calculated for the period from 1984-2007) replaced this constant value.

B.3.2.6. Influence of ozone, aerosol and cloudiness on erythemal UV doses at Uccle

The relative effects of changes in ozone, aerosol and cloudiness on the ereythemal UV doses at Uccle were derived from the observations. The effect of a 1% change of each of the parameters was determined from the long-term observations (De Backer, 2009). It turned out (

Figure 54) that the correlation factors between ozone and UV dose, and between global irradiation and UV dose are lager than the correlation between aerosol optical depth and UV dose. However, the sensitivity factors of the UV dose for aerosol optical depth changes are larger that for ozone and global irradiation. This must be considered when reconstructed data are interpreted. Indeed, reconstructions are mostly based on ozone data and CMFs from global irradiation, but due to the lack of data no aerosol effects are taken into account.

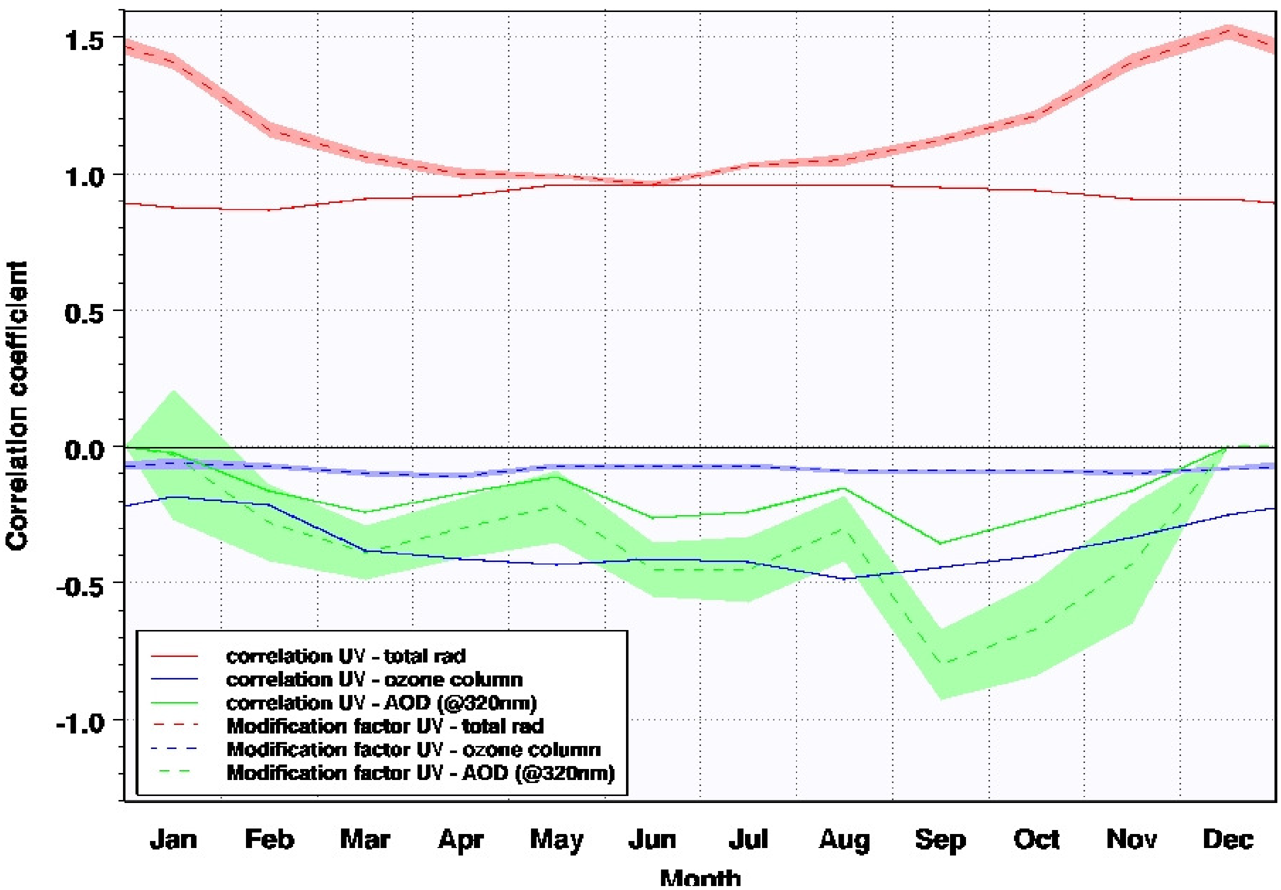


Figure 54: Seasonal correlation coefficients and sensitivity factors for the relation between daily erythemal UV doses and total solar radiation, ozone column and AOD in the UV-B. The shaded areas are the 1σ error estimates for the modification factors.

B.3.3. Perspective for next years

- Advanced analyses of the time series of ozone, taking into account the relations with solar cycle, atmospheric circulation indices.
- In particular a possible relationship with the cosmic rays (related to Forbush events) will be investigated.
- A system to measure the pump efficiency at reduced pressures in laboratory conditions will be set up.
- Validation of the new AOD retrieval method (from sun scan measurements at 340nm) with Cimel measurements.
- Development of an improved automatic cloud-screening algorithm to be used in the AOD retrieval method.
- Further improvement of the operational UV index forecast (e.g. by using measured AOD values averaged over a period of 15 days as input for the model).
- Installation of aerosol, ozone and UV instruments on the Belgian Base Princess Elisabeth in Antarctica

B.3.4. Personnel involved

Scientific staff:	Roeland Van Malderen (ozone research)
	Hugo De Backer (Project Leader)
	Veerle De Bock (Aerosols and UV research)
	Alexander Mangold (Aerosol research)
	Andy Delcloo (Validation of satellite observations)
Technical staff:	Jean-Claude Grymonpont (Technician)
	Andre Massy (Technician)

PART 4: SUPPORTING ACTIVITIES, INSTRUMENTATION AND DEVELOPMENTS

A. IT & Operational Infrastructure

A.1. Data Centre

A.1.1. Objectives

In the frame of the STCE, BUSOC implemented a satellite data centre. This facility will allow scientists to manage and store their data. The data centre is based on a fault-tolerant design.

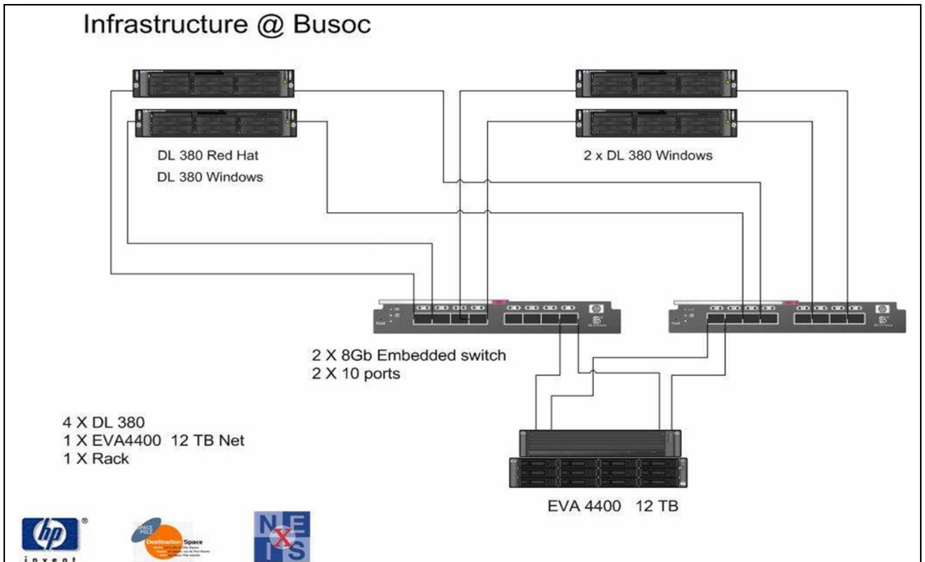


Figure 55 : BUSOC data storage system

Knowledge Management becomes a strategic capital for the three Institutes. Knowledge Management uses many tools of ICT but cannot be reduced to this only dimension. To set up such a system implies a much broader reflection on the methods of development of competences and training. The operation of the "new structured unit" is not possible unless a true culture of co-operation is established in the Pole. The Pole must take care to set up inciting systems pushing the employees to share their knowledge; this objective represents, in itself, an important cultural change.

A.1.2. Progress and results

The procedure to buy the data centre system has been completed. Installation is ongoing.

Concerning knowledge management, relying on different projects developed inside the BUSOC structure (ULISSE, CUBIST, PICARD, SOLAR, ..), we envision a framework with the following core features:

- It will be possible to federate data from a variety of both unstructured and structured sources.
- We will use a semantic Data Warehouse.
- Projects developed inside BUSOC will provide novel ways of visual analytics in which meaningful diagrammatic representations of the data will be used both for navigating through and depicting the data.

A.1.3. Perspective for next years

The data centre system will be ready for operation in the course of 2010.

The ULISSE project, accepted by the EC, will start January 2010. BUSOC will manage the demonstration of this new system of data management and dissemination. The CUBIST project will be negociated with the European Commission next year.

A.1.4. Personnel involved

Scientific staff: Didier Moreau (Project Leader), Christian Muller
Technical staff: Karim Litefti (project manager), Christian Noel (ground segment engineer), Alexis Muller (web specialist)

A.2. Mission Centre

A.2.1. Objectives

The development of operational services includes running mission operations centres.

A.2.1.1. ISS/SOLAR Mission Centre

Within the Columbus general framework, B.USOC assumes the management of the FRC (Facility Responsible Centre) for the external Solar Monitoring Observatory. Three space science instruments are combined in the Solar Monitoring Observatory (SOLAR). These three complementary instruments will measure the solar spectral irradiance with unprecedented accuracy across almost the whole spectrum: 17-3000 nm. This range carries 99% of the Sun's energy emission.

Apart from the contributions to solar and stellar physics, knowledge of the solar energy flux (and its variations) entering the Earth's atmosphere is of great importance for atmospheric modelling, atmospheric chemisty and climatology.

Figure 56: Columbus module on ISS and SOLAR payload

The three instruments are: SOVIM, SOLSPEC and SOLACES. They are mounted on the ESA-developed Course Pointing Device (CPD) with a pointing accuracy of the order of 1 degree to compensate for ISS motions.The fourth instrument, the Sky Polarisation Observatory, will be accommodated separately.

For this mission, B.USOC is Facility Responsible Centre. A Facilty Responsible Centre (FRC) is delegated the overall responsibility (by ESA) for a payload on board the Station. Its functions focus on payload systems aspects and are related to all phases of payload operations, i.e. pre-flight activities, in-flight operation and post-flight activities.

A.2.1.2. PICARD Scientific Mission Centre (CMS-P)

The Picard project was first proposed in 1998 by the aeronomy laboratory of the French national scientific research centre (SA/CNRS). The CNES (Centre National d'Etudes Spatiales) Board of Directors decided to authorize this project, which had been frozen since 30 April 2003, in line with the recommendations of its Science Programmes Committee. The mission went live in 2008. Picard is a CNES Myriade microsatellite that precisely measures the Sun’s diameter and its variations, as well as solar irradiance, with the twofold aim of learning more about how the Sun affects Earth’s climate and studying its physics and inner structure. Picard is now slated to launch in 2010 at the start of the next solar cycle, on a scheduled two-year mission. The microsatellite's payload will comprise:

- an imaging telescope (developed by SA/CNRS) capable of measuring the Sun's shape and diameter to within a few milliarcseconds,
- a suite of three photometers and radiometers (Swiss PREMOS 2 instrument) to study ozone and solar oscillations,
- a differential radiometer (Belgian SOVAP instrument) to measure total solar irradiance.

We are hosting the scientific mission centre.

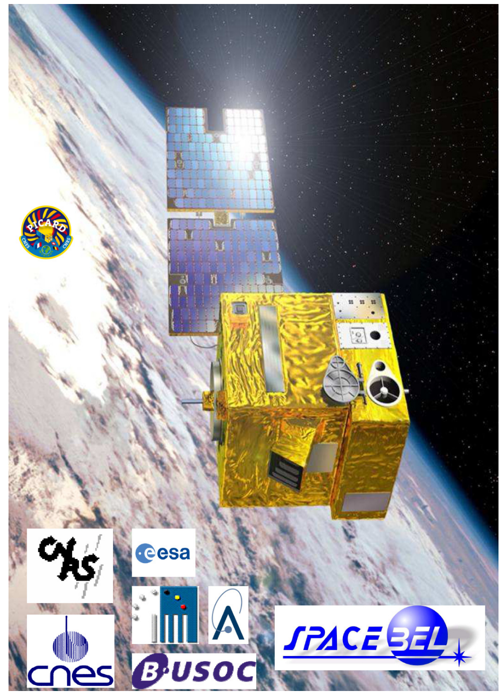


Figure 57: PICARD mission

A.2.2. Progress and results

A.2.2.1. ISS/SOLAR Mission Centre

Since the launch of the Columbus module (February 2008), BUSOC operates the SOLAR payload on a 24/7 basis.

A.2.2.2. PICARD Scientific Mission Centre (CMS-P)

The entire infrastructure has been implemented during the year 2009. The operational concept has been frozen by CNES and BUSOC and the team of operators hired. Technical and operational qualification tests have been successfully conducted and CNES approval for operations and launch has been given.

A.2.3. Perspective for next years

A.2.3.1. ISS/SOLAR Mission Centre

Objectives are to continue operations of the payload as well as to negociate with ESA a prolongation of the mission, in close collaboration with the scientifics involved in the mission.

A.2.3.2. PICARD Scientific Mission Centre (CMS-P)

The PICARD Scientific Mission Centre (CMS-P) will be operated by the B.USOC. Its main role is to:

- program the payload. This programming is then transferred to the Microsatellite Ground Segment (MIGS) which download it to the satellite
- control the health status of the payload at a later time
- realise the scientific products of the mission (L0 to L2A)
- acquire, store and process the data delivered by the Command Control Centre (CCC)
- acquire and store the external data from PICARD Scientific Expert Centres
- store and distribute the products to scientific users.

PICARD launch is scheduled for 15 June 2010. The commissioning phase should end in October 2010.

A.2.4. Personnel involved

Scientific staff: Didier Moreau (Project Leader), Christian Muller, Etienne Haumont

Technical staff: Alice Michel (payload engineer), Karim Litefti (ground segment engineer), Rachid Abjij (ground segment engineer), Michel Anciaux (project manager), Michiel Verschueren (payload engineer), Claudio Queyrolo (payload engineer), Rachid Abjij (ground segment engineer), Christian Noel (ground segment engineer)

A.3. Data Management and HPC support

A.3.1. Objectives

On top of the reduction of the ICT overhead for the colleagues there are several additional goals for this project:

- Increase the efficiency of storage usage on the networked storage infrastructure of the institute
- Increase the availability of data
- Increase the reliability of data processing tasks
- Mid-term goal: to automate the complete data processing chain (reception-processing-storage/distribution)

A.3.2. Progress and results

A.3.2.1. Data Management

The main task for this year was to make a complete inventory of all relevant data needed for the management of the data streams and storage:

- Which data streams exist in the institute (incoming, outgoing, internal)
- Which data are already available and where are they stored
- What is the link between the different project groups and the data and data streams.

A complete inventory was made with some impressive results:

- Over 90 Terabytes of data are online on networked storage systems
- 50 Million files and directories need to be managed
- 30 incoming and outgoing data streams are operational
- 40 GB of new data need to be stored each day.
- 15 different project groups are using/creating/disseminating data

A first effort was already made to centralize management of the different data streams.

Most datasets are now managed by the data manager. He helps users in deciding on where and how data should be stored on the infrastructure, how access is granted and he manages the total available capacity of networked storage.

A.3.2.2. HPC Support

The main challenge for data processing is to optimize the execution of the codes on the existing compute infrastructure of the institute as well as letting the infrastructure evolve with the changing needs. Special care has to be taken to increase the reliability of the operational processes.

To obtain these goals specialized support is needed to assist users with HPC needs. End of 2008 a dedicated HPC support specialist was hired with to this end.

The first part of the year was spent discovering the infrastructure (both local servers at the institute as well as the central compute servers) and making an inventory of the different codes and softwares used at the institute. In parallel support was already given to several groups to help port existing codes to the central compute servers and to assist in the installation and configuration of new programs.

To help the users in developing and running their codes, introductory courses where given to familiarize users with the computing environment.

The HPC support specialist is now responsible for several tasks:

- Configuring and maintaining the development environment on the different computing platforms
- Assisting users with their codes
- Managing the compute infrastructure to maximize available resources

- Providing courses and documentation to the users

A.3.3. Perspective for next years

Several objectives are set for the next years:

- Integrate the analysis of the data manager with the information concerning the data processing codes collected by the HPC specialist
- Provide a framework for automated data retrieval, -processing, -storage and -dissemination to ensure efficient and reliable execution of operational data-processing and the delivery of services

A.3.4. Personnel involved

Technical staff: Johan Bulcke (Project Leader), Olivier Rasson (Data Manager), Vincent Letocart (HPC specialist), Fabienne Leclère (Infrastructure specialist)

A.4. Hard- and software support

A.4.1. Objectives

This is a general support project with the aim of offering the needed basic IT tools to each member of the STCE, as there are: software, workstations, and small hardware.

A.4.2. Progress and results

Activities in this field, with the exception of the specific budgets, are highly integrated in the day to day workings of the ICT service at the institute.

They consisted of:

- Purchase and installation of end-user hardware (PC's, X-terminals)
- Purchase, maintenance and installation/configuration of software applications (ex: IDL)

A.4.3. Perspective for next years

Keep a high level of user-support to minimise ICT overhead in the daily activities of STCE staff. Keep a good integration with the standard ICT activities at the institute.

A.4.4. Personnel involved

Technical staff: Johan Bulcke (coordinator), Vincent Letocart (HPC specialist), Fréderic Counerotte (purchases, installation & support)

A.5. Storage Facilities

A.5.1. Objectives

Improve the basic storage infrastructure to prepare for the additional demands of future and evolving projects. This is a punctual investment.

A.5.2. Progress and results

Due to time constraints and an improved efficiency in the management of the existing infrastructure, this project was postponed to 2010.

A.5.3. Perspective for next years

Implementation is foreseen for 2010.

B. Solar ground-based observations

This WP focuses on the development and upgrade of new or already existing ground-based instruments devoted to the monitoring of the solar activity. Such instruments provide data for the science activities performed at ROB and other institutes, as well as for the operational space weather activities of the SIDC. These data are made available on the SIDC website, and are as well distributed through international networks. In the end, they participate to the long-term studies of the solar activity.

The SIDC operates two sets of ground-based solar instruments, the USET visible light telescopes in Uccle and so far one radio telescope in Humain near Marche-en-Famenne.

B.1. The Uccle Solar Equatorial Table (USET)

B.1.1. Objectives

In order to ensure the continuous operations of the USET instruments and also in order improve and to extend the capabilities of the Uccle solar optical facilities, new instruments are developed and existing ones are upgraded by introducing new techniques at the level of optics, mechanics or image detectors. As USET telescopes work in the visible light domain, the systems can mostly be built from existing commercial components and do not require specific industrial development. Instead, the new instruments involve primarily the study and development of unique custom solutions, adapting or combining newly available technologies for the specific requirements of modern solar imaging. This work thus relies on internal ROB workshops (mechanics, electronics) and it contributes to the development of a unique internal expertise in optical instrumentation at the ROB.
The USET instrumentation activities involve the following developments:

- Digital imaging system in white-light (photosphere)
- Digital imaging system in the Hα line (chromosphere)
- Digital imaging system in the CaII-K line (chromosphere)
- Telescope pointing system
- Telescope and dome automatization

B.1.2. Progress and results

In 2009, most of the progress in the USET hardware development took place in the first half of the year. No significant software developments took place in 2009, except for the conversion of the telescope control software from the old BASIC language version (DOS platform) to the C language (LINUX platform) in preparation of the future increased automation of the USET.

