Anna Belehaki
National Observatory of Athens, Greece

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Abstract
COST Action ES0803 “Developing Space Weather Products and Services in Europe” is primarily aimed at forming an interdisciplinary network between European scientists dealing with different issues relevant to Geospace as well as warning system developers and operators in order to assess existing space weather products and recommend new ones. This talk summarises the final achievements after four years of successful implementation, such as advances in modelling and predicting space weather, validation and demonstration of selected key models, recommendations for new space weather products and services, dissemination, training and outreach activities.

1. Introduction

"Space Weather" as a scientific term became widely used near the end of the 20th century. A definition of the discipline that was developed and adopted by the European COST Action 724 states that "Space Weather is the physical and phenomenological state of the natural space environments. The associated discipline aims, through observation, monitoring, analysis and modeling, at understanding and predicting the state of the sun, the interplanetary and planetary environments, and the solar and non-solar driven perturbations that affect them; and also at forecasting and nowcasting the possible impacts on biological and technological systems" (Lilensten and Belehaki, 2009).

The effects of Space Weather on several of the modern technology infrastructures on which we rely together with their impact on humans in air and space have been the subject of world-wide scientific and technical consideration for more than ten years. These effects cover a broad range of sectors such as radio communication problems, effects on synthetic aperture radar systems, GPS and the future European Galileo systems, aircraft crew and passenger radiation risks etc. Electric power network disturbances and enhanced corrosion effects observed in long-distance fuel supply pipelines are well known effects of unfavorable Space Weather. In severe cases, large scale power outages have also been traced back to Space Weather phenomena. This further stresses the importance of this interdisciplinary issue not only for the space sector, but also for the reliable operation of ground based infrastructures. Research efforts in various countries, including the U.S. multi-agency National Space Weather Program and several European initiatives sponsored by the European Space Agency (ESA), the European Commission (EC) and the International Space Environment Service (ISES) have demonstrated that:

- Adverse Space Weather poses a non-negligible threat to humans and modern technological systems and assets on the ground, in the air and in space,
- Methods to model some aspects of space weather have been developed, although their performance needs to be improved,
- Prediction of the behavior of various Space Weather related physical parameters is possible and has in some cases indeed been achieved. However,

for many of these physical parameters the prediction accuracy is insufficient to allow the transition into reliable operational services and so targeted research and development is needed to address this issue.

To meet further advances, COST Action ES0803 formed an interdisciplinary network between model developers in Europe, warning system developers, operators, users and policy makers. Through this network the Action aims to support further advances for the development of space weather prediction systems that meet the requirements of the users and to aware and educate the broader public about the implications that adverse space weather phenomena can cause in our daily life (Belehaki et al., 2009).

These objectives have been carried out in the frames of the Action ES0803 within the last 4 years (2008 - 2012) with the active participation of more than 80 experts from 24 countries. This paper reports the main scientific results obtained from this Action in three action lines a) advances in space weather models b) recommendations for new space weather products and services c) dissemination, education and outreach activities. In the final section, we summarize the main achievements that may have a future impact in the European space weather community and we present some plans for the future.

2. Space Weather Prediction models in Europe

This activity has as the main objective to compile and analyse the recent advances in the field of space weather modeling, to make recommendations for the assessment and validation of prediction models and to simulate further upgrades of the models in order to be implemented in an operational environment.

i. Advances in space weather modeling

Recent advances on solar dynamics (the origin of space weather), space plasma processes (the transmission process) and long-term variability of the Sun, interplanetary space and geospace (the medium which moderates it) have been compiled and analyzed for a successful description, nowcasting and forecasting of the state of the space environment and of specific Space Weather events.

Zuccarello et al. (2012) have reviewed the state of the art of our comprehension of phenomena occurring in the solar atmosphere that are due to the solar magnetism and are the basis of the space weather. The review includes combined multi-disciplinary, multi-instrument, multi-wavelength studies of these phenomena, starting from the very first manifestation of solar active region formation and evolution, to the analysis of explosive phenomena (i.e., flares, erupting prominences, coronal mass ejections), till the study of the interaction of plasma magnetized clouds expelled from the Sun with the interplanetary magnetic field and medium.