B.1.2.1. New purchased equipment

- **New refractor for the planned CAII-K CCD imaging system**: an apochromatic refractor of 132MM aperture (Willimas-Optics FLT-132) ordered in 2008 was delivered early in 2009. This was the last order on the LOTTO solar instrumentation budget from 2002.
- **New full-aperture solar filter for the white-light CCD camera**: in order to improve the image quality on the white-light channel (recently upgraded CCD camera) a new custom-made 4-density filter was ordered from Lichtenknecker Optics in December 2009.

B.1.2.2. New equipment designed, tested and installed:

Internal development was carried out, involving equipment search and selection, mechanical design, test and commissioning. The main steps in 2009 were:

- **Mounting of the new H-alpha optics and camera on a common optical rail** (June 2009): this rail, acting as an optical bench, maintains collimation while easing the fine pointing of the telescope. It is also the first step in the planned motorization of the focusing and off-pointing of each individual solar telescope on the USET.

- **Design and commissioning of the 0.94 focal reducer for the white-light imaging system**: a final version of this reducer, installed in May 2009, provides an optimal match of the image scale with the sensor size of the new CCD cameras.
- After more than one year of flawless continuous operation of the new H-alpha telescope and filter, the old H-alpha telescope and Lyot monochromator was removed from the USET in September 2009, after more than 50 years of service (installed around 1957, first for a photographic camera system). This reconfiguration required a major rebalancing of the USET.

B.1.2.3. Optical design:

Next to the design of the 0.94 focal reducer mentioned above, a major development for 2009 was the **study of a telecentric Barlow lens system** needed to feed the narrow band filter (2Å) of the CaII-K telescope now in preparation. The initial design was carried out in-house by F.Clette using the Olive ray-tracing software (Edmund Inc.). This design was then checked and optimized interactively by a manufacturer of custom optics, Molenaar Optics, in the context of the preparation of a quotation for the manufacturing of the multiple lenses.

B.1.2.4. USET data distribution:

- Some improvements were introduced in the USET web pages, improving the display of images and the navigation over the past solar Carrington rotation.
- As we have entered routine production of the USET white-light and H-alpha synoptic images at the high 2Kx2K pixel resolution, our data can be fed to global solar data portals next to a few ground-based stations worldwide for continuous solar monitoring purposes. Therefore, by the end of 2009, contacs were established with three primary portals: the Global High-Resolution H–alpha Network (GHN, New Jersey Institute of Technology), the Virtual Solar Observatory (VSO, NASA) and BASS2000 (Observatoire de Paris-Meudon). Technical requirements for data transfers to those portals have been established and will be implemented in 2010.

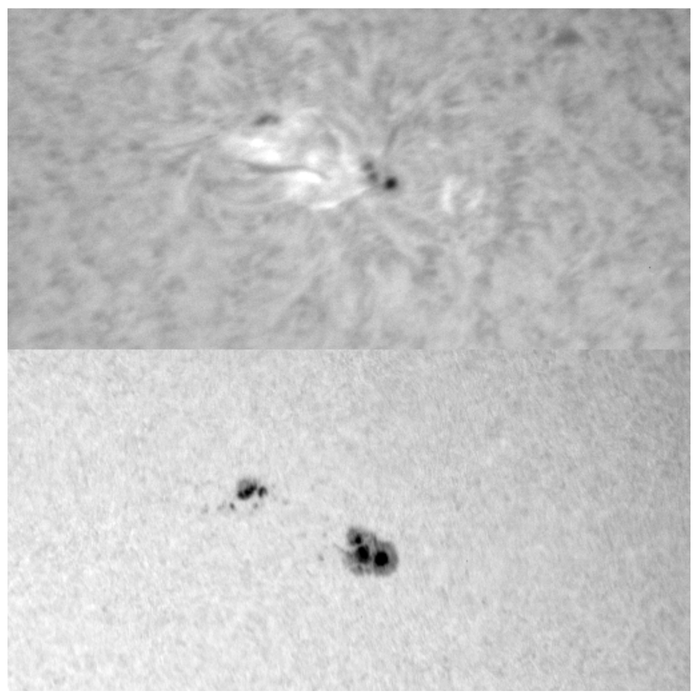


Figure 58 Close up of Hα (top) and white light (bottom) pictures of an active region, from the USET telescopes in Uccle, in March 2010

- As a support to the SoTerIA FP7 project (Work Package 6), we also provided all USET images as a testing ground and initial data set for the implementation of the global data portal that will be implemented by the ROB for the entire SoTerIA project.

B.1.3. Perspective for next years

The priorities for 2010 will be:

- Coordination and supervision of the USET hardware and software developments.

- Instrument development (hardware):
  - Ordering, installation and commissioning of the CaII-K telescope internal optics in connection with the Observatory of Rome (PSPT).
  - Design and construction of the thermally-controlled enclosure of the CaII-K filter.
  - Design and construction of the motor-actuated mechanical support and focus systems for the H-alpha and white-light telescopes.
  - Completion of the solar pointer: this will involve a study phase in order to optimize the system to the actual properties of image turbulence at the Uccle site.
- Instrument development (software):
  - Development of new programs (SunGlasses) for the selection and pre-processing of high-cadence images from the 3 new camera systems.
  - Development of new data archiving and distribution procedures.
  - Implementation of systematic procedures for the determination of the camera dark level and flat-field, which will be used in the routine observations of the new cameras.
  - Upgrade and reorganization of the USET web pages (with O. Lemaître).

B.1.4. Personnel involved

Scientific staff: F. Clette (Project Leader)
Technical staff: O. Boulvin (Technician), J. –L. Dufond (Electronics Engineer), A. Ergen (Technician), O. Lemaître (Technician), S. Vanraes (ICT Expert)

B.2. Humain radio telescopes

B.2.1. Objectives

The second aspect of this WP concerns the solar radio observations. The idea is to take opportunity of the existing facilities in Humain: parabola on equatorial mounts, laboratories, and on-site personal, to re-develop a small set of solar dedicated radio telescopes. Compared to the past observations operated at Humain, which involved in particular the maintenance of a 48-antenna interferometer, the new observations do not deal with radio imaging but rather with the monitoring of solar activity through wide-band spectral observations (decimetric-metric band related to CMEs and flare activities) and flux measurements at selected individual frequencies (flare physics and irradiance). It involves therefore a smaller set of radiotelescopes. The scientific goals of the project fit very well with the other projects of the Solar Physics department, in particular with the Proba-2 instruments SWAP and LYRA. In addition, the project is aimed at supporting the SIDC space weather forecast activities as well as perpetuating the long-term solar radio observations in Belgium.

B.2.2. Progress and results

B.2.2.1. Spectral Observations

Spectral observations performed at the Humain station relie on a Callisto receiver built by the ETH Zürich institute. In April 2009, the mount supporting the antenna plugged to Callisto received a new control software written by A. Ergen and running under the Linux operating system. This new software is designed to receive commands both locally, from a human operator (Mr. P. Janssens) and remotely with command lines. After being installed, the next step was to make the software able to communicate with positioners in such a way that the pointing of the antenna mount can be checked for remote control or automatic procedure, which is the final goal of this work. A. Ergen designed the necessary electronic interface. The positioners and the last version of the software need to be tested and installed on site.
Frequency converters were partly built and tested during the year (with J.-L. Dufond) to explore other frequency bands than the one initially covered by the Callisto receivers. They will permit to monitor the

solar activy or the man-made interferences in the bands 1-2 GHz, and 2-3 GHz. One of the frequency converters still needs some work before being operational (stabilized Local oscillator).

For the improvement of the observations, a filter rejecting the FM band (85-110 MHz) was installed in May 2009. By preventing the strong FM band to enter the receiver, saturation and intermodulation at other frequencies could also be suppressed, leading to a significant improvement of the data quality.
A new frequency program was implemented in order to optimize the scientific interest of the collected data. The new observing program extends the frequency coverage from 45-92 MHz (below the FM band) to 45 to nearly 400 MHz. This program was chosen together with J. Magdalenić.
Solar activity was rather low during the year 2009: no burst was observed during the first 4 months of 2009. Between May and December, about 25 bursts were however detected, especially in December (see example in Figure 59). For most of them, they are type III bursts, related to electron beams accelerated during weak flaring events along open field lines.

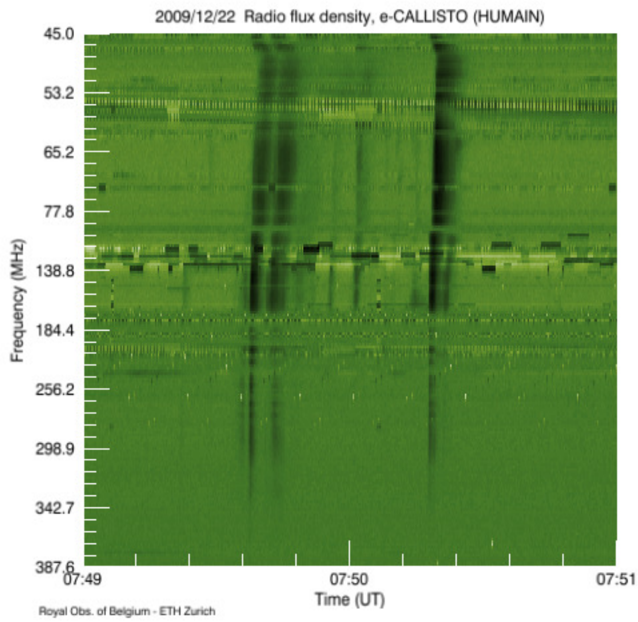


Figure 59 Group of type III bursts observed with the Callisto spectrograph in Humain on December 22nd 2009. (Reverse video: dark means bright)

B.2.2.2. Flux measurements

The project of measuring the solar flux at fixed selected frequencies is made in cooperation with Canadian colleagues from DRAO and NRCan (K. Tapping and D. Boteler). On the Belgian side, most of the work performed in 2009 consisted in the set up of laboratory infrastructures and hardware research (related to the antenna mount).

C. Marqué and J. -L. Dufond finalized the purchase of laboratory HF equipments, namely a signal generator and a spectrum analyzer from Agilent. The frequency coverage allows its usage for both the spectral observations (maintenance and future developments) and the flux measurement project. A room was refurbished by the technical services of the Observatory to set up a small HF laboratory. C. Marqué and J. -L Dufond collected from the Royal Meteorological Institute a Faraday cage that will be used during the test and calibration of the future receivers.

C. Marqué performed some researchs related to the antenna mount that will be used on site (in Humain) for the solar flux observations. Different solutions were tested, from a complety new commercial system, to the refurbishment of the existing hardware at the station. The latter was chosen to be the most reasonable, and in December 2009, a company was selected to perform the mechanical refurbishment of an existing 4m-parabola mount from the old solar interferometer. Due to the lack of precise documents about the performances of such mounts, pointing tests accuracy will be performed after the refurbishment.

The flux measurements are foreseen in the microwave range (above 1 GHz), and the current mesh parabolas are not suitable for precise flux measurements. C. Marqué and J.-L. Dufond investigated the possibility to reuse existing parabolic dishes from the RMI. On the other hand, C. Marqué performed several preliminary tests based on data sheets of commercial telecommunication parabolas. These studies show that such a solution could be envisioned, in terms of performances. The final decision will be made once the mechanical performances of the refurbished mount will be known. Another problem is related to the wind load on a plain parabola and the mechanical stress that is transmitted to the mount. C. Marqué made preliminary estimations of this effect, based on documents available on the web. However more precise calculation will be needed in the future.

B.2.2.3. RFIs at the station

C. Marqué is involved in the monitoring of the Radio Frequency Interferences (RFI) situation on site. Broadband observations like the spectral ones currently performed at the station are very sensitive to man-made emissions. Practical decisions have been taken to reduce the level of interferences, such as filtering, selection of a new frequency program, etc…

C. Marqué replaced F. Clette during the 48th CRAF (Committee on Radio Astronomy Frequency) meeting in Paris, in May 2009. He presented a talk about the importance (both scientific and economic) of solar radio observations in the Sun-Earth relationship frame. He participated to discussions, at the observatory, dedicated to establish good relationships with a nearby industry. He made a preliminary study of the possible impact of wind turbines on the radio observations, in response to projects of wind farms nearby the Humain station.

B.2.2.4. Digitization of past observations

With the help of J.-L. Dufond and two summer students (A. Hernould and N. Willems), C. Marqué initiated the digitization of past radio observations performed at the Humain station. It consists essentially of the daily flux measurement at 600 MHz, which was operated during nearly 50 years. A quick analysis reveals that the data need to be validated before being made available on the web. Beyond the usual absolute calibration issues in such kind of measurements, several years are unfortunately missing (cycle 21) and others reveal technical problems (cycle 22), which seem, fortunately, to be easily solvable.

B.2.3. Perspective for next year

B.2.3.1. Spectral Observations

Spectral observations will be developed during the year 2010, with the primary goal of extending the frequency coverage above the current upper limit of 400 MHz. The Callisto project, lead by the ETH institute in Zürich will go on. On the Belgian side, a second Callisto, which is currently used for tests in laboratory, should be set up in Humain with the frequency converters developed in Uccle, and be used for solar observations and RFI monitoring (in preparation of the flux measurement project). Discussions are ongoing to take over another spectrograph (frequencies up to 4 GHz) from the ETH institute, as solar radio observations from this institue are likely to slow down in the near future.

A project for a new spectrograph built with a French team from the Paris Observatory is also in discussions, for the frequency band below 1GHz. It should be by design, less sensitive to RFIs than the current instrument in use in Humain.

If both projects succeed, it is conceivable that by mid 2011, a full set of spectrographs will be operating in Humain, from 45 MHz to 4 GHz, providing a full coverage of the solar activity from the low to the upper corona.

C. Marqué wishes also to facilitate the usage and analysis of the current set of observations within the SIDC (a Presto alert was issued in February 2010 based on a type II burst observed in Humain). A new quicklook display of the data is already in use since the beginning of 2010. Some preliminary tests of automatic burst detection programs are currently performed and will be developed further on during the year, with the goal of providing a near real time list of solar bursts.

B.2.3.2. Flux measurements

The primary goal in 2010 for this project is to finalyze the control and pointing of the refurbished mount, choose and set up a suitable parabolic reflector, and start building the prototype of the receiver.

Pointing and tracking accuracy measurements will be made on the mount, to see if the accuracy needed for the project can be achieved. Based on the results, a final choice will be made on the parabolic mirror to be installed on the mount itself. The horn needed to collect the radio waves at the focal plane should be purchased.

The design of the whole control system, aimed to be as automatic as possible, will be established.

With the set up of a radio laboratory in Uccle, and the near completion of the design phase of the receiver by our Canadian colleagues, the building of the first prototype should start during the year 2010.

Finally, to help the current team to achieve the different tasks, the hiring of new staff members will be finalyzed, since no suitable candidates could be found in 2009.

B.2.4. Personnel involved

Scientific staff: F. Clette (Project Leader), C. Marqué
Technical staff: J. –L. Dufond (Electronics Engineer), A. Ergen (Technician)

C. Space Based Solar Observations

C.1. Advanced technologies: UV detectors and Filters developements

The Advanced Technology for Solar Observations (ATSO) Group initiates and monitors multidisciplinary research and technology development activities. The main objectives are to consolidate and extend our technological expertise of high relevance to the hardware and software of solar instruments. This WP addresses particularly the definition, development, and experimental characterization of critical components such as UV Leds, UV optical filters and UV photodetectors, with emphasis on single-pixel and imaging sensors, on their associated proximity electronic. The application wavelengths can include the electromagnetic spectrum from the near-infrared to gamma rays, with special interest in the ultraviolet ranges. The ATSO group provides also project management, engineering and scientific support in the various technologies projects for solar observation e.g. LYRA**Error! Reference source not found.**, SWAP, BOLD, APSOLUTE, EUI, … .

C.1.1. Objectives

Future missions for space astronomy and solar research require innovative vacuum ultraviolet (VUV) photodetectors and filters. Present UV and VUV detectors exhibit serious limitations in performance, technology complexity and lifetime stability. For the next envisaged space missions planned to study the Sun, e. g., the *Solar Orbiter*, solar-blind photodetectors capable of operating at high temperatures and in harsh environments are a crucial ingredient. For these reasons, new developments of wide band gap materials photodetectors and UV filters are investigated.

C.1.2. Progress and results

New metal-semiconductor-metal (MSM) photodetectors based on diamond, cubic boron nitride (c-BN) and aluminium nitride (AlN) semiconductors were successfully fabricated (Figure 60). The electrical characteristics (e. g., I-V curves) and the absolute radiometric responsivities are reported and published **Error! Reference source not found.**. Dr A. BenMoussa is strongly involved in the design and the optical characterization of the reported photodetectors. He was also the co-supervising of the Thesis of Dr H.A. Barkad [93] based on UV photodetectors for space applications. The results of the fabrication and performance of new diffractive filters designed for space-based x-ray and EUV solar observations were published **Error! Reference source not found.**. Unlike traditional thin film filters, diffractive filters can be made to have a high resistance against the destructive mechanical and acoustic loads of a satellite launch. The filters studied are made of plastic track-etched membranes that

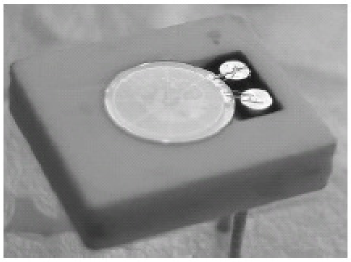


Figure 60 : Photograph of the new diamond MSM photodetector.

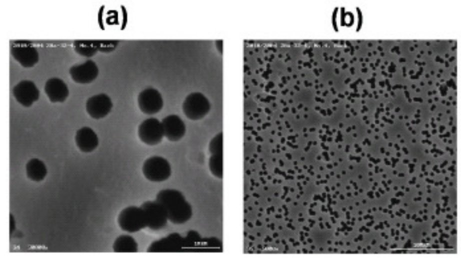


Figure 61: SEM micrographs of filters: (a), (b) "inner" surface of filter #4 at two different magnifications.

are metal-coated on one side only. They have all-through open cylindrical pores with diameters as small as 500 nm (cf Figure 61), limiting their transmittance to very short wavelengths. The spectral transmittance of various diffractive filters with different pore parameters was measured from the soft x-ray to the near IR range (namely, from 1–1100 nm).

C.1.3. Perspective for next years

By their nature, diamond, AlN and c-BN semiconductors are the primary choice of photosensitive materials for VUV photon detection. They present figure of merit that is several orders of magnitude higher compared to silicon semiconductors, since they provide high radiation hardness, low dark signal at room temperature, solar-blindness, and chemical as well as thermal stability. Dr A. BenMoussa is involved on the progress and development of VUV detectors. New calibration campaigns are planned for 2010 at the PTB-Bessy II synchrotron (see BOLD and APSOLUTE projects). This activity will assess the performance of new design photodetectors. Other different design approaches to improve the responsivity of UV photodetectors are investigated such as size reduction towards submicron contact fingers, semi-transparent electrodes, and/or asymmetric electrodes. All these solutions can provide better detector characteristics in terms of dark current, UV/visible contrast ratio, linearity, and VUV responsivity **Error! Reference source not found.**.

A new porous filter design (with pore parameter as small as 100 nm) is under development with the collaboration of Dr L. Jalabert from Tokyo University (Fujita Laboratory). This new filter spectral transmittance need to be measured in the soft x-ray range. In accordance to the support activity foreseen for the specification of the EUI filters (see EUI project), we have followed up and participated in, when and where adequate, the activity of filter development.