The group of Saiz et al. (2012) focused their review on the geomagnetic response to solar and interplanetary disturbances. Following an analysis of their long-term evolution, they discuss short-term responses, where they distinguish between responses of the terrestrial environment to solar activity (and specifically to solar energetic events) and to the solar wind. Geomagnetic responses at low and high latitudes are considered separately. At low latitudes, the evolution of the ring current in both the main and recovery phases is analysed. At high latitudes, achievements in modelling the coupling between magnetospheric and ionospheric processes are studied, with special attention to the polar caps and field-aligned currents.

The impact of solar activity on the Earth’s upper atmosphere has been studied by Kutiev at al. (2012a). This review is focused on methods based on data-driven analysis. Medium- and long-term ionospheric response to the changes in solar and geomagnetic activity contains results on 27-day response of low latitude ionosphere to solar EUV radiation, response to the recurrent geomagnetic storms, long-term trends in the upper atmosphere, latitudinal dependence of total electron content (TEC) to EUV changes, and statistical analysis of ionospheric behavior during prolonged period of solar activity. Storm-time ionospheric response to the solar and geomagnetic forcing contains results from studies of ionospheric variations induced by recurrent CIR-driven storm, a case-study of polar cap absorption due to an intense CME, and a statistical study of geographic distribution of the so called E-layer dominated ionosphere. Empirical models for forecasting bottomside ionospheric parameters, the electron density and the total electron content are reviewed. A new method for the retrieval of the basic thermospheric parameters from ionospheric sounding data is also presented. The detection, monitoring and forecast of ionospheric perturbations in Europe to support GNSS systems has been also reviewed and further studied by Jakowski et al. (2012).

Moen et al. (2012) have focused their work on the study of phenomena in the polar cap ionosphere and the effects on space weather. The main part of the work has been directed towards the study of plasma instabilities and scintillations in association with cusp flow channels and polar cap patches, which is considered as critical knowledge in order to develop forecast models for scintillations in the polar cap. The problem has been approached by multi-instrument techniques that comprise the EISCAT Svalbard Radar, SuperDARN radars, in-situ rocket measurements, and GPS scintillation measurements.

Finally, the impact of cosmic rays and solar energetic particles on the Earth's environment has been studied by Velinov et al. (2012), with emphasis on numerical models that compute the cosmic ray ionization profiles at a given location and time. Intercomparison of the models, as well as comparison with direct rocket measurements of the atmospheric ionization, validates their applicability for the entire atmosphere and for the different levels of the solar activity.

ii. Assessment and validation of existing Space Weather research and operational models

The assessment requires the development of criteria and metrics which can objectively be applied to judge the performance of the models. Strengths and weaknesses include (but are not limited to) the quantitative accuracy of the model results, the weight of constraints on input parameters and boundary conditions, the validity range of the model, the spatial and temporal scales over which useful predictions are possible in case the models are predictive.

The first systematic effort to review assessment and validation efforts of space weather models made by European teams was held in the third workshop of the Action (Alcala, March 2011). A comprehensive report was compiled by Watermann (2011), where he summarised key issues from the three scientific sessions on (1) Interdisciplinary activities and validation approaches, (2) Space weather prediction and validation concepts, (3) Space weather research – models and model support activities. Following this first step, Wintoft et al. (2012) provided a recommended methodology that can be applied to any space weather model. Verification approaches described in their report are taken both from the meteorological and space weather communities. A survey of current space weather model verification has been carried out, with focus on models and algorithms developed by institutes participating in COST Action ES0803. The most common approach is to use one, or a few, metrics to verify the models. It is recommended that the more advanced approaches, like the distributions oriented, used in meteorology are also used for the space weather model verification.

iii. Stimulation of models' upgrades and of the development of reliable computer codes for predicting important Space Weather parameters

The assessment and validation of selected models led to stimulating the improvement of existing models to enable their implementation in an operational environment.