C.2. BOLD-GSTP and APSOLUTE

C.2.1. Objectives

The purpose of the BOLD project is to demonstrate the suitability of the Nitride-based wide-bandgap imaging detectors for the Solar Orbiter in order to have a solid detector baseline for its EUV telescopes. A project has been set up by ESA involving Belgian and French partners with the goal of developing new solar-blind APS detectors (focal-plane array demonstrator) using wide band gap materials where BOLD stands for "Blind to Optical Light Detectors".

In parallel to the BOLD project, a new project called APSOLUTE started beginning of October 2009 for the adaptation of existing Silicon CMOS APS detectors technology to the Solar Orbiter EUI scientifique requirements. The purpose of this project is to provide a demonstrator by end of 2010 that complies as much as possible with the EUI detector specification (typically: 10µm pixel EUV sensitive, read noise ≤ 5e⁻rms).

C.2.2. Progress and results

BOLD: Blind to optical Light Detectors

Initially the BOLD project started in June 2006 for a period of 26 months. The project was first extended from 30/06/2008 to 31/07/2009 (CCN1) then from 01/07/2009 to 30/04/2010 (CCN2). We are actively involved (as WPs leader) on the conceptual pixel design study and on the UV optical testing. During this period the effort was focused on the technology predevelopment e.g. design of the new mask set as well as on the preparation of samples (256x320 arrays with 22.5 µm pitch) were in processing for testing the flip-chip of the diode on the ROIC step. More integration samples were processed and were delivered for flip-chip (
Figure 62).

We are involved in the definition of the detection system architecture, configuration and interfaces, translation of observational requirements into detector specifications. We support/coordinate with other partners in terms of UV testing, standards and numerical simulation. We are involved in the planning of calibrations measurements as well as the analysis of the results.

APSOLUTE: APS Optimized for Low-noise and Ultraviolet Tests and Experiments

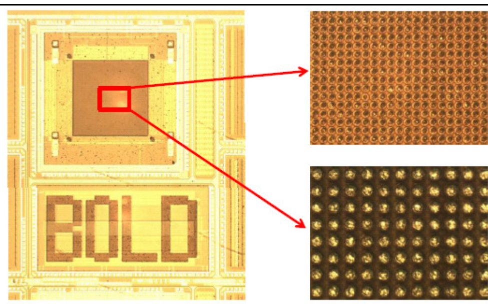


Figure 62 : BOLD CMOS ROIC

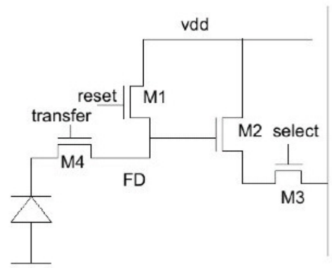


Figure 63 : Apsolute pixel architecture

The Belgian company CMOSIS was selected by PRODEX to develop a prototype of a new CMOS APS detector (Figure 63), according to specifications provided by STCE/ROB and the EUI Detector Working Group (DWG). We are supporting studies for EUI onboard Solar Orbiter [93]-[97]. The purpose for CMOSIS is to propose several detector designs and small scale prototypes which would respond to the EUI specifications [105]. In order to provide CMOSIS with the proper inputs for their design of the detector prototypes, additional iterations occurred on the specifications for EUI detectors. The management and follow-up of the contract between CMOSIS and PRODEX was agreed to be performed by CSL. Beginning of October, the APSOLUTE activity was kicked off. As a consequence of the redirecting of responsibilities between CSL and ROB, Dr. Ali BenMoussa, who is leading the DeMeLab development, is now also leading the EUI Detector WG.

C.2.3. Perspective for next years

In 2010, the processing activities will be focused on the integration of the 2D demonstrator. 2D AlGaN arrays will be integrated with the CMOS ROICs. Five integrations (detector flip-chip bonded to ROIC) should be performed.

A BOLD calibration campaign is planned for April 2010 at the PTB-Bessy II synchrotron. This activity will assess the performance of the first 2D arrays demonstrator with respect to the absolute efficiency (spectral response) in the EUV-VUV range. APSOLUTE demonstrators should be tested by end of 2010 according to the planning to allow for a best selection among the prototypes (and designs). The prime goals of the prototypes concern ultra low noise performance and maximal EUV sensitivity. Further challenges relate to the large dynamical range, small pixel pitch, advanced read-out concept(s), and radiation hardness.

C.3. DEMELAB

C.3.1. Objectives

Technology is an important driver in space science. Fore some fields, it is not sufficient to merely watch the industry progress. It has been a successful tradition in solar terrestrial physics to trigger or to perform specific technological development. At STCE, we have identified and developed a specific expertise in two technological disciplines: image processing and UV light detection. For both, a voluntarist way has proven beneficial in order to meet the needs with the possibilities in a timely manner. On the UV characterization, it is worth noticing that the Uccle facilities have already been exploited by the LYRA hardware (filters and detectors) and they are again considered in the frame of BOLD and EUI projects.
The primary purpose of the Demelab is to perform and interpret electro-optical measurements on imaging and non-imaging detectors of interest to solar physics including a fully automated analysis workstation in clean environment.

C.3.2. Progress and results

In the context of the detectors developments, we have continued setting up a detector laboratory (called DeMeLab), to be able to test in particular signal and noise characteristics. On 24th June 2009, Dr BenMoussa Ali sent two HAS (High Accuracy Startracker) detectors (SWAP spares #13, #14) to ESTEC/ESA (contact person: Dr Ludovic Duvet). The HAS sensor flies on-board the PROBA2 SWAP instrument and it can be seen as a backup solution for EUI detector (Solar Orbiter mission). The HAS detector (see
Figure 64) is a technologically advanced CMOS device coated with a scintillator layer to improve sensitivity in the EUV range. It has 1024 by 1024 pixels, each pixel having a 18 µm x 18 µm size. This particular type of detector is a radiation hardened, active pixel sensor (APS) see http://swap.sidc.be. The goal of this activity is to consolidate and extend our technological expertise of the HAS hardware and software and to improve the design of the Detector Measurements Laboratory.

Figure 64 : Picture of the HAS (#13, spare of SWAP)

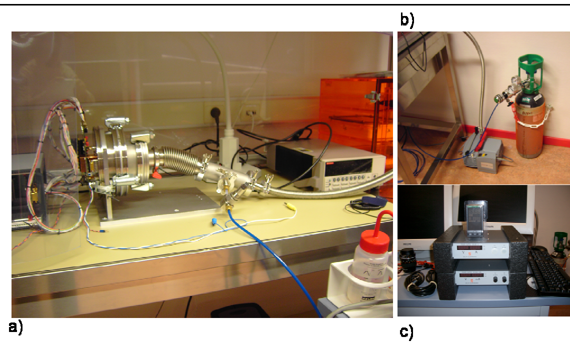


Figure 65 : a) HAS vacuum chamber connected to the vacuum and N2 lines (blue). b) MVP 040-2 vacuum pump and N2 bottle, c) 2 power supplies and PID temperature controller.

Figure 66 : Optical bench at Demelab (with Deuterium & Tungsten lamps, chopper, monochromator, integrating sphere, Θ-x-y-z translation stage,...).

This activity started beginning of October 2009 and the working progress is described as follow: We assessed the missing Demelab equipments (mandatory or nice-to-have HW and SW) for a full opto-electrical characterization set up (Figure 66). In collaboration with Eng. A. Mekaoui, a student from ESPRIT school (Tunisia), they analyzed the two SW (cypress and python script) of the HAS set up and improved them (e.g. image processing using Matlab). The acquisitions made already contribute to a real improvement of the characterization of the HAS. It is now possible to acquire dark frame images under vacuum and/or N2 atmosphere. We started evaluating the noise performance of the HAS sensor from -5°C to +40°C using the PID temperature controller (see

Figure **65**). Complete optical characterization (e.g. spectral response, linearity, flat field) should follow in 2010.

C.3.3. Perspective for next years

A student training (A. Mekaoui, SW engineer) started working on Demelab and on the HAS setup by mid-November 2009 and for a period of 6 months. His work addresses particularly the development and experimental characterization of the HAS detectors, the design and implementation of an archival system for test data and their metadata and the design and implementation of a library of analysis software for detector electro-optical characterizations. In 2010, the HAS sensor will be characterized at ESTEC/ESA for EUV test using the Mc Pherson spectrometer. We will provide technical support and expertise during the detector tests. DeMeLab will also provide support during the detector characterization tests of BOLD and APSOLUTE project and will analyze the results.

C.4. Solar Orbiter/EUI

C.4.1. Objectives

Solar Orbiter (S.O.) is the major ESA solar (and heliophysics) mission since SOHO. It is planned for launch in 2017. Thanks to several attributes of its orbit, it will offer unique new possibilities to solar and heliospheric observations. We have, with the support of BELSPO, indicated strong interest in the EUI instrument suite of UV telescopes (Figure 67), in line with the SIDC/ROB heritage and expertise.

C.4.2. Progress and results

Until April 2009, ROB-SIDC, with J.-F. Hochedez as Principal Investigator, has led the EUI consortium (CSL (B), MSSL (UK), MPS (D), IO (F), IAS (F), and SAO (USA)) towards the formal acceptance of the instrument by ESA, end of March 2009. From April 2009 on, reorganization within the EUI consortium results in a transfer of PI-ship to CSL i.e P. Rochus, while each country was allocated a Co-PI. For Belgium, the Co-PI is David Berghmans (ROB). Erik Pylyser is the institute Project Manager (IPM) for the EUI project related activities at ROB.

As a EUI member, Dr Ali BenMoussa initiates the local management and follow-up of the detector activities [98][112][116]. Dr A. BenMoussa is the WP leader of the detector specifications (WP5110), the detectors EUV calibration (WP11212-11222) and the detectors radiation tests (WP 11213-11223).

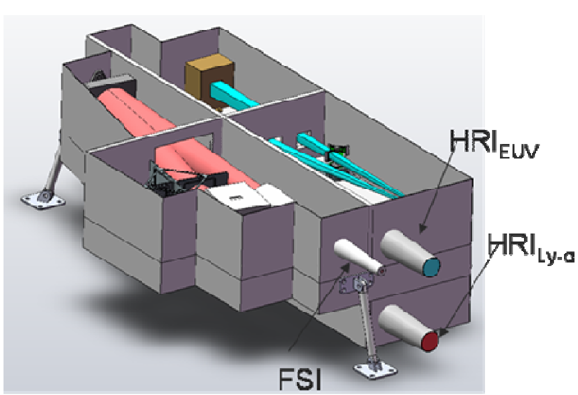


Figure 67: Schematic representation of EUI telescopes

C.4.3. Perspective for next years

Dr Ali Benmoussa will perform the EUI management activities in 2010. A smooth transfer from Erik Pylyser responsibilities to Ali BenMoussa will start beginning of 2010.

In Q4 of 2009, the CMOSIS contract was finally passed with PRODEX, and 2010 will see the emergence of the prototyping results of CMOSIS on the EUI detectors. As the leader of the WP EUV Calibration and WP Radiation Tests, Dr A. BenMoussa will describe the (E)UV testing activities (Electro & Optical device characterization) of the Bread Board detectors. Light source (in particular synchrotron) is already identified at this stage for the determination of the EUV sensitivity (incl. at Ly-α) of the EUI demonstrators. These activities will provide a detailed description of all performed tests (with a detailed description of the measurement set up), their results (publication) and interpretations including critical analysis of the results. These activities should start in 2010 and will assess the suitability of the EUV detectors for Solar Orbiter (identify the limitation of the detector & ROIC) and give recommendations for the 2nd batch of EUV detectors.

C.4.4. Personnel involved

Scientific staff: A. BenMoussa (ATSO Leader), B. Nicula (SW engineer), B. Giordanengo (Detector physicist), J-F Hochedez (Physicist), M. Dominique (Optical engineer)

Technical staff: J-L Dufond (Electronics Engineer), A. Ergen (Technical assistant)

C.5. PROBA-3

C.5.1. Objectives

PROBA-3 is an ESA experimental mission devoted to the in-orbit demonstration of formation flying techniques and technologies. The mission will be implemented with a pair of small spacecraft, which together form a coronagraph. One spacecraft will carry the main optical bench and associated detectors, electronics, etc., while the second spacecraft will carry the occulter. STCE scientists participated in the proposal of the coronagraph for the PROBA-3 mission, ASPIICS (Association de Satellites Pour l'Imagerie et l'Interférométrie de la Couronne Solaire), led by Laboratoire d'Astrophysique de Marseille (France). ASPIICS heralds the next generation of coronagraphs for solar research, exploiting formation flying to gain access to the inner corona under eclipse-like conditions (field of view from 1.04 to 3 solar radii) for long periods of time. ASPIICS will make a giant step in our knowledge of the solar corona by providing observations that will lead to the insights necessary for understanding key physical processes and for the prediction of space weather in the Sun – Earth system. The ASPIICS unprecedented field of view makes it uniquely suited for studies of the solar corona, as it will fill the crucial observational gap between the fields of view of low-corona EUV imagers and usual space coronagraphs.

C.5.2. Progress and results

Scientific support was provided to the ASPIICS consortium, namely by writing the chapter 2 (Scientific Objectives) of the proposal.

C.5.3. Perspective for next years

PROBA-3 ASPIICS activities will be continued as the ASPIICS selection was announced in January 2010. The nominal launch date of PROBA-3 is the fall 2013.

C.5.4. Personnel involved

Scientific staff: B. Nicula, L. Rodriguez, A. Zhukov

C.6. Optics laboratory facilities

C.6.1. Objectives

The optics laboratory of BIRA-IASB provides facilities for the radiometric characterization and calibration of optical instruments generally dedicated to the measurements of the solar radiation and atmospheric trace species. Such characterizations are performed on commercial instruments designed for ground-based measurements or space qualified instruments developed in the frame of space projects.

Within the spectral range 185 – 900 nm, the tasks are typically:

- The determination of wavelength scales using various spectral light sources.
- The absolute calibration of spectroradiometer using standards of spectral irradiance
- The characterization of various sub-systems as optical diffuser (entrance optics), filters, lamps …
- The production of a monochromatic and tunable light source for the characterization of the diffuse light of spectrographs, the transmission of filters, or the measurement of detector response. It can be achieve by using a solar simulator coupled to a monochromator

The goal of this work package is to maintain the available facilities as a service for the UV-VIS, to extend the spectral range down to 100 nm or below for vacuum radiometry and to provide an upgrade for the NIR (up to 3 µm) for which less equipment is actually available. The objective consists of bringing this infrastructure up-to-date as a service for possible external collaborations (ROB, universities, …).

For space projects (SOLSPEC, LYRA, BOLD, …) for which some optical components have to be tested under vacuum and the detectors should be characterized for wavelength below the cut-off of the atmospheric pressure (~185 nm), there is a demand for a VUV facility that can be achieve by the refurbishment of the B225 (McPherson Inc, USA) spectrometer of BIRA-IASB. Connected to a cell, the facility can also offer an opportunity for absorption cross section measurements of molecule in the VUV (SO_2, ..). For the NIR, an upgrade of an existing UV-VIS instrument is proposed (Bentham, UK).

C.6.2. Progress and results

The tasks developed since many years in the optics laboratory are covering a wide range of works, for example:

- The determination of relative spectral function (SRF) of multichannel filters radiometers, measured in the frame of European project FARIN
- The maintenance of the radiometers end spectroradiometers operational on the Belgian network for UV-VIS monitoring of the global solar irradiance (angular response, absolute calibration, …).
- Synergies between different teams at BIRA-IASB: characterization (for internal diffuse light) of spectrographs dedicated to the measurements of atmospheric trace species (NO_x, O_3, …).
- Biological dosimetry for which UV effective doses were delivered for the calibration of biological dosimeters (BIODOS project)

The Space experiment SOLSPEC, the UV-VIS-IR spectroradiometer onboard the SOLAR payload on COLUMBUS (ISS) was developed at BIRA-IASB (joined project with LATMOS, France and ZAH, Germany). Before and after the integration, a wide range of tasks were performed in the laboratory Error! Reference source not found.: check-up of detector response, selection of flight model of internal lamps, vacuum tests, adjustment of filters, followed by the complete characterization (linearity measurements, angular response, wavelength scale, …). For LYRA, the transmission of some filters was verified at IASB.

Up to now, only the thermal vacuum chamber of IASB was available for radiometry below 200 nm. A solution was to refurbish the old B225 spectrometer with accessories as lamps and a motorization for the gratings. The objective is to extend the spectral range for the production of a monochromatic and tuneable light beam.

A deuterium lamp coupled to an energy optimizer, and a hollow cathode lamp have been ordered and delivered. A predispersor will be connected to the B225 to have a complete system with a level of performance of a double monochromator. Some mechanical works are required for connecting the new accessories to the B225 as holders and base plates. This work is in progress. The commissioning of the new equipment under vacuum and using software for the motors is a current task. For the IR upgrade, the ordering is in progress. This equipment is expected for developing some validation procedure for the absolute calibration of SOLSPEC in the IR.

C.6.3. Perspective for next years

To follow the same objectives: to complete the delivery of some accessories for vacuum if necessary and to put the lamps and spectrometers ready-to-use.

C.6.4. Personnel involved

Scientific staff: Bolsée David (Project Leader), D. Gillotay (scientist)
Technical staff: Willy Decuyper (technician)

C.7. Solar Irradiance

C.7.1. Objectives

The climate on earth is directly determined by the amount of energy that the earth receives from the sun. This energy is transmitted from the sun to the earth in the form of light, or Total Solar Irradiance (TSI). The measurement from space of the TSI is a long term specialisation of the RMIB, as can be seen from the space missions summarised in table 1.

Name	**Misson/Agency**	**Year**	
Solcon	Spacelab-1 NASA	1983	
	Atlas-1 STS-45 NASA	1992	
Sova 1	**Eureca ESA STS-46 NASA**	**1992**	**Brought back to earth**
Solcon	Atlas-2 STS-56 NASA	1993	
Solcon	Atlas-3 STS-66 NASA	1994	
TAS	TAS STS-85 NASA	1997	
IEH-3	IEH-3 STS-95 NASA	1998	
Freestar	Freestar STS-107 NASA	2003	
Currently in space :			
Diarad/Virgo	**SOHO ESA**	**1996**	**Still running**
Diarad/Sovim	**Columbus/ISS ESA**	**2008**	**Most accurate**
Planned (in 2009) :			
Sovap	**Picard CNES**	**2010 (plan)**	

Table 6: RMIB space missions dedicated to the measurement of the TSI from space.

The space missions which are important for current or future activities within the STCE are indicated in bold in table 1. These missions are:

1) the SOVA instrument which flew in space on the Eureca satellite in 1992, and which, thanks to the unique capabilities of the NASA space shuttle, has been brought back to earth. Future on-ground laboratory analysis of this instrument will allow to improve our knowledge of the absolute value of the TSI. This absolute value of the TSI, or Solar Constant, is a matter of controversy since the launch of the Tim/Sorce instrument in 2003.
2) The Diarad/Virgo instrument is our most successfull long term measuring TSI instrument so far. Long term TSI variations are directly relevant for the quantification of the solar influence on climate change on earth. Diarad/Virgo has measured over a complete solar cycle, and has significantly contributed to our understanding of long term TSI variations.
3) The Diarad/Sovim instrument on the ISS is our most accurate instrument in space so far. Particular attention has been paid to its absolute level since it was launched after Tim/Sorce.
4) The planned (in 2009) Sovap/Picard instrument is meant to provide continuity for the ageing Diarad/Virgo instrument and to possibly reconstruct the TSI level 300 years ago during the so-called little ice age, which was probably due to a dimmer sun than we know today.