Tsagouri et al. (2012) summarised the outcome of this activity, including both the introduction of new models and the improvements to existing codes and algorithms that address the broad range of space weather's prediction requirements from the Sun to the Earth. For each case, the following have been considered: input data, output parameters, products or services, operational status of the model and whether it is supported by validation results, in order to provide a solid basis for future developments. The analysis concerns:

- Advances in solar weather predictions: solar activity prediction tools, near Real Time detection and tracking of Active Regions and Coronal Holes, Forecasting SEP Events
- Advances in Geomagnetic predictions: Warnings for geomagnetic disturbances, Nowcasting and forecasting the K index
- Advances in Satellite environments predictions: Specification of the electron density structure up to geosynchronous heights, Thermospheric monitoring, Short-time forecast of relativistic electrons at geosynchronous orbit
- Advances in Communication predictions: Improvements in ionospheric mapping techniques, solar wind driven ionospheric forecasting algorithms, geomagnetically driven ionospheric forecasting algorithms
- Advances in GNSS predictions: ionospheric monitoring based on GNSS data, TEC modeling algorithms
- Advances in the prediction of space weather effects in the Earth's atmosphere: Now- and Short-term Forecasting of the Chemical Composition of the Middle Atmosphere, Cosmic Ray Ionization Model for Ionosphere and Atmosphere

3. Recommendations for new Space Weather products and services

Recommendations are based on the experience that our experts already gained from the operation of space weather prediction systems (in Regional Warning Centers or at national research institutes and universities), on systematic contacts with users in the frames of workshops or focused meetings, and on specific studies carried out in the frames of this Action. More specifically, Work Group 2 that implemented the specific set of activities, has as main objective to collect updated users' requirements for space weather products and services, and to propose models that can meet these requirements, based on the work performed for the identification of the new models and the stimulation of their validation. The first systematic effort to perform an organised exchange of ideas with users, was held in the second workshop of the Action, in March 2010. Valuable insights into the needs of users in several space weather domains including spacecraft operations, aviation and trans-ionospheric radio propagation have been collected and compiled by Hapgood (2010) in a comprehensive report. The main points that give a qualitative indication of future needs for space weather specification and forecasting information are presented in the following paragraphs.

Spacecraft operators consider valuable to have situational awareness of space weather so that they understand what is happening to their spacecraft and can quickly analyse anomalies (Pitchford, 2010). Thus they want assured European long-term access to data and to models of spacecraft environment and effects in order to correlate spacecraft effects with environmental conditions. These correlations can be used to set alarms that will warn teams of adverse conditions. A future need will be to extend the range of data available for such studies, and to further improve the data analysis techniques through use of advanced data mining techniques and models validation (Donati, 2010). Also the assessment of hardware components behavior to various space weather conditions is a future requirement for spacecraft operators.

Space weather effects faced by Galileo, the European satellite navigation system, include both radiation effects on the Galileo spacecraft and ionospheric effects on the Galileo navigation signal. The radiation effects are severe because Galileo's medium earth orbits expose the spacecraft to the radiation belts, especially the outer belt. The impact of ionospheric space weather on Galileo has two main aspects. One is the need to support single-frequency receivers of the Galileo signal as these must use an ionospheric model to correct for group delay. The other ionospheric aspect is the risk that ionospheric scintillations reduce position accuracy and may even cause loss of the Galileo signal. Thus it is important to monitor and understand the occurrence of scintillations – to warn of adverse conditions and to help design of robust receivers (Arbesser-Rastburg, 2010).

The European augmentation system, EGNOS, which is now operational, experience problems due to space weather. Augmentation systems significantly improve the position accuracy obtained from satellite navigation. The major needs for improved handling of space weather effects include: (a) the need for better information on current levels of disturbance due to space weather, especially ionospheric scintillation, and (b) the need to assess the integrity of the service against current space weather (Cueto, 2010)

Ice-monitoring missions such as ESA's Cryosat-2 project, have specific space weather needs. Cryosat flies at an altitude of 700 km and use radar altimetry to monitor the thickness of both sea-ice and land-based ice-sheets to centimetre accuracy and thus must be corrected for ionospheric group delay. Hapgood (2010) speculated how our modern knowledge of the polar ionosphere might be applied to the problem, highlighting the role of polar patches that can add considerable variability to the corrections needed by Cryosat (compared to the much smoother variations seen at mid-latitudes).

Space weather effects into aviation operations is studied systematically by the Cross-Polar Working Group, set up by the aviation regulatory authorities of the countries bordering the Arctic. The group has considered the full range of space weather risks to trans-polar communications, including effects on HF radio communications, radiation hazards and disruption of satellite navigation (Jones, 2010). The group has a strong focus on the aviation needs to specify the severity of space weather effects expected at a particular time and geolocation, the confidence level on that information and the timeliness of its delivery to users (increased use of graphical formats for efficient presentation and use of common international standards). The provision of space weather information for aviation, planned to be standardized by 2015, is a concern because aircrew have 15-20 min to absorb such briefing material. Another concern for aviation operators is the aircrew exposure to cosmic radiation, i.e. covering all routes, not just trans-polar. Statistical data on recent aircrew radiation exposure (Lübbe, 2010) show a clear upward trend due to the extended solar minimum and the consequent increases in cosmic ray fluxes as well an annual modulation (due to seasonal modulation of demand for air travel) and a double peak in the overall distribution (reflecting different exposure times of crews operating long- and short-haul flights). An important fact is that aircrews are now the work group with highest radiation exposure as much has been done to reduce exposure of other work groups. Lübbe (2010) identified several important space weather needs to better mitigate radiation risks to aircrew: (a) better handling of space weather inputs into flight planning, (b) early warning of high radiation fluxes, (c) improved on-board monitoring of radiation levels and improved procedures to respond to warnings from such monitoring.

Finally, specific military interest in space weather concerns especially the radio spectrum management and the ability to distinguish space weather impacts from interference by hostile human activity (Wojciechowski, 2010). It is important to note that recently NATO Research and Technology Organization (RTO) formed an Experts Team (SCI-229) to study space weather, space debris and near-Earth objects for NATO needs, and to develop Space Situational Awareness tools for NATO (Messerotti, 2010).

Given the specific requirements detailed above and the activities performed by European research groups to improve space weather prediction models, the following new products and services for space weather have been identified as those that have the potential to meet users' needs:

- Automatic tools to predict solar activity (Ahmed et al., 2011; Colak & Qahwaji 2011)
- Forecasting SEP Events (Núñez, 2011)
- Warnings for geomagnetic disturbances (Saiz et al., 2008).
- Nowcasting and forecasting the K index (Kutiev et al., 2009)
- Forecast of relativistic electrons at geosynchronous orbit scintillations of Pc5 type (Degtyarev et al., 2009; Degtyarev et al., 2010; Potapov and Polyushkina, 2010).
- 3D specification of the electron density structure up to GNSS heights (Belehaki et al., 2012; Kutiev et al., 2012b)
- System for thermospheric monitoring (Mikhailov et al., 2012)
- Nowcasting and forecasting models of ionospheric parameters at the peak height with an accuracy range (Tsagouri, 2011; Pietrella, 2012; Hoque & Jakowski 2012)
- Maps of vertical TEC calculated in real-time with activity index (Bergeot et al., 2011)
- Real-time GIC analyser software (Viljanen, 2011)
- Advanced data analysis techniques to correlate satellite anomaly data for different orbits with various characteristics of space weather, using reach databases of anomalies recordings (Dorman, 2012)

4. The education and outreach programme of COST ES0803

A detailed report on education and outreach activities held in the frames of this Action is published by Vanlommel et al. (2012). Here we focus on a brief presentation of some key activities.

International advanced school on space weather modeling and applications

The school aimed at providing the scientific knowledge for monitoring, modelling and predicting Space Weather but with special attention to the applied aspects of Space Weather, i.e., to the monitoring and modelling resources based on advanced data handling for Space Weather. Scientific co-organisers were the EC COST Action ES0803 and EC FP7 Project SOTERIA. This disciplinary approach matches the scientific, dissemination and educational goals of both scientific co-organisers.