C.7.2. Progress and Results

C.7.2.1. Total Solar Irradiance Observations

During 2009 the validation of the DIARAD/SOVIM absolute level was finalised and submitted for publication. Figure 68 shows the different independent long term TSI measurements by independent groups, with one color per group. The RMIB measurements are shown in red, including the time series of SOVA1, DIARAD/VIRGO and DIARAD/SOVIM, see also table 1. Prior to the launch of TIM/SORCE, indicated in purple in Figure 68, all the recent independent instruments agreed with each other within their stated accuracy of the order of +/- 1 W/m². The TIM/SORCE instrument, launched in 2003, measures about 5 W/m² lower than the other radiometers, while it has a stated accuracy better than +/- 1 W/m². Thus, clearly, there is a problem of stated versus real accuracy, which needs to be resolved. Every instrument group needs to critically re-examin its absolute acuracy. On the RMIB side, we did this by making an extra effort to characterise the DIARAD/SOVIM radiometer. For its two independent channels, with DIARAD/SOVIM, we measure 1364.75 W/m² +/- 1.38 W/m² with the right channel and 1364.5 W/m² +/- 1.38 W/m² with the left channel. The difference between the two channels of 0.25 W/m² is smaller than we ever obtained before with our space radiometers. This progress is probably due to improved aperture area measurements made at NIST and NPL.

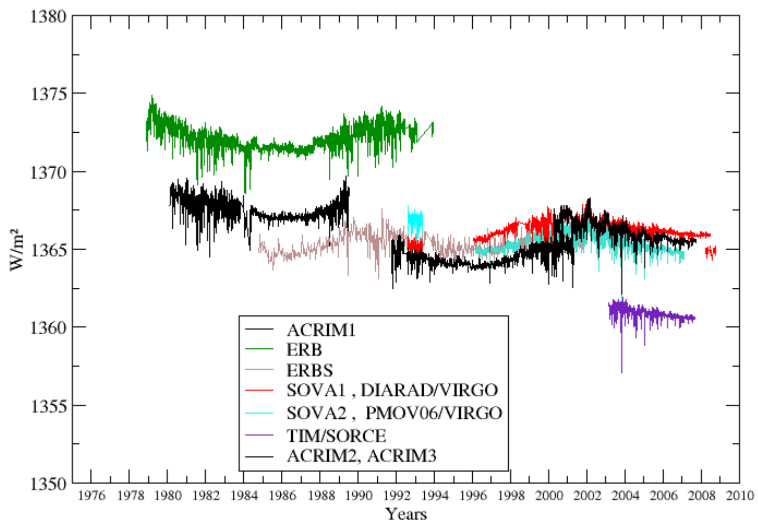


Figure 68: Independent space measurements of TSI. The measurements from the RMIB are given in red, including the new measurements from DIARAD/SOVIM.

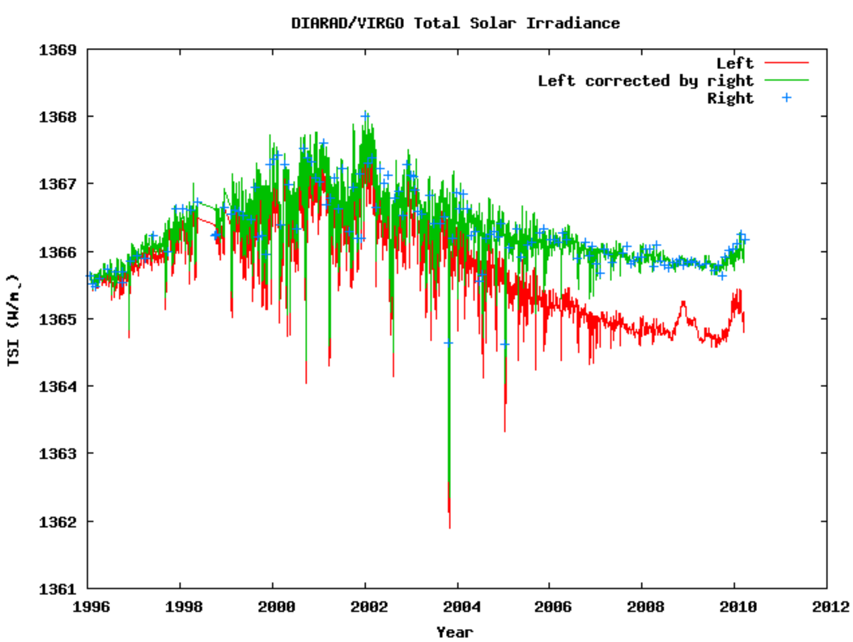


Figure 69: Measurements of DIARAD/VIRGO.

In 2009 we also continued the processing and analysis of DIARAD/VIRGO measurements, and its comparison with other TSI time series. 2009 was a particularly interesting year, since it was the end of an unusual long solar minimum, and for characterising the long term behaviour of the sun it is interesting to know if after this solar minimum a lower TSI was reached compared to the previous minimum (reached in 1996).

Figure 69 shows the measurements of DIARAD/VIRGO over the complete solar cycle 23. The red curve gives the measurements of the left channel, which is exposed to the sun continuously. Under the effect of the solar UV radiation the channel is ageing. The blue crosses are the measurements of the right channel, which is only exposed to the sun for about one hour every month. Since the right channel exposure is sufficiently low, we know it does not age significantly, and so the blue crosses give the true long term behaviour of the TSI. The green line shows the ageing corrected left channel measurement series, which has the long term behaviour of the right channel and the short time behaviour of the left channel.

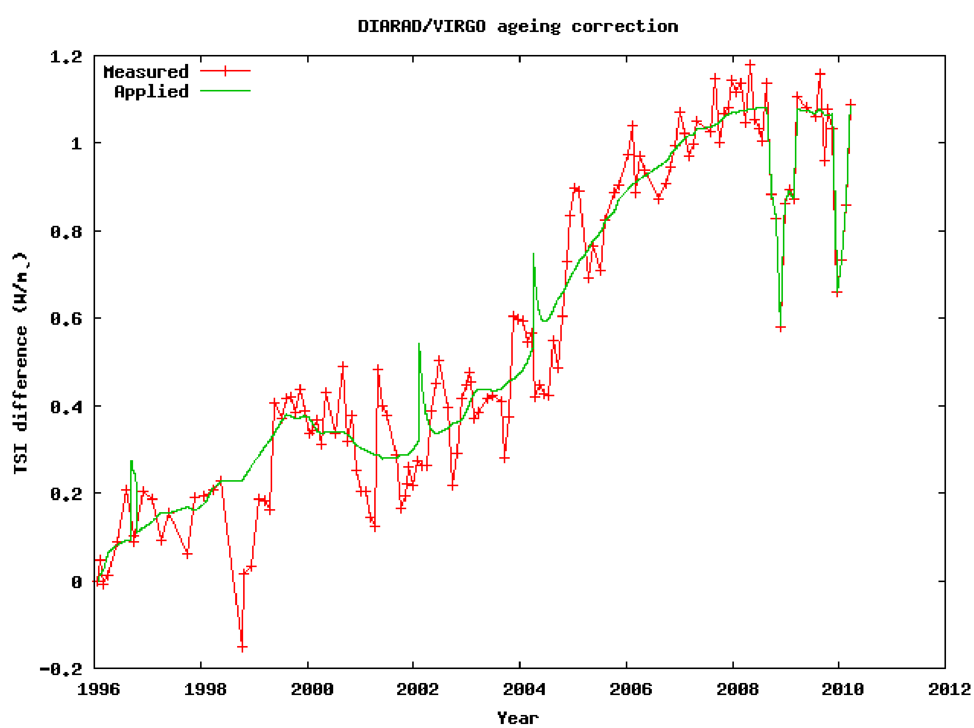


Figure 70: DIARAD/VIRGO ageing correction.

Figure 70 shows the difference between the right and left channel measurements (red crosses) and a smoothed curve (green line) running trough it. As the left channel ages, it becomes less sensitive with time, and the right minus left difference increases. The ageing correction of the left channel is done by adding the green curve to the left channel measurements. The two downward spikes twoards the end of the curve in Figure 70 appear to be an anomaly of the left channel, which fortunately is not present in the right channel, and is therefore removed by the ageing correction.

The long term variation of the TSI needs to be known as accurately as possible to quantify the influence of the sun on the climate change on earth. For the variation over a solar cycle, the most important question is whether the TSI level changes in between solar minima. For the last solar cycle, DIARAD/VIRGO provides one of the four independent time series shown in red on Figure 71, the other time series are provided by PMO6/VIRGO (in green), by the combination of ERBS (in blue) and TIM (in purple), and by the combination of ACRIM 2 (in light blue) and ACRIM 3 (in orange/brown). By comparing these time series, it can be assessed in an objective way that the first three time series agree well and give the true solar behaviour, while the ACRIM 3 series suffers from some instrumental effects.

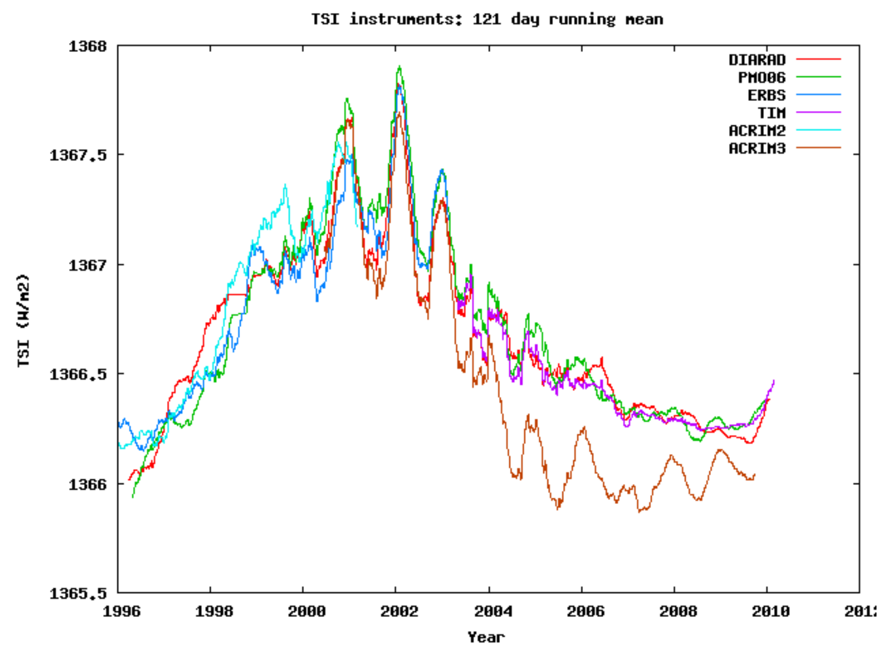


Figure 71: Independent time series of TSI variation over cycle 23.

Our best estimate of the measured TSI variation is the average of all available measurements, except ACACRIM 3. This is shown as the red curve in figure 72. Alternative composite measurements are provided by the PMOD group (green curve in fig. 72) and the ACRIM group (blue curve in fig. 72). A regression model fitted to our composite measurements is shown as the purple curve. For solar cycle 23, we have a good agreement between our composite measurements and our model, which gives us a high confidence in their correctness. We find no significant change in the TSI level of the two minima, contrary to the other composite measurement series.

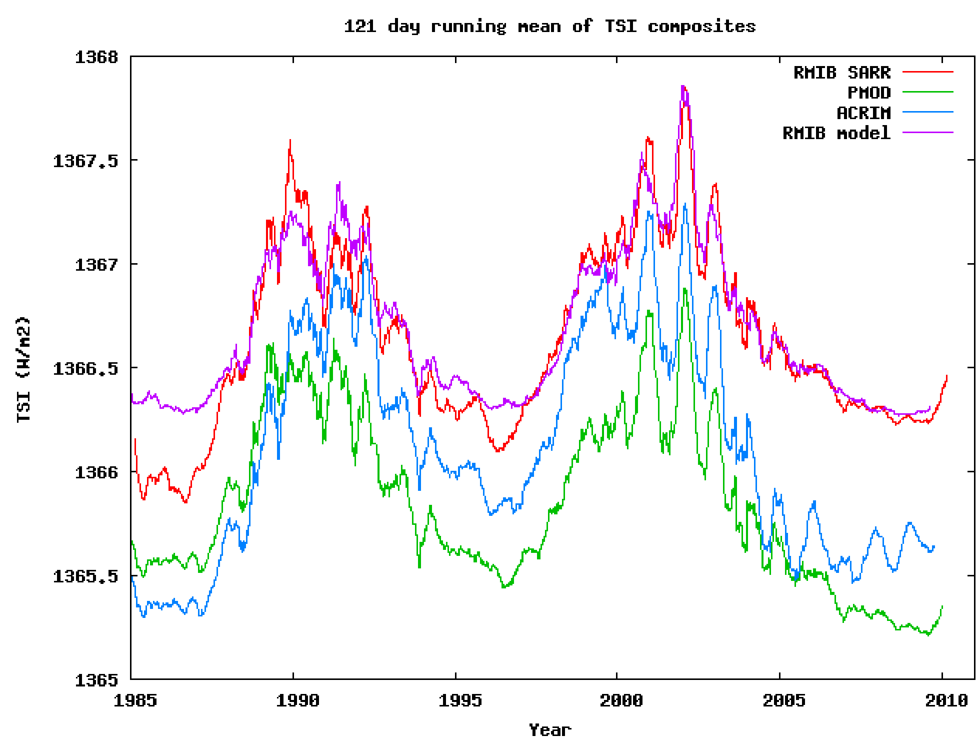


Figure 72: Different composites and regression model of TSI variation over solar cycles 22 and 23.

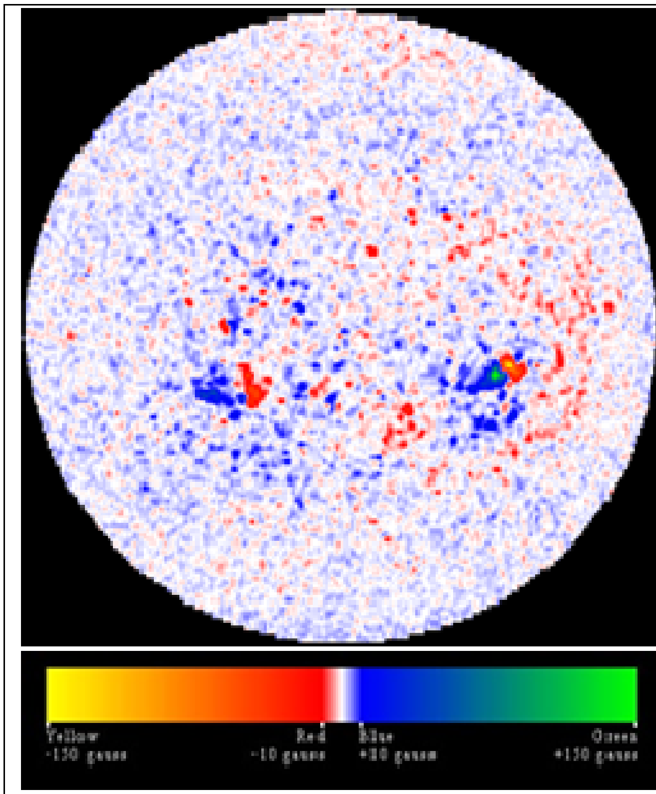


Figure 73: example of Mount Willson magnetogram used for characterising sunpots and facula.

Our TSI regression model is based on Mount Willson magnetograms. An example of such a magnetogram is shown in Figure 73. A dipole of strong magnetic fields is visible as the green and the yellow dot in the lower right quarter of the image. The strong magnetic fields correspond to sunspots, which are dark and hence cause a decrease in TSI. With time the strong magnetic fields are diffused over the solar disc, and become intermediate strength magnetic fields, visible in the blue and red colors in Figure 73. These intermediate mangetic fields correspond to facula, which are bright, and hence cause an increase of the TSI.

Sunspots are characterised by the so called Mount Wilson Sunpsot Index (MWSI), which is defined as the average field strength over the magnetogram pixels with field strength higher than 100 gauss. Facula are characterised by the so called Mount Wilson Plage strength Index (MPSI), which is defined as the the average field strength over the magnetogram pixels with a field strength between 10 and 100 gauss. The time series of these indices is shown in Figure 74. Both indices show an 11 year solar cycle. In general, within a solar cycle, the maximum of the MWSI is reached earlier than the maximum in MPSI, which can be understood since the medium field strength facula are generated from a diffusion of the high field strength sunspots.

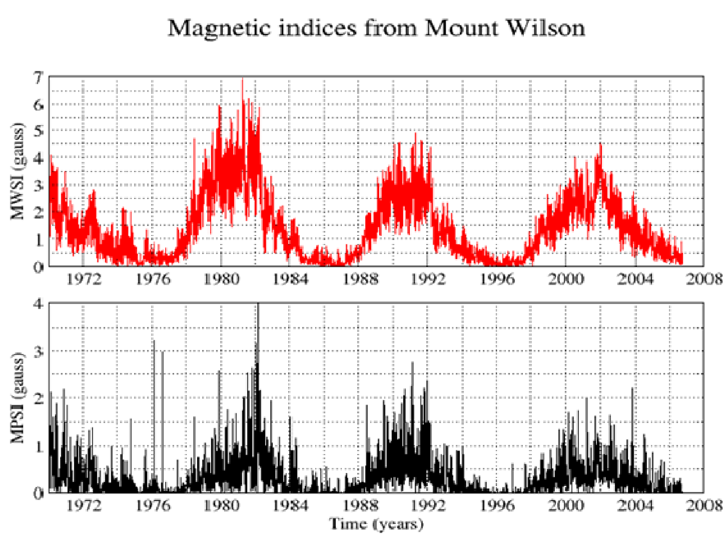


Figure 74: Time series of Mount Willson MPSI and MWSI indices

Our regression model (the purple curve in Figure 72) is obtained from the magnetic indices from Figure 74 trough a simple linear regression, TSI= a + b MPSI + c MWSI.

Figure 75 shows the evolution in time of the difference between our composite measurements and the model. In time, we see a clear improvement of the agreement between both, this is due to the increase in the number and quality of TSI instruements. For the last 5 years, we reach an excellent agreement within +/- 0.1 W/m².

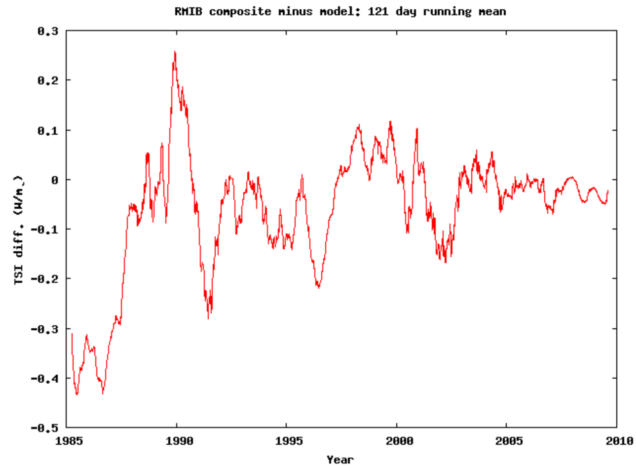


Figure 75: Time series of RMIB TSI composite minus model

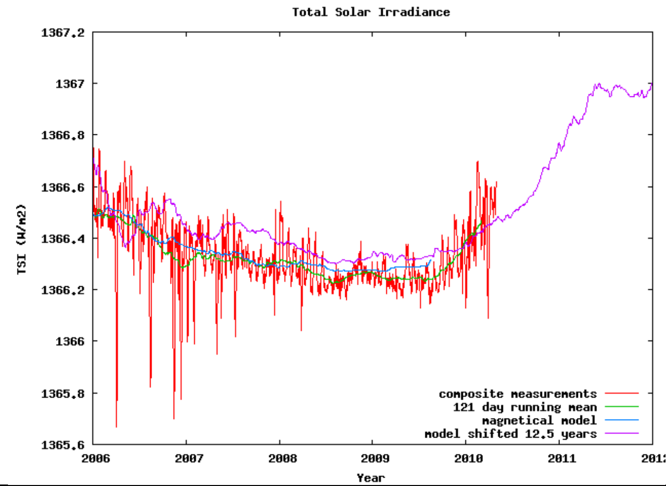


Figure 76: TSI variation at end 2009, and prediction for 2010.

The goal of the new Picard mission is to measure the fast TSI increase expected at the beginning of solar cycle 24 and to establish a possible correlation between solar irradiance and diameter variations. Figure 76 shows the measured TSI variation in 2009 (red curve) and a prediction for the TSI increase at the start of solar cycle 24 (purple curve). As can be seen, the TSI increase of solar cycle 24 started already at the end of 2009, so a launch of Picard in 2010 became very urgent.

During 2009 we supported the integration and testing of the Picard satellite at CNES Toulouse and we prepared the dataprocessing software for Sovap. igure 77 shows the thermal balance testing of Picard at CNES Toulouse.

igure 77: Picard thermal balance testing at CNES Toulouse

C.7.2.2. Sun-earth radiation imbalance

The sustained funding of the STCE allows to develop new space instruments. Building on the experience we have gained with the measurement of the TSI, we want to develop the Sun-earth IMBAlance (SIMBA) radiometer which can measure both the radiation coming from the sun and from the earth. A first application is the continuation of the TSI time series with an improved instrument. A second application is a calibration of the earth emitted radiation with the sun as best possible calibration source. A third application is the first ever direct measurement of the net radiation entering the earth (incoming solar minus nearly equal outgoing terrestrial radiation), which is the driver for climate change on earth.

In 2009, in collaboration with two eningeering master theses from the University of Liege, the first Simba instrument design and its possible integration on a nanosatellite were studied.

C.7.3. Perspective for next years

For 2010, for Sovap/Picard, a support to the CNES Picard launch campaign and the Sovap Commissioning is foreseen.

A continuing analysis of Diarad/Virgo and the other available TSI instruments is also foreseen.

An improvement of the Simba instrument design is foreseen, in order to have more margin to meet the very demanding science requirements.

A reprocessing of the historical NASA Wide Field Of View radiometers for the period from 1978 to 1999 is foreseen, in order to demonstrat the feasability of the Simba data processing.

C.8. Constructing and Operating Space Instruments

C.8.1. Objectives

We are targeting a more active participation in the construction and/or operation of space weather-related instruments. In this framework, we have hired Dr. Sylvain Ranvier, scientist/engineer, for experiment feasability studies and initial project developments. He started on 15/10/2009 under the supervision of H. Lamy. Three projects are in progress: the Xylophone Bar Magnetometer, the study of meteors with the BRAMS (Belgian RAdio Meteor Stations) network and the study of polarization.

Xylophone Bar Magnetometer

The short-term goal is to study the feasibility of developing a resonating XBM suited to miniaturization using MEMS technologies. The long-term goals is to embark a set of such miniature magnetometers onboard a fleet of micro/pico-satellites to carry out simultaneous measurements of the small- and large-scale structures of the Earth's magnetic field. In particular the study of the structure of the current sheet regions above auroral regions would be of great interest. For this project, BISA works in collaboration with the CSL (Dr. Pierre Rochus), the LTAS at ULg (Dr. Véronique Rochus), the Microwave Laboratory at UCL (Dr. Laurent Francis) and Open Engineering (Pascal de Vincenzo, Stéphane Paquay).

BRAMS radio meteor network

The goal is to build a network of radio receiving stations using forward scattering techniques to detect and study meteors. The acronym of the network is BRAMS for Belgian RAdio Meteor Stations. Some of the scientific goals of this project are to calculate flux densities and mass indexes for both meteor showers and sporadic meteors, retrieve meteoroid trajectories from multiple-station observations, and determine physical parameters such as ionization, mass and velocity whenever possible. BRAMS will help us to better characterize the mass, velocity, temporal and spatial distributions of meteor showers and sporadic meteors. This project is done in collaboration with ROB, RMI and several groups of radioamateurs or amateur astronomers (see below).

Polarization instruments

The initial goal of BISA is to use the polarization of some auroral emission lines to better understand the ionosphere/magnetosphere coupling and the physics of the ionosphere. Space weather applications are also envisaged. To observe auroral emission lines, we rely on 2 collaborations: 1) with Jean Lilensten and Mathieu Barthélemy from the LPG in Grenoble who have built an instrument called POLARLIS to measure the polarization of the auroral red line and, 2) with the ALIS team in Kiruna to test polarization capabilities of the current ALIS cameras and to develop new cameras which could be hosted in some of the existing empty facilities of the ALIS network. In the future, depending on the results of the first observational campaigns, three-dimensional tomography of the polarized auroral emissions could be envisaged. Meanwhile, following the international workshop organized at BISA in October 2009, our initial goal evolved a bit and we are now also interested in polarization measurements in other planetary atmospheres like for example Mercury or Jupiter. We also plan to develop a European network of scientists specialized in all aspects of polarization, i.e. observations, theory, modeling, instrumentation and laboratory measurements.

C.8.2. Progress and results

Much progress has been made for the three specific tasks.

C.8.2.1. Xylophone Bar Magnetometer

The working principles of the XBM have been studied in detail followed by parametric and finite-element simulations. The goal is to obtain the largest possible sensitivity with optimized parameters leading to the largest possible deflection of the bar. In the parametric study, the influence of the bar dimensions, of the quality factor and of the Young modulus on the bar displacement has been considered analytically. The current flowing into the bar creates Joule effect and thermoelectric coupling which, in a preliminary step, have been modeled with electric circuit analogy to obtain orders of magnitude. Then, simulations with finite element methods have been carried out with the Oofelie platform and have been compared to analytical solutions. In the design of the bar, we considered holes regularly spaced to facilitate the etching of the sacrificial layer under the bar. The influence of the holes on the mechanical properties of the bar has been modeled with simulations. Electrokinetic, thermal and mechanical simulations have also been realized but coupling effects such as thermo-electric and thermo-mechanic effects have not yet been studied properly and will be considered in 2010. Several methods of detecting the bar displacement have been considered, the most promising one being capacitive methods. All these results can be found in the document written by Innocent Nyonzima in the framework of his Master Thesis at the University of Liège as well as in a paper submitted to Acta Astronautica. They have also been presented in national and international conferences.

In parallel with these simulations, a first prototype has been made at the Microwave Laboratoty of UCL with SOI processes. Several designs have been realized: 1) mono-layer and multi-layer bars, 2) several values of the length and width of the bar, the thickness of the bar being imposed by the process. Two materials have been used: doped silicon and aluminium. First measurements with a profilometer indicated that the structure of these prototypes is strongly curved in the central part due to a large difference of the thermal expansion coefficients between the silicon substrate and the aluminium layer. The other measurements will start at LTAS in early 2010 and will include mechanical measurements (resonance frequency, bar displacement with optical methods) as well as measurements of some properties of the bar (e.g. Young's modulus) and of the external magnetic field (with the Hall probe of CSL). In particular, the influence of the residual thermal stresses on the mechanical properties of the bar is very important to know and model.

C.8.2.2. BRAMS radio meteor network

The BRAMS network will comprise approximately 20 receiving stations; most of them will be hosted by radioamateurs or groups of amateur astronomers. Among them let us cite the VVS (Vereniging Voor Sterrenkunde), the GAS (Groupe d'Astronomie de Spa), the SAL (Société Astronomique de Liège), the Public Observatory of MIRA in Grimbergen, the Public Observatory of Urania in Hove, etc … BISA will also host a receiving station. A station with interferometric capabilities will be installed in the radioastronomical site of Humain, in collaboration with ROB. The interferometer consists of 5 antennas arranged along 2 perpendicular baselines. Several discussions have been undertaken with Frédéric Clette and Christophe Marqué (from the Solar Physics group of ROB) to choose the most appropriate location on the site taking into account possible reflections on metallic surfaces, accessibility during winter time, facilities to bring the electrical power and an internet connection. A visit of the Humain site is planned for March 2010.

For the transmitters, there is currently a beacon emitting in Ypres which was developed by VVS members a couple of years ago. It emits a pure sinusoidal signal at a frequency of 49.99 MHz and with a constant power of 50 watts. The signal is mainly emitted towards the zenith with a beam width of approximately 30°. In 2010, we will add another similar beacon in Dourbes, at the "Centre de Géophysique du Globe" of RMI. An agreement has already been concluded with Prof. René Warnant, responsible of the Dourbes activities, as long as the initial tests with the beacon do not perturb the other instruments. Our beacon will also emit a pure sinusoidal wave but at a frequency of 49.97 MHz and with a constant power of 150 watts. To secure the frequency and avoid interferences from other sources, BISA has bought an annual licence from IBPT (Institut Belge des Postes et Télécommunications).

In 2009, the following list of material has been ordered for the BRAMS network:

- 2 shelters for the BISA and Humain stations. Each shelter is equipped with a heating resistance and a fan. They will contain the receivers, PCs and acquisition cards.
- 2 industrial PCs for the BISA and Humain stations.
- 3 acquisition cards for the BISA and Humain stations. Each card has 4 inputs. We need 4 for the BISA station (2 antennas + 2 polarizations each) and 6 for the Humain station (5 antennas + 1 common reference at 10 MHz).
- A signal generator to be used for the beacon in Dourbes.
- 25 GPS clocks that will be used at each station to accurately determine the beginning of the meteor echoes.
- 42 meters of coaxial cables and associated connectors for the BISA, Humain and Dourbes stations.
- A 3-element Yagi antenna which was used during the open doors in October 2009 and will be used in 2010 to calibrate the prototype antenna we build at BISA (see below).
- An AR-5000 commercial receiver which was used during the open doors in October 2009 and will be used in 2010 to calibrate the new improved HRO receivers (see below).

In addition, based on the plans of the 3-element Yagi antenna, we ask the workshop at BISA to build a similar antenna. The prototype will be ready in February 2010 immediately followed by tests of its impedance and sensitivity. For the BISA and Humain stations, we would like to analyze the profile of the meteor echo (i.e. the power of the received signal vs time). Special acquisition cards were ordered in this purpose while other receiving stations will only use the sound card of the PC as A/D converter. Moreover, to receive the complete power of the reflected signal, we need to measure both vertical and horizontal polarizations. Therefore we asked the workshop at BISA to build in 2010 another prototype of a crossed 3-element Yagi antenna.

Most of the radioamateurs currently use a Japanese HRO receiver specially adapted to receive the frequency of 49.99 MHz. However, this receiver suffers from a relatively strong frequency shift due to variations of the external temperature. In the course of 2009, it was decided to build improved HRO receivers for both frequencies (49.97 and 49.99 MHz) which are more stable and also allow an external entry to use a 10 MHz reference as input. This task was given to the company ICOMS, specialized in radar detections for traffics. Unfortunately, due to internal problems in the company, this solution has to be abandoned. In 2010, we must find a back-up solution.

Another goal of BISA is to equip each receiving station with a new antenna designed at the BISA workshop, one or two new commercial receivers, possibly some coaxial cables and a GPS clock. Each radioamateur or group of astronomers will take charge of the local PC. Data will be stored locally on hard disks and collected on a regular basis by BISA which will analyse and archive them with their IT facilities.

A website about BRAMS is available at brams.aeronomie.be and is maintained by Emmanuel Gamby and Hervé Lamy. An ftp server has been created to allow easy exchange of data among the various observers to discuss and study special cases such as head echoes or epsilon echoes.

The study of radio meteors is also a very valuable subject for outreach activities. During the open doors, a temporary receiving station was exhibited in the BISA marquee with the Yagi antenna and the AR-5000 receiver. This scientific exhibition turned out to be very successful. The BRAMS network was also presented in the "Education, Outreach and Education Markets" splinter session at the 6th European Space Weather Week.

C.8.2.3. Polarization instruments

During a meeting in Grenoble on March 2-4 2009, it was decided to organize an international workshop about polarization in BISA on October 12-14 2009. The acronym of the workshop was SEPAGE for Space Environments Polarization: Applications to Geophysics and planetary Environments. The scientific committee was composed of Hervé Lamy (BISA), Mathieu Barthélemy (LPG), Cyril Simon (BISA), Jean Lilensten (LPG) and Johan De Keyser (BISA). 24 scientists from 7 countries participated to the meeting and we had 17 presentations. 3 sessions were organized: observations, instrumentation, and theoretical aspects of the polarization of some lines. Two open round tables between the participants concluded the workshop. One of the decisions following these open discussions was to introduce a COST proposal to EU to obtain fundings to create a European network of scientists specialized in all aspects of the polarization. It will be introduced in March 2010 before the next call for COST proposals. It was also decided to organize a similar workshop once a year in the future. A website with all the details of the workshop as well as links to the presentations is available at http://www.pola.oma.be/workshop.php.

H. Lamy had a progress meeting with the ALIS team in Kiruna from 20 to 22 April. Two topics were discussed: 1) the polarization capabilities of ALIS stations and, 2) the preparation of coordinated observations between ALIS and POLARLIS. First, the polarization capabilities of current cameras is limited by several strong constraints such as the dome in plexiglas and the large FOV, both creating a lot of spurious instrumental polarization which would vary accross the field and would therefore be difficult to correct. The solution to the dome would simply to remove it but this can only be done during limited periods of time when external temperature and moist are not too critical. Several ideas were proposed to test the instrumental polarization of the ALIS cameras and will be tested in 2010. Then, the possibility of running a coordinated campaign between ALIS, EISCAT and POLARLIS in December 2009 was also briefly discussed but it was concluded that the geometry is inadequate and coordinated observations are not feasible. POLARLIS will have to be moved to mainland during winter 2010-2011. The Lycksele observatory in the south of Kiruna has been suggested by the ALIS team. We concluded this meeting by a short discussion about the creation of new ALIS cameras designed to measure the polarization of auroral lines. The ALIS team would agree to host these new cameras in one of their empty existing facilities with electrical power and internet access such as Nikkaluotka or Merasjärvi. This option will be discussed again after the first POLARLIS measurements on the mainland.

C.8.3. Perspective for next years

C.8.3.1. Xylophone Bar Magnetometer

In 2010, with the hiring of Dr. Sylvain Ranvier, BISA will be more implied in the design and simulations of the magnetometer. For that reason, in December 2009, BISA bought an annual licence from Open Engineering for the multi-physics platform Oofelie driven by Samcef. Dr. Sylvain Ranvier also followed intensive 5 day training in Open Engineering.

Several designs will be simulated as well as several fabrication processes such as SOI or SOIMUMPS. The detection method will also be included in these designs. After some studies and discussions in 2009, we think that capacitive methods are the most promising technique and the designs will be realized accordingly. All the simulations will be compared to determine the final design of the XBM by the end of 2010.

A GSTP proposal will be introduced to ESA to obtain additional fundings. Two possibilities are considered: either to submit a proposal to GSTP 5 Element 3 (G533-006) in the future SSA space segment or to submit a proposal within the open AO for technology product development. Contacts have been taken with Dr. Eamonn Daly for the SSA space segment and with Dr. Marchand for the open AO. The final decision will be taken during the first half of 2010.

C.8.3.2. BRAMS radio meteor network

We will continue and finish developing the BRAMS network. The BISA receiving station will be operational in March 2010. We expect the beacon in Dourbes and the interferometer in Humain to be operational in summer 2010. For the beacon, an order will be placed to buy a power amplifier in order to emit 150 watts.

The workshop at BISA will produce 3 types of antennas: a 3-element Yagi antenna, a crossed 2-element Yagi antenna and a crossed 3-element Yagi antenna. The first one will be used in each receiving station (as well as for 4 antennas in the interferometer in Humain), the second one will be used for the Dourbes beacon (where we need an antenna which is not too directional) and the last one will be used in the BISA station and for the central antenna of the interferometer in Humain.

Contacts will be taken with another external company in order to build the new HRO receivers. As soon as they are ready, BISA will send the adequate material to each receiving station to complete the BRAMS network.

An Action 1 proposal will be written and submitted to Belspo to obtain funding to hire a scientist in January 2011 to work on the BRAMS data.

C.8.3.3. Polarization instruments

A COST proposal will be introduced to EU in March 2010. Another workshop about polarization will be organized in BISA in October 2010. Some tests for the polarization capabilities of the ALIS cameras will be done by the ALIS team in 2010. After discussion with the group of Utrecht during the workshop, it was suggested to use modulators in front of the polarizing lenses instead of a rotating filter. We will consider this option. POLARLIS will be moved to mainland during winter 2010-2011. BISA might be associated to some proposals to observe Jupiter and possibly Mercury with facilities such as the Hubble Space Telescope, the VLT in Paranal or the THEMIS instrument on the Solar Telescope in Tenerife.

C.8.4. Personnel involved

Scientific staff: Hervé Lamy (Project Leader), Johan De Keyser, Sylvain Ranvier, Stijn Calders, Emmanuel Gamby, Cyril Simon

Technical staff: Jeroen Maes & various people from the mechanical workshop of BISA

C.9. Measurements of solar irradiance

The measurement of the solar UV radiation is essential in the Sun-Earth interaction with the atmosphere. As a long term goal, the STCE will continue and expand its activities concerning UV measurement techniques.

C.9.1. Objectives

The STCE aims at obtaining measurements of solar UV both on the ground and in space.

The objective of the ground-based measurements is to exploit, upgrade, and/or make publicly available the existing UV measurements at the 5 stations of the STCE network (at Uccle, Redu, Oostende, Virton and Mol) and STCE calibration facilities. The outputs would include a regional UV database including ancillary data as ozone column, aerosols, cloud cover …

Space-based measurement objectives include data acquisition from SOLSPEC, data processing and validation of those data.

C.9.2. Progress and results

Concerning the ground-based network, during 2009, the full equipment of the additional stations has been deployed in Virton (Gaume), Mol (Kempen), and Diekirch (Gr. D. Luxembourg). They have been fully integrated in the UV-Visible monitoring network. The stations (Uccle, Redu, Oostende, Virton, Mol, Diekirch) provide UV-B, UV-A, and Visible sets of data of the solar irradiance reaching the Earth's surface. Ancillary meteorological data (temperature, relative humidity, pressure, wind speed and direction, pluviometry, cloud cover) complete the data set.

The space experiment SOLAR SOLSPEC, launched in February 2008 is dedicated to the absolute measurement of the extraterrestrial solar spectral irradiance from 166 to 3088 nm. SOLSPEC is integrated on the solar tracker CPD (Coarse Pointing Device), the SOLAR external payload of CULUMBUS on ISS. SOLAR SOLSPEC is the unique space experiment measuring the solar IR absolute irradiance above 2.4 µm.

SOLSPEC is equipped with three separate channels optimized for the detection of UV, VIS and IR irradiance. An internal lamp unit provides onboard relative calibration to monitor the trends of the channels response and wavelength scale due to ageing.

SOLSPEC was fully operational during the year 2009 and performed 735 direct solar or internal lamp spectral measurements. The mission is organized in 'Sun Windows' (periods of approximately 10 days of solar observations per month).

Operating SOLSPEC in orbit is a compromise between the need to accumulate a large amount of irradiance data and the need to reduce the exposure of the channels and entrance optics against hard radiation from space. The same strategy is applied for the internal lamps that provide a key signal (the relative irradiance) while being used sparingly to preserve their stability and lifetime. The acquisition is an alternation between nominal operations on the full spectral range combined with special operations using longer integration time focalized on some spectral ranges where the signal to noise ratio must be improved.

During 2009, SOLSPEC performed solar measurements (the spectrum, MgII and CaII index, more than 170 acquisitions) and measurements for the maintenance and for improving the characterization of the instruments (ageing, linearity, angular response, quartz plate's transmission …).

The calibration and validation of the spectral solar data are in progress, consolidated by many efforts based on the improvement of the characterization, especially for the IR.

The solar spectrum as measured by SOLAR SOLSPEC during the solar minimum activity is under construction. Collaboration was developed with the SORCE and Sciamachy teams for the UV and IR part of the spectrum.

C.9.3. Perspective for next years

We will continue to support/expand our ground network for measurement of the solar irradiance in UV-VIS-IR. An extension is planned with the deployment of a new station in Antarctica, and 2 extra stations in Belgium.

Concerning the space-based measurements, one channel of LYRA presents an operating spectral range common with the UV channel of SOLSPEC. After the commissioning phase, the first solar measurements of LYRA and comparisons will start at the beginning of 2010.

C.9.4. Personnel involved

Scientific staff: Didier Gillotay (Project Leader), David Bolsée
Technical staff: Willy Decuyper

C.10. Solar UV Index

The solar UV index has practical consequences. A long term goal is to monitor the UV index and to produce warnings; there is a synergy with the RMI in this domain. The short term goal is to develop a web service offering near-real-time solar UV measurements and short-term prediction of the UV index locally for Belgium (in synergy with RMI).

C.10.1. Objectives

We aim at the exploitation of UV measurements to produce a near-real-time UV index at the various measurement sites. We developed a web service offering near-real-time solar UV measurements and short-term prediction of the UV index locally for Belgium
Output: A web service that gives access to

- the measured UV index for the existing station network
- local short-term UV index predictions in clear sky conditions
- local UV index predictions in all weather conditions

C.10.2. Progress and results

The web service is available at the internet address http://www.aeronomie.be/uv/. It offers access to the real-time measurements at the six stations (Uccle, Redu, Oostende, Virton, Mol, Diekirch). Ancillary data, such as basic meteorological data (temperature, relative humidity, pressure, wind speed and direction, and pluviometry, as well as the measurement of the cloud cover) are made available too. A color coding is used to highlight elevated levels of UV radiation. Preparations are being made for implementing software to predict the UV index in realistic conditions.
An overview of our UV activities has been published.

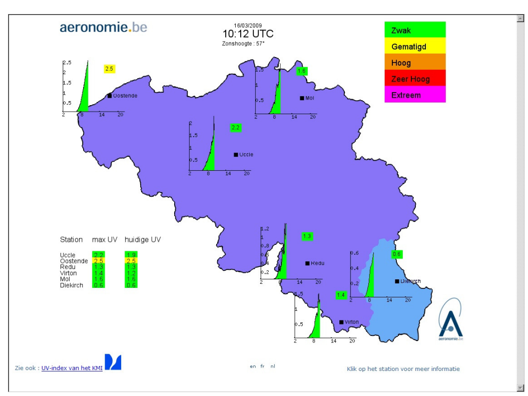


Figure 78: UV STATIONS IN BELGIUM

C.10.2.1. Long-term UV climatology

All the data are being gathered and stored to construct a long-term UV climatology for Belgium.

C.10.3.Perspective for next years

UV index web service: We will continue to offer and improve our web service.
Long-term UV climatology: This activity is really a multi-year effort. Data are acquired continuously.

C.10.4.Personnel involved

Scientific staff: Didier GILLOTAY (Project Leader), Cedric DEPIESSE
Technical staff: Willy DECUYPER

C.11. Observations and models of the Earth's magnetosphere - MIM

C.11.1.Objectives

Studies of the Earth's environment in space are based on in situ observations and models. Any progress in the field should confront both with each other. The objective of this work package is to develop (1) software that can be used to process observations, to display them, and to compare them with model output, and (2) software for modeling magnetospheric processes, in particular kinetic plasma simulations.

C.11.2.Progress and results

The MIM software (Manager of Interactive Modules) has been developed at BIRA-IASB in the course of the past years. Within the context of the STCE it is further expanded, maintained, and distributed. MIM is written in Matlab and creates an interactive and user-friendly environment for the visualization of spacecraft data, for applying data interpretation algorithms, and for performing simulations and comparing their output against observed data. It is written in a modular way. Several modules have been developed in the past, such as modules to process multi-point data, such as gradient computation and magnetopause reconstruction and modules to model the chemistry of the cometary coma. MIM is available via the European Space Weather Portal (http://www.spaceweather.eu/en/software/mim).
A major activity during 2009 was the elaboration of the module for solving the Lyons problem (magnetosphere-ionosphere coupling in the auroral regions). There have been improvements to the numerical scheme, more general magnetospheric electric potential configurations are now allowed, and a linear current-voltage relation is now provided.

An example of the characteristics of an auroral circuit is given in the accompanying figure (a MIM screenshot) where a nested-V magnetospheric potential gives rise to narrow parallel potential region and an associated sharp field-aligned current: That is a characteristic configuration for a discrete auroral arc.

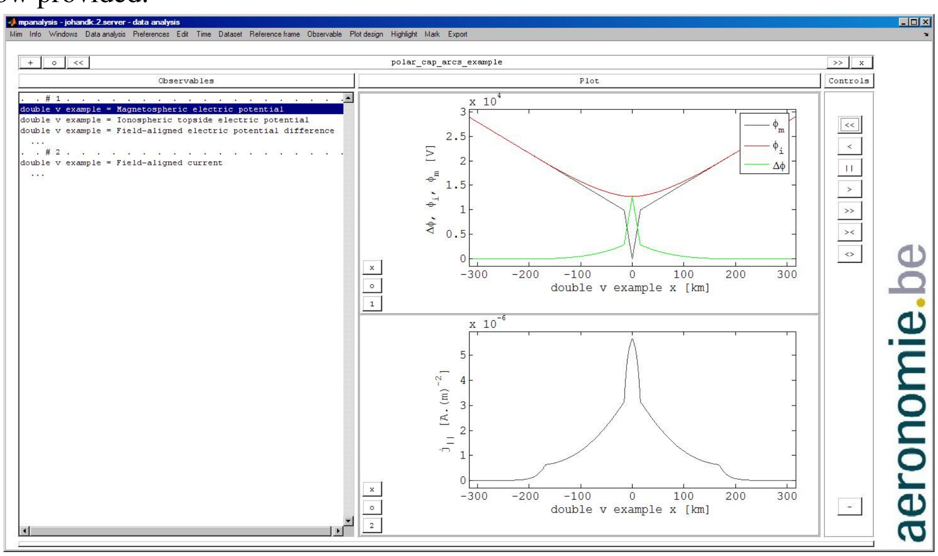


Figure 79: MIM software results for ionosphere-magnetosphere coupling

Further work has been done on

- the concept of "channels" through which MIM can access local or remote data sources, in particular for working with data from the Cluster Active Archive. MIM automatically converts the data files to its own preferred format, so as to import the remote data in a flexible manner.
- the integration of new algorithms for multi-spacecraft least-squares gradient calculation developed in the context of the Cluster mission,
- the addition of new data item categories, including loading and saving multi-dimensional datasets,
- the extension of functionality of the tangential discontinuity module to allow parameter studies,
- recurrent basic maintenance activities (bug fixes, efficiency improvements, …).

Initial work has been done to generalize and expand the graphical engine, but this work will be further elaborated and completed during 2010.

Several conference presentations were given that relate closely to the MIM work.

C.12. Kinetic simulations

C.12.1.Objectives

We are developing computer codes for performing Vlasov simulations of kinetic plasma phenomena. The goal is to work first on kinetic simulations of specific regions in the magnetosphere, to better understand the physical processes going on there, while this could later on result in larger-scale simulations of the magnetosphere as a whole.

A literature survey has been conducted. Experiments have been done with a simple code obtained freely from the Internet. A one-dimensional electrostatic code for multi-species unmagnetised plasmas is read-has been prepared. The goal is to arrive at a code that includes magnetic fields and two velocity dimensions, the aim being to use it for studies of auroral physics.

We are pursueing a double approach. First, we work with an existing code. This code has been tested and parallelized. A second line of work aims at designing a more general type of software, DSIM, for this type of simulations. We had a major discussion on the basic design choices of the DSIM software that we will construct. The idea is to re-use software for management of data-parallel structures (DObject and supporting classes, developed earlier) and for handling distributed meshes (DMesh and supporting classes, developed earlier). This software runs in data parallel mode on the parallel computer of the Space Pole. A number of suitable test problems has been identified Error! Reference source not found..

A complementary activity is particle simulation at plasma interfaces, in collaboration with people from the Institute for Space Sciences in Bucharest in Romania, which resulted in a paper and several conference presentations.

M. Echim and J. Lemaire together with O. Lie-Svendsen (University of Oslo, Norway) have finished a review on kinetic and fluid modeling of the solar wind. This paper reviews the complementarity between the two approaches and outlines their common theoretical roots lying in the fundamental kinetic theory of plasma physics. This study has been solicited by the Editor of Surveys in Geophysics, a Springer journal, and has been submitted for publication in November 2009. A conference presentation of this review has been given.

C.12.2.Perspective for next years

We intend to continue our support for MIM. A major task for 2010 is to finish the redesign/generalization of the plotting engine. This will be accompanied by a provision of a broader class of data item types, in particular to include multidimensional data sets such as particle differential energy spectrograms or pitch angle distributions, which are very often used in space physics.

With respect to the kinetic simulations, we will address first a problem in auroral physics. This can serve both as a very good test problem for the kinetic code, but it can be related to other work going on in our group on observational studies of the auroral system (e.g. in the context of the Cluster mission).

C.12.3.Personnel involved

Scientific staff: J. De Keyser (Project Leader), H. Gunell (scientist), M. Echim (scientist)
Technical staff: E. Gamby (computer scientist)

PART 5: PUBLICATIONS

1. Publications with peer review

[1] A. BenMoussa, I.E. Dammash, J.F. Hochedez, M. Dominique, S. Gissot, B. Giordanengo et al.
Pre-Flight Calibration of LYRA, the Solar VUV radiometer on board PROBA2
A&A 508 (2009) 1085-1094

[2] A. BenMoussa, A. Soltani, U. Schühle, K. Haenen, Y. M. Chong, W. J. Zhang, R. Dahal, H. X. Jiang, D. Bolsee, C. Hermans, M. Richter, U. Kroth, B. Giordanengo, H.A. Barkad, V. Mortet, J.C De Jaeger, F. Scholze and J.F. Hochedez
Recent developments on wide bandgap based UV sensors
Diamond and Related Materials 18 (2009) 860-864

[3] Bidaine B., Warnant R. (2010)
Assessment of the NeQuick model at mid-latitudes using GNSS TEC and ionosonde data.
Adv. Space Research, Vol. 45, pp. 1122-1128, doi:10.1016/j.asr.2009.10.010.

[4] Bruyninx C., Carpentier G., Roosbeek F.
The EUREF Permanent Network: Monitoring and On-line Resources
"Geodetic Reference Frames", IAG Symposia Series Vol. 134, Springer, pp. 137-142, DOI: 10.1007/978-3-642-00860-3_21

[5] Bruyninx C., Altamimi Z., Boucher C., Brockmann E., Caporali A., Gurtner W., Habrich H., Hornik H., Ihde J., Kenyeres A., Mäkinen J., Stangl G., van der Marel H., Simek J., Söhne W., Torres J.A., Weber G.
The European Reference Frame: Maintenance and Products
"Geodetic Reference Frames", IAG Symposia Series, Springer, Vol. 134, pp. 131-136, DOI: 10.1007/978-3-642-00860-3_20

[6] Buresova, D., B. Nava, I. Galkin, M. Angling, S. M. Stankov, P. Coisson (2009):
Data ingestion and assimilation in ionospheric models.
Annals of Geophysics, Vol.52, No.3-4, pp.235-253.

[7] Burston, R., Astin I., Mitchell C., Alfonsi L., Pedersen T., Skone S.
Correlation between scintillation indices and gradient drift wave amplitudes in the northern polar ionosphere
Journal of Geophysical Research-Space Physics, 114.

[8] Cheymol Anne, L. Gonzalez Sotelino, K.S. Lam, J. Kim, V. Fioletov, A.M. Siani and H. De Backer
Intercomparison of Aerosol Optical Depth from Brewer Ozone Spectrophotometer and CIMEL Sunphotometer measurement
Atmos. Chem. Phys., 9, 733-741, 2009.

[9] Dasso S., Mandrini C. H., Schmieder B., Cremades H., Cid C., Cerrato Y., Saiz E., Démoulin P., Zhukov A. N., Rodriguez L., Aran A., Menvielle M., Poedts S.
Linking Two Consecutive Non-Merging Magnetic Clouds with Their Solar Sources
Journal of Geophysical Research, 114, A02109 (2009)

[10] De Backer, Hugo
Time series of daily erythemal doses at Uccle, Belgium
International Journal of Remote Sensing, volume 30, issue 1516, 4145-4151, doi: 10.1080/01431160902825032, 2009

[11] Dehant V., Folkner W., Renotte E., Orban D., Asmar S., Balmino G., Barriot J.P., Benoist J., Biancale R., Biele J., Budnik F., Burger S., de Viron O., Häusler B., Karatekin Ö., Le Maistre S., Lognonné P., Menvielle M., Mitrovic M., Pätzold M., Rivoldini A., Rosenblatt P., Schubert G., Spohn T., Tortora P., Van Hoolst T., Witasse O., Yseboodt M.
Lander Radioscience for obtaining the rotation and orientation of Mars
Planet. Space Sci., 57, pp. 1050-1067, DOI: 10.1016/j.pss.2008.08.009.

[12] Dolla L., Solomon J.
Solar Off-limb Line Widths with SUMER: Revised Value of the Non-thermal Velocity and New Results
Annales Geophysicae, 27, 3551–3558 (2009)

[13] M. Dominique, A.V. Mitrofanov, J.-F. Hochedez, P. Apel, U. Schuehle, F.A. Pudonin, O.L. Orelovich, S.Yu. Zuev, D. Bolsee, C. Hermans, A. BenMoussa.
Track membranes with open pores used as diffractive filters for space-based X-ray and EUV solar observations
Applied Optics (2009), vol. 48, issue 5, p. 834

[14] Faricheva E.V., Kiyan M.A., Podladchikov. V.N. Podladchikova O.V.
Cluster Analysis for and NEMO tool improvement
New Technologies, 2010, Volume. 28, pp 149-153 (2010) (in Russian)

[15] Kutiev I., Muhtarov P., Andonov B., Warnant R. (2009)
Hybrid model for nowcasting and forecasting the K index
J. of Atmospheric and Solar-Terrestrial Physics, Vol. 71, pp. 589-596, doi:10.1016/j.jastp.2009.01.005.

[16] Kutiev I., Marinov P., Fidanova S., Warnant R. (2009)
Modeling medium-scale TEC structures observed by Belgian GPS receiver network
Adv. Space Research, Vol. 43, pp. 1732-1739, doi:10.1016/j.asr.2008.07.021.

[17] Mierla M., Inhester B., Marqué C., Rodriguez L., Gissot S., Zhukov A. N., Berghmans D., Davila J.
On 3D Reconstruction of Coronal Mass Ejections: I. Method Description and Application to SECCHI-COR Data
Solar Physics, 259, 123–141 (2009)

[18] Pham L.B.S., Karatekin Ö, Dehant V.
Effect of Impacts on the atmospheric evolution of Mars
Astrobiology, Special Issue on 'Early Mars', 9(1), pp. 45-54, DOI: 10.1089/ast.2008.0242.

[19] Pireaux S., Defraigne P., Wauters L., Bergeot N., Baire Q., Bruyninx C.
Influence of ionosphere perturbations in GPS time and frequency transfer
Advances in Space Research, Special Issue "Recent Advances in Space Weather Monitoring, Modelling and Forecasting", DOI: 10.1016/j.asr.2009.07.011 (on-line only)

[20] Pireaux S., Defraigne P., Wauters L., Bergeot N., Baire Q., Bruyninx C.
Higher-order ionospheric effects in GPS time and frequency transfer
GPS Solutions, DOI: 10.1007/s10291-009-0152-1 (on-line only)

[21] Podladchikova, O.; Vourlidas, A.; Van der Linden, R. A. M.; Wülser, J.-P.; Patsourakos, S.
Extreme Ultraviolet Observations and Analysis of Micro-Eruptions and Their Associated Coronal Waves
The Astrophysical Journal, Volume 709, Issue 1, pp. 369-376 (2010)

[22] Pottiaux E.

GNSS Near Real-Time Zenith Path Delay Estimations at ROB: Methodology and Quality Monitoring
Bulletin of Geodesy and Geomatics, 2009(2), pp. 125-146

[23] Pottiaux E., Brockman E., Söhne W., Bruyninx C.
The EUREF - EUMETNET Collaboration: First Experiences and Potential Benefits
Bulletin of Geodesy and Geomatics, 2009(3), pp. 269-288

[24] Rodriguez L., Zhukov A. N., Cid C., Y., Saiz E., Cremades H., Dasso S., Menvielle M., Aran A., Mandrini C. H., Poedts S., Schmieder, B.
Three Frontside Full Halo CMEs with a Non-Typical Geomagnetic Response
Space Weather, 7, S06003, doi:10.1029/2008SW000453 (2009)

[25] Rodriguez L., Zhukov A. N., Gissot S., Mierla M.
Three-Dimensional Reconstruction of Active Regions
Solar Physics, 256, 41–55 (2009)

[26] Schnadt Poberaj, Christina, J. Stähelin, D. Brunner, V. Thouret, H. De Backer and R. Stübi
Long term changes in UT/LS ozone between the late 1970s and the 1990s deduced from GASP and MOZAIC aircraft programs and from ozonesondes
Atmos. Chem. Phys., 9, 5343-5369, 2009

[27] Stankov, S. M., Warnant R., Stegen K. (2009)
Trans-ionospheric GPS signal delay gradients observed over mid-latitude Europe during the geomagnetic storms of October-November 2003.
Adv. Space Research, Vol. 43, pp. 1314-1324, doi:10.1016/j.asr.2008.12.012.

[28] Stankov, S. M., Warnant R. (2009)
Ionospheric slab thickness - analysis, modelling and monitoring.
Advances in Space Research, Vol.44, No.11, pp.1295-1303, doi:10.1016/j.asr.2009.07.010.

[29] Strangeways, H.J., I. Kutiev, L. R. Cander, S. Kouris, V. Gherm, D. Marin, B. De La Morena, S. E. Pryse, L. Perrone, M. Pietrella, S. M. Stankov, L. Tomasik, E. Tulunay, Y. Tulunay, N. Zernov, B. Zolesi (2009):
Near-Earth space plasma modelling and forecasting.
Annals of Geophysics, Vol.52, No.3-4, pp.255-271.

[30] Torres J.A., Altamimi Z., Boucher C., Brockmann E., Bruyninx C., Caporali A., Gurtner W., Habrich H., Hornik H., Ihde J., Kenyeres A., Mäkinen J., van der Marel H., Seeger H., Simek J., Stangl G., Weber G.
Status of the European Reference Frame (EUREF)
“Observing our Changing Earth”, IAG Symposia Series, Vol. 133, pp. 47-56, DOI: 10.1007/978-3-540-85426-5

[31] A. Vuiets, P. Leontiev
The filtering algorithm of solar wind spatial images
New Technologies Volume 1, pp. 23-73 (2009) (in Russian)

[32] Warnant R., Foelsche U., Aquino M., Bidaine B., Gherm V., Hoque M. M., Kutiev I., Lejeune S., Luntama J.-P., Spits J., Strangeways H. J., Wautelet G., Zernov N., Jakowski N. (2009)
Mitigation of ionospheric effects on GNSS
Annals of Geoph., Vol. 52, 3/4, pp. 373-390.

[33] Zhukov A. N., Rodriguez L., de Patoul J.
STEREO/SECCHI Observations on December 8, 2007: Evidence against the Freely Propagating Wave Hypothesis of the EIT Wave Origin
Solar Physics, 259, 73–85 (2009)

2. Publications without peer review

[34] Asmar W. S. and more than 10 authors, including Dehant V., Karatekin Ö., Rosenblatt P., and Van Hoolst T.
Planetary Radio Science: Investigations of Interiors, Surfaces, Atmospheres, Rings, and Environments
Planetary Science Decadal Survey Community White Paper, 8 p, available on the web

[35] Baire Q., Defraigne P., Aerts W.
Combining Single Differences of GPS and GLONASS data for Time and Frequency Transfer
Proc. 2nd colloquium Scientific and Fundamental Aspects of the Galileo Programme, CD-rom, 2009

[36] Baire Q., Defraigne P., Pottiaux E.
Influence of Troposphere in PPP Time Transfer
Proc. EFTF-IFCS, 2009

[37] Bruyninx C., Bergeot N., Legrand J., Pottiaux E.
Moving the EPN from a GPS-only to Multi-GNSS Network: Challenges and Pitfalls
Proc. of 2nd International Colloquium - Scientific and Fundamental Aspects of the Galileo Programme, October 2009, Padua, Italy (on CD)

[38] Bruyninx C., Roosbeek F.
EPN Status and New Developments
Mitteilungen des BKG, Band 42, EUREF Publication No. 17, Ed. BKG, Frankfurt am Main, pp. 71-81

[39] Bidaine B., Warnant R.
Measuring Total Electron Content with GNSS : investigation of two different techniques.
Proceedings of "Ionospheric Radio Systems & Techniques" [CD-Rom], Edinburgh, 28 April – 1 May 2009.

[40] Bidaine B., Warnant R.
Ionosphere modelling based on the NeQuick model and GNSS data ingestion.
Proceedings of the Second International Colloquium - Scientific and Fundamental Aspects of the Galileo Programme [CD-Rom], Padoue, Italie, 14-16 October 2009.

[41] Dehant V., Folkner W., Chicarro A., and the LaRa team and the SDT of Mars-NEXT
Rotation and internal dynamics from future geodesy experiment
Proc. Journées Systèmes de Référence Spatio-temporels, Dresden, Germany, 21-23 September 2008, pp. 135-136

[42] Defraigne P., Martinez M.C., Jiang Z.
Time transfer from combined analysis of GPS and TWSTFT data,
Proc. of the 40th PTTI 2008, 1st -4th December 2008, Reston, Virginia, USA

[43] Defraigne P., Pireaux S.
Ionospheric perturbations in GNSS time transfer
Proc. 2nd colloquium Scientific and Fundamental Aspects of the Galileo Programme, CD-rom, 2009

[44] Defraigne P., Pireaux S.
Ionospheric perturbations in GNSS time transfer
Proc. 2nd colloquium Scientific and Fundamental Aspects of the Galileo Programme, CD-rom, 2009

[45] E. D'Huys, B. Nicula, C. Marqué, D. Berghmans
Visualization of distributed solar data and metadata with the Solar Weather Browser

Space Climate Symposium 3, Saariselkä, Finland, Poster presentation, March 18-22, 2009.

[46] E. D'Huys, B. Nicula, C. Marqué, D. Berghmans
Visualization of distributed solar data and metadata with the Solar Weather Browser
Space Weather Workshop, Poster and live demonstration, Boulder, Colorado, April 27-30, 2009

[47] E. D'Huys, B. Nicula, C. Marqué, D. Berghmans
Visualization of distributed solar data and metadata with the Solar Weather Browser
Sixth European Space Weather Week, Poster presentation, Brugge, Belgium, November 16-20.

[48] B. Giordanengo, A. BenMoussa, J.-F. Hochedez, A. Soltani, P. de Moor, K. Minoglou, P. Malinowski, J.-Y. Duboz, Y.M. Chong, Y.S. Zou, W.J. Zhang, S.T. Lee, R. Dahal, J. Li, J.Y. Lin and H.X. Jiang.
Recent ROB developments on wide bandgap based UV sensors
Astrophysics Detector Workshop 2008. EAS Publications Series, 37 (2009) 199-205

[49] Ihde J., Bruyninx C., Söhne W., Weber G.
Evolution of the EPN resources toward real-time GNSS
Proc. Int. Symp. on GNSS, Space-Based and Ground-Based Augmentation Systems and Applications, Berlin, 30 Nov-2 Dec 2009, Germany, pp 44-45

[50] Martinez-Belda M.C., Defraigne P.
Combination of GPS and TWSTFT data for time and frequency transfer
Proc. EFTF-IFCS, 2009

[51] C. Marqué, F. Clette
Solar radio astronomy, global change and space weather
CRAF Newsletter, No. 20, December 2009

[52] Pireaux S., Defraigne P., Bergeot N., Baire Q., Bruyninx C.
Influence of Ionosphere Perturbations in GPS Time and Frequency Transfer
40th Annual PTTI Systems and Applications Meeting Proc., 2008

[53] Pireaux S., Defraigne P., Wauters L., Bergeot N., Baire Q., Bruyninx C.
Higher order ionosphere perturbations in GPS time and frequency transfer
Proc. EFTF-IFCS 2009

[54] Spits J., Warnant R.
Total Electron Content monitoring using triple frequency GNSS: results with GIOVE-A data.
Proceedings of the Second International Colloquium - Scientific and Fundamental Aspects of the Galileo Programme [CD-Rom], Padoue, Italie, 14-16 October 2009.

[55] Stankov, S. M., R. Warnant, R. Kozarev
On the TEC short-term forecast with corrections based on the average ionospheric response to background and storm-time geomagnetic conditions.
Geophysical Research Abstracts, vol.11 (Proc. EGU General Assembly, 19-24 Apr 2009, Vienna, Austria), Abs.No. EGU09-13283.

[56] Stankov, S. M., R. Warnant, K. Stegen
Local ionospheric electron density reconstruction from simultaneous ground-based GNSS and ionosonde measurements.
Geophysical Research Abstracts, vol.11 (Proc. EGU General Assembly, 19-24 Apr 2009, Vienna, Austria), Abs.No. EGU09-10956.

[57] P. Vanlommel, R. Van der Linden, L. Wauters and S. Willems
10.7cm Solar Flux: Forecast Verification
Space Climate Symposium 3, Saariselkä, Finland, Poster presentation, March 18-22, 2009.

[58] Wautelet G., Lejeune S., Warnant R.
Effects of ionospheric small-scale structures on GNSS.
Proceedings of "Ionospheric Radio Systems & Techniques" [CD-Rom], Edinburgh, 28 April – 1 May 2009.

[59] L. Wauters, R. Van der Linden, D. Berghmans, S. Willems, P. Vanlommel, E. D'Huys
Solar Sub-cycles
Space Climate Symposium 3, Saariselkä, Finland, Poster presentation, March 18-22, 2009

[60] SIDC team
Provisional sunspot numbers, Monthly solar indices, Monthly Summary of Solar and Geomagnetic activity
SIDC sunspot bulletin (12 monthly issues)

[61] SIDC team
Definitive sunpot numbers
SIDC-News (4 quarterly issues)

3. Publications in press, submitted

[62] Andert T.P., Rosenblatt P., Pätzold M., Häusler B., Dehant V., Tyler G.L., and Marty J.C.
Mass, Density and Porosity of Phobos
Geophys. Res. Letters, accepted.

[63] Baire Q., Bruyninx C., Defraigne P., Legrand J.
Precise Point Positioning with ATOMIUM using IGS Orbit and Clock Products : First Results
Submitted to Bulletin of Geodesy and Geomatics

[64] H. A. Barkad, A. Soltani, M. Rousseau, B. Benbakhti, J.-C. De Jaeger, A. BenMoussa, J.-F. Hochedez and E. Monroy
Modeling, Fabrication and Measurement of AlN based Photodetectors
Diamond and Related Materials (2010) in press

[65] Bergeot N., Bruyninx C., Pottiaux E., Pireaux S., Defraigne P., Legrand J.
Detection of abnormal ionospheric activity from the EPN and impact on kinematic GPS positioning
Proc. EUREF 2008 Symposium, June 2008, Brussels, Belgium, in press

[66] Bergeot N., C. Bruyninx, P. Defraigne, S. Pireaux, J. Legrand, E. Pottiaux, Q. Baire
Impact of the Halloween 2003 Ionospheric Storm on Kinematic GPS Positioning in Europe
Submitted to GPS solutions

[67] Bergeot N., Bruyninx C., Pireaux S., Defraigne P., Legrand J., Baire Q., Pottiaux E.
Using the EUREF Permanent Network to Monitor the Ionosphere
Proc. EUREF 2009 Symposium, 27-30 May 2009, Florence, Italy

[68] Bidaine B., Warnant R. (2010)
Ionosphere modeling based on the NeQuick model and GNSS data ingestion.
Submitted to Adv. Space Research.

[69] Bruyninx C., Habrich H., Söhne W., Kenyeres A., Stangl G., Völksen C.
Enhancement of the EUREF Permanent Network Services and Products
IAG Symposia Series, accepted

[70] Bruyninx C., Legrand J., Roosbeek F.
Status and Performance of the EUREF Permanent Tracking Network
Proc. EUREF 2008 Symposium, June 2008, Brussels, Belgium, in press

[71] Bruyninx C., Legrand J., Roosbeek F.

EPN Status and Network Management
Proc. EUREF 2009 Symposium, 27-30 May 2009, Florence, Italy

[72] Burston R., Astin I., Mitchell C., Alfonsi L., Pedersen T. and Skone S.
Turbulent Times in the Northern Polar Ionosphere?
Journal of Geophysical Research-Space Physics, in press

[73] Chicarro A., Breuer D., Chassefière E., Dehant V., Grady M., Pinet P., Rossi A.
Scientific and technical aspects of the ESA MarsNEXT mission
Advances in Geosciences, Proc. AOGS meeting, submitted.

[74] Chicarro A., Breuer D., Chassefiere E., Dehant V., Grady M., Pinet P., Rossi A.
Scientific and technical aspects of the ESA MarsNEXT mission
Advances in Geosciences, Proc. AOGS meeting, submitted.

[75] Clette, F., 2010
Past and future sunspot indices: new goals for SoTerIA
J. Atmos. Solar-Terrestr. Phys., in press

[76] Dolla L., Zhukov A. N.
On the Nature of the Spectral Line Broadening in Solar Coronal Dimmings
Astrophysical Journal (submitted 2009)

[77] Issler J.-L., Tawk Y., Jovanovic A., Botteron C., Farine P.-A., Landry R. Jr., Sahmoudi M., Dehant V.
Contribution to the worldwide multimodal SBAS standard
In: Proc. Workshop GNSS Standards, Joint Meeting ESA, DLR and UniBwM of Munich, submitted.

[78] L. Jalabert, T. Sato, M. Kumemura, D. Bolsee, C. Hermans, A. BenMoussa, H. Fujita.
Embedding vertical nanosheets into PDMS with a reusable template engineering
Proc. 23rd IEEE International Conference on Micro Electro Mechanical Systems (MEMS 2010), Hong-Kong 24-28 January 2010.

[79] Jonson Jan Eiof, A. Stohl, M.M. Fiore, P. Hess, S. Szopa, O. Wild, G. Zeng, F.J. Dentener, A. Lupu, M.G. Schulz, B.N. Duncan, K. Sudo, P. Wind, M. Schultz, E. Marmer, C. Cuvelier, T.J. Keating, A. Zuber, A. Valdebenito, V. Dorokhov, H. De Backer, J. Davies, G.H. Chen, B. Johnson an D.W. Tarasick
A multi-model analysis of vertical ozone profiles
Atmos. Chem. Phys, submitted, 2009(now already in ACP-D, 9, 26095-26142, 2009)

[80] N. F. Kleimeie, T. Haarlammert, H. Witte, U. Schühle, J-F Hochedez, A. BenMoussa and H. Zacharias.
Autocorrelation and phase retrieval in the UV using two-photon absorption in diamond pin photodiodes
Submitted in Optics express

[81] Lejeune S., Wautelet G., Warnant R.
Ionospheric effects on single-epoch GNSS relative positioning: a network approach.
Submitted to GPS Solution.

[82] Magdalenić J., Marqué C., Zhukov A. N., Vršnak B., Žic T.
Origin of Coronal Shock Waves Associated with Slow Coronal Mass Ejections
Astrophysical Journal (submitted 2009)

[83] Martinez M.-C., P. Defraigne,
Combination of TWSTFT and GPS data for time transfer

Metrologia, submitted

[84] Mierla M., Inhester B., Antunes A., Boursier Y., Byrne J. P., Colaninno R., Davila J., de Koning C. A., Gallagher P. T., Gissot S., Howard R. A., Howard T. A., Kramar M., Lamy P., Liewer P. C., Maloney S., Marqué C., McAteer R. T. J., Moran T., Rodriguez L., Srivastava N., St. Cyr O. C., Stenborg G., Temmer M., Thernisien A., Vourlidas A., West M. J., Wood B. E., Zhukov A. N.
On the 3-D Reconstruction of Coronal Mass Ejections Using Coronagraph Data
Annales Geophysicae (in press 2009)

[85] Mocquet A., Rosenblatt P., Dehant V., Verhoeven O.
The deep interior of Venus, Mars, and the Earth: a brief review and the need for surface-based measurements
In: Proc. ESLAB 2009, Planet. Space Sci., accepted

[86] Nkono C., Rosenblatt P., Dehant V., A. Zhokov, Mitrovic M., Bird M., Le Maistre S.
Quantification of Solar Corona effects on Radio Frequency waves using radial profiles of electron density
IEEE, submitted

[87] Pham L.B.S., Karatekin Ö., Dehant V.
Effects of impacts on the atmospheric evolution: comparison between Mars, Earth and Venus
Planet. Space Sci., submitted

[88] Pottiaux E.
Detecting small-scale Tropospheric Phenomena Using GNSS Observations from Dense National Networks
Proc. of the EUREF 2008 Symposium, July 2008, Brussels, Belgium, in press

[89] Spits J., Warnant R.
Total Electron Content Monitoring using triple frequency GNSS: results with Giove-A/-B data.
Submitted to Adv. Space Research.

[90] Staiger Henning, J. Kaurola and H. De Backer
Merged daily gridded European fields of bias corrected ERA-40 and solar cloud modification factorsderived from pyranometer observations
J. Geophys. Res, submitted, 2009.

[91] Van Malderen Roeland and De Backer H.
A drop in upper-tropospheric humidity in autumn 2001, as derived from radiosonde measurements at Uccle, Belgium
Journal of Geophysical Research, submitted, 2009

[92] Zhukov A. N., West M. J., Rodriguez L., Veselovsky I. S.
First STEREO Observations of an EIT Wave from Two Widely Separated Viewpoints
Astronomy & Astrophysics (submitted 2009)

4. Reports, etc

[93] Asma C. O. and QUBENET team, including Aerts W., Bergeot N., Bruyninx C., Burston R.
A Network of Cubesats to Study Space Weather related Phenomena in the Upper Atmosphere: QUBENET
Reply to FP7-SPA.2010.2.3-01 “Security of space assets from space weather events” call, 76 pages

[94] H. A. BARKAD
Conception et Réalisation de photodetecteurs X-UV a base de semiconducteurs a large bande interdite destines a des applications spatiales

Thesis from University of « Sciences et Technologies de Lille spécialité Micro et Nanotechnologies, Acoustique et Télécommunication », December 2009

[95] Bastos L. and PLEGG team, including Bruyninx C.
Platform for European GNSS and other Geo-products: PLEGG
Reply to FP7- INFRA-2010-1.2.3 “Virtual Research Communities” call, 171 pages

[96] A. BenMoussa et al. (+DWG contribution)
EUI detectors specifications V4.3
Technical Report

[97] A. BenMoussa et al. (+DWG contribution)
EUI Detector Requirements
Technical Report

[98] A. BenMoussa and B. Giordanengo
CNES_CMOS_Worshop_report_ROB_22-12-2009.doc
Technical Report

[99] J. Broche,
La meteo du soleil informatisee
Rapport de Stage effectué à l’Observatoire royale de Belgique

[100] Burston R.
Investigating Ionospheric Scintillation Mechanisms via Theory and Experimentation
PhD Thesis, University of Bath Library

[101] Chevalier J.M., promotors: Bruyninx C., Legrand J., Bergeot N, Gallagher K.
Feasibility Study of Ionospheric Tomography based on GNSS Observations over Europe
Final internship report of J.M Chevalier Master's degree

[102] Dehant V. and EMRAL team including Bruyninx C., Bergeot N., Pottiaux E
Atmospheric, ionospheric, and interplanetary plasma propagation corrections on Earth-Mars RAdio Link (EMRAL)
Reply to FP7-SPA.2010.2.1-03 “Exploitation of science and exploration data” call

[103] De Mazière Martine, K. Clémer, M. Kruglanski, F. Hendrickx, C. Hermans, M. Van Roozendael, C. Vigroux, H. De Backer, V. De Bock, A. Mangold, R. Van Malderen, M. Carleer, P.F. Coheur, S. Fally, J. Vander Auwera, E. Mahieu, P. Demoulin and P. Duchatelet
Advanced exploitation of Ground-based measurements for Atmospheric Chemiscty and Climate research
Final report, in press.

[104] E. D’Huys, P. Vanlommel
PROBA2: ruimteweer waarnemen met een Belgische satelliet
Documentatietekst voor leraren, 47 p

[105] JP Halain, A. BenMoussa, JF Hochedez, E. Pylyser et al.
SoW APSOLUTE
Statement of Work, Technical Report

[106] Lytinska Zenobia, P. Koepke, H. De Backer, J. Groebner, A. Schmalwieser and L. Vuilleumier
Long term changes and climatology of UV radiation over Europe
Final report of Cost action 726, in preparation.

[107] The RWC team
Outgoing messages from RWC Belgium: e.g. 365 daily ursigrams, 52 weekly bulletins, 4 quarterly bulletins, 12 Monthly Ri Reports, 12 Monthly Ri_hemispheric Reports, all-quiet-alerts, presto

alerts, halo CME alerts, GOES X-ray flare detection alert, reduced GPS accuracy alert, advance alert: enhanced geomagnetic activity warning.
E-mail distribution. The alerts are sent when needed, the other bulletins are sent on a regular basis

[108] Schueler T. and SX5 team including Bruyninx C., Legrand J.
Scientific Service Support based on GALILEO E5 Receivers: SX5
Reply to call FP7-GALILEO-2008-GSA-1, 117 pages

[109] Slemzin V., Bothmer V., Kuzin S., Urnov A., Bogachev S., Lapenta G., Skender M., Bettarini L., Innocenti M. E., Sylwester J., Temmer M., Veronig A., Otruba W., Berghmans D., Zhukov A., Seaton D., Marqué C., Magdalenić J., Rodriguez L., van Driel-Gesztelyi L., Török T., Vršnak B., Žic T.
Energy Release Through Flares and CMEs, Their Evolution and Geospace Impact Parameters for Special Events
SOTERIA WP3 online report

[110] R. Van der Linden and the SIDC team.
Annual report 2009 to the International Space Environment Service.
ISES Annual Report

[111] P. Vanlommel
The sixth European Space Weather Week: the final result
Work report

5. Meeting presentations

[112] Baire Q., Defraigne P., Aerts W.
Combining Single Differences of GPS and GLONASS data for Time and Frequency Transfer
2nd International Colloquium - Scientific and Fundamental Aspects of the Galileo Programme, COSPAR Colloquium, Oct. 14-16 2009, Padua, Italy

[113] Baire Q., Defraigne P., Pottiaux E.
Influence of Troposphere in PPP Time Transfer
European Frequency and Time Forum 2009, 20-24/04/2009, Besançon, France

[114] Baire Q., Bruyninx C., Defraigne P., Legrand J.
Precise Point Positioning with Atomium using IGS Orbit and Clock Products: First Results
EUREF 2009 Symposium, 27-30 May 2009, Florence, Italy

[115] A. BenMoussa
Recent development of wide band gap semiconductor based UV sensors
NIMIJ/AIST, 5-9/10/2009, Tsukuba, Japan

[116] A. BenMoussa et J-P Halain
Development of EUV imagers for EUI onboard Solar Orbiter
Solar Orbiter Detector Working Meeting, ESTEC, 12/06 2009

[117] Bergeot N., Bruyninx C., Pireaux S., Defraigne P., Legrand J., Baire Q., Pottiaux E.
Vertical Total Electron Content Maps Over Europe from EUREF Permanent Network GPS Data
Data EGU General Assembly 2009, April 19-24, 2009, Vienna, Austria (Geophysical Research Abstracts, Vol. 11, Abstract EGU2009-5654)

[118] Bergeot N., Bruyninx C., Pireaux S., Defraigne P., Legrand J., Baire Q., Pottiaux E.
Using the EUREF Permanent Network to Monitor the Ionosphere
EUREF 2009 Symposium, 27-30 May 2009, Florence, Italy

[119] D. Berghmans, E. D'Huys, D. Seaton

Space Weather tutorial 'from science to applications': quiz
ESWW6, Brussels, Belgium, November 16-20

[120] Bruyninx C., Legrand J., Bergeot N., Pottiaux E.
EPN Status, Monitoring and Network Management at the Central Bureau
EGU General Assembly 2009, April 19-24, 2009, Vienna, Austria (Geophysical Research Abstracts, Vol. 11, Abstract EGU2009-10088)

[121] Bruyninx C., Legrand J., Roosbeek F.
EPN Status and Network Management
EUREF 2009 Symposium, 27-30 May 2009, Florence, Italy

[122] Bruyninx C., Habrich H., Kenyeres A., Söhne W., Stangl G., Völksen C.
Enhancement of the EUREF Permanent Network Services and Products
IAG General Assembly 2009, Aug. 31-Sept.24 2009, Buenos Aires, Argentina

[123] Bruyninx C., Bergeot N., Legrand J., Pottiaux E.
Moving the EPN from a GPS-only to Multi-GNSS Network: Challenges and Pitfalls
2nd International Colloquium - Scientific and Fundamental Aspects of the Galileo Programme, COSPAR Colloquium, Oct. 14-16 2009, Padua, Italy

[124] Cerrato Y., Saiz E., Cid C., Aguado J., Aran A., Cremades H., Dasso S., Lathuillère C., Mandrini C., Menvielle M., Poedts S., Rodriguez L**.,** Sanahuja B., Schmieder B**.,** Zhukov A. N.
Halo CMEs far from central meridian: why are they geoeffective? (poster)
International Living With a Star (ILWS) conference 2009, Ubatuba, Brazil, October 4–9

[125] Chicarro A., Breuer D., Chassefière E., Dehant V., Fisackerly R., Grady M., Pinet P., Rossi A., and Santovincenzo A.
The Mars-NEXT mission: science and technical aspects
MarsExpress Science Working Team and Mars-NEXT Science Definition Team join meeting, ESA/ESTEC, 15 January 2009

[126] Cid C., Cerrato Y., Saiz E., Gonzalez W., Aguado J., Aran A., Cremades H., Dasso S., Lathuillère C., Mandrini C., Menvielle M., Poedts S., Rodriguez L., Sanahuja B., Schmieder B., Zhukov A. N.
Solar sources related to the largest Dst variations of solar cycle 23 (oral presentation)
International Living With a Star (ILWS) conference 2009, Ubatuba, Brazil, October 4–9

[127] Dasso S., Demoulin P., Gulisano A. M., Cremades H., Mandrini C. H., Schmieder B., Cid C., Cerrato Y., Saiz E., Rodriguez L., Zhukov A. N., Aran A., Menvielle M., Poedts S.
Expansion of magnetic clouds under different solar wind conditions (oral presentation)
Solar Wind 12 Conference, St. Malo, France, June 21–26

[128] De Bock Veerle and H. De Backer
Comparison of AOD values at 340nm from Brewer#178 and Cimel measurements at Uccle Belgium
WMO-GAW Brewer Users Group Meeting, Aosta, Italy, 20-26 September 2009

[129] Defraigne P.
Precise GNSS time and frequency transfer TUTORIAL (2h)
European Frequency and Time Forum 2009, 20-24/04/2009, Besançon, France

[130] Defraigne P.
GNSS time and frequency transfer at the highest precision level: review on the laboratory equipment
Meeting of the WG on TAI, Paris, June 2009

[131] Defraigne P.
Ionospheric perturbations in Time transfer

2nd International Colloquium - Scientific and Fundamental Aspects of the Galileo Programme, COSPAR Colloquium, Oct. 14-16 2009, Padua, Italy

[132] Defraigne P., Petit G., Uhrich P.
Requirements on GNSS receivers from the perspective of timing applications
2nd International Colloquium - Scientific and Fundamental Aspects of the Galileo Programme, COSPAR Colloquium, Oct. 14-16 2009, Padua, Italy

[133] Dehant V., Mitrovic M., Chicarro A.
Future radioscience missions with landers and orbiters to Mars; a study of the error budget
European Planetary Science Congress, EPSC2009, Potsdam, Germany, 14-18 September 2009

[134] E. D'Huys
PROBA2 Science Centre: commanding
Press conference: launch PROBA2, November 2

[135] Dolla, L., Solomon, J.
Solar off-limb line widths: Alfvén waves, ion-cyclotron waves, and preferential heating (poster)
Solar Wind 12 (Saint Malo, France), June 21–26

[136] Dolla, L., Solomon, J.
Solar off-limb line widths: Alfvén waves, ion-cyclotron waves, and preferential heating (oral presentation)
STEREO 3/SOHO 22 Conference (Bournemouth, United Kingdom), April 28th 2009

[137] Ihde J., Bruyninx C., Söhne W., Weber G.
Evolution of the EPN Resources towards real-time GNSS
International Symposium on Global Navigation Satellite Systems, Space-Based and Ground-Based Augmentation Systems and Applications, Nov. 30- Dec. 2 2009, Berlin, Germany

[138] Lombardi D., Camelbeeck T., Rapagnani G., Van Camp M., Bergeot N., Bruyninx C., Francis O., van Dam T.
Geodetic and Seismological Research at the new Princess Elisabeth Station, Queen Maud Land, East Antarctica
AGU 2009 Fall meeting, Dec 14-18 2009, San Francisco (AGU Abstract C43A-0495)

[139] Le Maistre S., Rosenblatt P., Dehant V., Marty J.C.
Study of the rotation of Mars through radioscience between lander/rover and the Earth
European Planetary Science Congress, EPSC2009, Potsdam, Germany, 14-18 September 2009

[140] Le Maistre S., Rosenblatt P., Dehant V., Marty J.C.
Simulations of Mars rotation radioscience observation and retrieval for a rover/lander on Mars
Session P15: 'Recent Results in Planetary Science and Their Impact on Future Science and Mission Priorities Sponsor: Planetary Sciences', AGU Fall Meeting, San Francisco, USA, December 14-18, 2009

[141] P. Leontiev, A. Vuets, V. Podladchikov, O. Podladchikova
NEMO Operational Developmnet
ESWW6, November 16-20, Brugge, Belgium Poster

[142] P. Lisnichenko, O. Podladchikova
NEMO EIT Wave catalogs
ESWW6, November 16-20, Brugge, Belgium, Poster

[143] Lombardi D., Camelbeeck Th., Rapagnani G., Van Camp M., Bergeot N., Bruyninx C., Francis O., van Dam T.

Geodetic and seismological research initiatives at the new Princess Elisabeth station, Queen Maud Land, East Antarctica
95th Journées Luxembourgeoises de Géodynamique, Nov. 9-11, 2009, Echternach, G.-d. Luxembourg

[144] Matrinez-Belda M.C., Defraigne P.
Combination of GPS and TWSTFT data for time and frequency transfer
European Frequency and Time Forum 2009, 20-24/04/2009, Besançon, France

[145] C. Marqué, F. Clette
Solar radio astronomy and global change (talk)
48th CRAF meeting, Paris observatory, May 14th 2009

[146] C. Marqué, C. Monstein
RFI monitoring with CALLISTO (talk)
48th CRAF meeting, Paris Observatory, May 14th 2009

[147] C. Marqué, F. Clette, J.-L. Dufond, A. Ergen, J. Magdalenić, B. Dabrowski
Solar radio observations in Belgium (talk)
2nd LOFAR KSP workshop, June 24-25 2009

[148] C. Marqué, F. Clette, J.-L. Dufond, A. Ergen
Radio solar flux measurements in Belgium (Poster)
6th European Space Weather Week, Bruges, November 16th-18

[149] Mierla M., Inhester B., Marqué C., Rodriguez L., Gissot S., Zhukov A. N., Berghmans D., Davila J.
On 3D reconstruction of coronal mass ejections using SECCHI-COR data (poster)
European Geosciences Union (EGU) General Assembly 2009, Vienna, Austria, April 19–24

[150] Mitrovic M. and Dehant V.
Error budget on radioscience transponder on Mars for future mission
Session P15: 'Recent Results in Planetary Science and Their Impact on Future Science and Mission Priorities Sponsor: Planetary Sciences', AGU Fall Meeting, San Francisco, USA, December 14-18, 2009

[151] Nkono C., Rosenblatt P., Dehant V.
Solar Corona and plasma effects on Radio Frequency waves
Session P15: 'Recent Results in Planetary Science and Their Impact on Future Science and Mission Priorities Sponsor: Planetary Sciences', AGU Fall Meeting, San Francisco, USA, December 14-18, 2009

[152] Parenti S., Zhukov A. N., Auchère F., Teriaca L., Hochedez J.-F., Harra L., Golub L., Klimchuk J. A., Reale F.
Observing the hot coronal plasma with the EUI/HRI on board Solar Orbiter (poster)
3rd Solar Orbiter Workshop, Sorrento, Italy, May 25–29

[153] Pireaux S., Defraigne P., Wauters L., Bergeot N., Baire Q., Bruyninx C.
Higher-order ionosphere perturbations in GPS time and frequency transfer
European Frequency and Time Forum 2009, 20-24/04/2009, Besançon, France

[154] O. Podladchikova
Coronal Wave Height Definition
European Geophysical Union, (EGU-2007), April 24, Vienna, Austria – Invited

[155] O. Podladchikova
3D Parameters reconstruction for diffusive objects Observed with STEREO

SOHO/STEREO consortium meeting, April 28, Bournemouth, UK – Invited

[156] O. Podladchikova
Driving Scales for Coronal Heating
“Solar Wind” general meeting, June 28, Saint-Malo, Poster

[157] O. Podladchikova
EIT Wave Observations with STEREO
“Solar Wind” general meeting, June 28, Saint-Malo, Poster

[158] Pottiaux E., de Haan S., Legrand J., Bruyninx C.
Dense GNSS Networks to Access Fine Structures in the Troposphere
EGU General Assembly 2009, April 19-24, 2009, Vienna, Austria (Geophysical Research Abstracts, Vol. 11, Abstract EGU2009-4453)

[159] Pottiaux E.
E-GVAP II Analysis Centre Report: Royal Observatory of Belgium
E-GVAP II Joint Expert Team Meeting - November 16, 2009, De Bilt, The Netherlands

[160] Rodriguez L., Zhukov A. N., West M., Kilpua E., Mierla M.
Linking CMEs observed by STEREO with their interplanetary counterparts (poster)
Solar Wind 12 Conference, St. Malo, France, June 21–26

[161] Rodriguez L., Zhukov A. N., Gissot S., Mierla M.
Three-dimensional reconstruction of active regions (poster)
European Geosciences Union (EGU) General Assembly 2009, Vienna, Austria, April 19–24

[162] Rosenblatt P., Mocquet A., and Dehant V.
Assessing the structure of planetary interiors from satellite and ground-based geophysical data: A comparative study
ESLAB 2009, International Conference on Comparative Planetology Venus-Earth-Mars, solicited paper, ESTEC - Noordwijk, The Netherlands, 11-15 May 2009

[163] Rosenblatt P., Le Maistre S., Dehant V., Bruinsma S., Mueller-Wodarg I. (VExADE team)
VEX drag experiment (VExADE) results from drag-1 and drag-2 campaigns
VeRa team meeting, Brussels, Belgium, November 10, 2009

[164] Rosenblatt P., Beuthe M., Le Maistre S., Dehant V., Marty J.C.
Status on VEX gravity from VExADE campaign#2
VeRa team meeting, Brussels, Belgium, November 10, 2009

[165] Stankov S**.,** Warnant R**.,** Stegen K. (2009)
Iono slab monitoring service.
Presented at the International GBAS Working Group Meeting (IGWG-8), 3-6 March 2009, Palermo.

[166] Stankov S., Warnant R., Stegen K., Lejeune S., Wautelet G., Spits J., Brenot H. (2009)
Local ionospheric activity – nowcast and forecast services.
Presented at LATO-15 meeting, Brussels, 16-18 June 2009.

[167] Vanhoenacker-Janvier Daniele, C. Oestges, B. Montenegro-Villacieros, R. Van Malderen, and H. De Backer
Scintillation prediction using improved pre-processed radiosounding data
3rd European Conference on Antennas and Propagation (EUCAP), Berlin, Germany, 23-27 March 2009

[168] Van Malderen Roeland, H. De Backer, and A. Delcloo
Revision of 40 years of ozone measurements in Uccle, Belgium

EGU 2009, Vienna, Austria, 19 – 24 April 2009

[169] Van Malderen Roeland and H. De Backer
Analysis of the upper-tropospheric humidity trend from radiosondes at Uccle, Belgium
WaVaCs Workshop, Schliersee, Germany, 17 – 19 June 2009

[170] Van Malderen Roeland and H. De Backer
Analysis of the upper tropospheric humidity trend from radiosondes at Uccle
MOCA-09, the IAMAS-IAPSO-IACS Joint Assembly on "Our warming planet", Montréal, Canada, 19-29 July 2009

[171] Van Malderen Roeland and H. De Backer
A drop in UT humidity in Autumn 2001, as derived from radiosonde measurements at Uccle, Belgium
Cargese International School on "Water Vapour in the Climate System", Cargèse, France, 14 – 26 September 2009

[172] R. Van der Linden
Annual RWC report
ISES annual meeting, Boulder, Colorado, April, 2009

[173] R. Van der Linden, P. Vanlommel
The Solar-Terrestrial Centre of Excellence: Building Sun-Earth know-how in Belgium and beyond
Directors Committee BELSPO, Brussels, Belgium, September 18, 2009

[174] R. Van der Linden, L. Wauters, P. Vanlommel
User Feed back and Performance Metrics
Workshop 'Forecasting the All-Clear', Boulder, Colorado, April 22-24, 2009

[175] P. Vanlommel
Ruimteweervoorspeller in 60 minuten
Student Workshop KULeuven, March 10

[176] P. Vanlommel
Space Weather Prediction Centre: SWAP-LYRA applications
Press conference: launch PROBA2, November 2

[177] Verdini A., Hochedez J.-F., Zhukov A. N.
Possible synergies between the Extreme Ultraviolet Imager onboard Solar Orbiter and the Solar Probe Plus mission (poster)
3rd Solar Orbiter Workshop, Sorrento, Italy, May 25–29

[178] Wautelet G., Lejeune S., Lonchay M., Warnant R. (2009)
Influence of Geometry in the Case of Relative Positioning
Presented at Sixth European Space Weather Week (ESWW6), Gent, Belgium, 16-20 November 2009.

[179] West M. J., Zhukov A. N., Rodriguez L.
STEREO and SOHO observations of white light CME shock formation (poster)
STEREO-3/SOHO-22 Workshop, Bournemouth, England, April 27–May 1

[180] Zhukov A. N.
Solar coronal mass ejection observations in the EUV (oral presentation)
Seminar at Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia, December 29

6. Public Outreach publications

[181] O. Podladhikova
Introduction to Solar Physics
AACIMP-09 (SOC member), 6-15 August, Kiev, Ukraine – Invited Tutorial

[182] S. Raynal and R. Van der Linden
Sixth European Space Weather Week: press release
http://www.sidc.be/news/117/pressrelease_end_esww6.pdf, Nov 13, 2009.

[183] P. Vanlommel
Visit of the godfather of the solar wind, E. Parker
http://www.sidc.be/news/110/welcome.html, February 10, 2009.

[184] P. Vanlommel
Solar radio silence ended
http://www.sidc.be/news/111/welcome.html, May 08, 2009.

[185] P. Vanlommel, the PROBA2 Science Centre and Verhaert Space
Belgium on its way to space: PROBA2 packed
http://www.sidc.be/news/112/welcome.html, July 01, 2009.

[186] P. Vanlommel and the SIDC team
Where to find sunspot data
http://www.sidc.be/news/113/welcome.html, July 31, 2009.

[187] P. Vanlommel
The European Space Weather Week
http://www.sidc.be/news/114/welcome.html, September 10, 2009.

[188] P. Vanlommel and the PROBA2 Science Centre
Launch PROBA2: eyes focused on the Sun and Space Weather
http://www.sidc.be/news/115/launchPROBA2.pdf, October 27, 2009.

[189] P. Vanlommel
Debate: Space Weather and the Earth's Climate
http://www.sidc.be/news/116/welcome.html, Nov 09, 2009.

[190] P. Vanlommel and the SIDC team
The Sun is NOT dead/De Zon is NIET dood
http://www.sidc.be/news/118/minimum_eng.pdf, http://www.sidc.be/news/118/minimum_ned.pdf, Nov 09, 2009.

[191] P. Vanlommel
The Fingerprint of the New Solar Cycle
http://www.sidc.be/news/119/welcome.html, Dec 14, 2009.

7. Press releases

[192] The PROBA2 consortium
Technology-testing PROBA2 opens new eye on the Sun
(English, Dutch, French) January 26, 2010

[193] S. Raynal and R. Van der Linden
Sixth Eropean Space Weather Week: press release
Nov 13, 2009

[194] P. Vanlommel and the PROBA2 Science Centre, French translation by S. Raynal

Belgium on its way to space: PROBA2 packed
June 30, 2009

[195] P. Vanlommel and the PROBA2 Science Centre, French translation by S. Raynal
PROBA2 launch: Eyes focused on the Sun and Space Weather
(English, Dutch, French) October 26, 2009

8. Publications in popular journals

[196] P. Vanlommel and the PROBA2 Science Centre, French translation by S. Raynal
PROBA2: les scientifiques belges garden un oeil sur le soleil – Belgische wetenschappers zetten de Zon in haar blootje
Science Connection, nr 29, publicatie van april-mei 2010

[197] P. Vanlommel, E. D'Huys and the PROBA2 Science Centre, French translation by S. Raynal
De Koninklijke Sterrenwacht van België aan boord van PROBA2 – een blik op de toekomst
Submitted to Science Connection