The school was organized as morning sessions, focused on the theory propaedeutic to the applications, and afternoon sessions, where the applications were taught via practicals with the direct participation of the attendees.

The main topics were respectively:

- Space Weather Drivers and the Relevant Physical Environments
- Space Weather Impacts on Technological Systems and Humans
- Space Weather Monitoring and Data Handling
- Space Weather Modelling Techniques

The school was organized with the support of ICTP and INAF with 2 weeks of duration in October 2010. More than 80 trainees, graduate students and early stage researchers attended.

First European School on fundamental processes in space weather: a challenge in numerical modeling

In 2012 the Action co-organised, with the SWIFF EU project, a training school on "First European School on fundamental processes in space weather: a challenge in numerical modeling". The programme was divided in 4 topics:

- Space Weather: Basic processes for Space Weather, Modeling of space weather, Coupling at the solar surface, Coupling in the Earth environment
- Theory: Magnetic Reconnection, Instabilities in space
- Simulations: Multi-scale and multi-physics modeling, Fluid simulations, Kinetic Simulations, Adaptive methods
- Computing: Parallel computing, High performance computing

The school was addressed to PhD students and researchers, and had one week duration, in June 2012 in Spineto, Tuscany.

Our experience from the organization of the two training schools shows that training schools are powerful means for dissemination and education, very effective in raising awareness on the subject, attract new scientists in the field and they also are very effective in synergising new collaborations.

The outreach programme of the Action consists of a comprehensive set of outreach material that can be used by experts willing to organize outreach activities in their own country. Main contributions to this material come from the programme *I Love my Sun*, and the *Planeterrella* experiment.

The *I Love My Sun* programme is a COST example for international collaborative outreach presented in details by Tulunay et al. (2012).

“I Love My Sun” is an educational outreach tool that has been developed for school children in the approximate age range of 7 through 11 years. The main objective of this tool is to make children aware of space weather, the Sun, Sun-Earth relations and how they, the children, are part of this global picture. Children are given a lecture about the Sun. The lecture is preceded and followed by the children drawing a picture of the Sun. Several events have been organised from COST ES0803 experts in Turkey, Belgium, Ukraine and Serbia, and the results are presented and analysed.

The *Planeterrella* is another important tool for public outreach proposed and developed by Lilensten et al. (2012). It is based on the Terrella experiment created by the Norwegian scientist K. Birkeland. With this experiment, Birkeland demonstrated the making of the auroras. The Terrella has been greatly improved and constitutes now a new experiment called the Planeterrella. It allows to picture many phenomena occurring in our space environment. It is flexible and attractive. This experiment had initially been developed to be small and modest, shown to local people by a demonstrator. It met a great success which relies on two strong points: (i) there is no patent on it and the plans are given freely to any public institution and (ii) the advertisement does not rely on press release, books or web sites but mainly on national and European scientific networks such as COST ES 0803.
Today, nine Planeterrellas are operating or under construction in four different countries, and more are foreseen. In five years, about 50,000 people (and much more on TV's) in Europe could directly see the making of auroras, picture the space environment and get an introduction to space weather with this experiment.

5. Summary and Conclusions

The main scientific achievements of this COST Action are: the recommended methodology for the validation of space weather models, the stimulation of improvements of models based on assessment results, the collection of updated information concerning users' requirements and recommendations for new products and services that can be derived from advanced space weather algorithms.
In parallel, networking and coordination activities organized by the Action further supported the establishment of the European Space Weather scientific community with two important achievements:

- The organization for four consecutive years of the European Space Weather Weeks, in collaboration with ESA and STCE (ESWW6 to ESWW9). ESWWs are now an international event attracting a large audience of more than 300 participants consisting of scientists, users, policy makers, all concerned about space weather.
- The establishment of the international scientific peer review open access Journal of Space Weather and Space Climate (SWSC) published with EDP Sciences. The journal accepts submissions (http://www.swsc-journal.org/) since 2011. First papers are already published. The final report of this Action will be published in a special issue of SWSC as a selection of papers.

Future developments in the field must consider the general requirements of space weather users that concern:

a) continuous improvements of SW prediction models in order to adjust the accuracy and delivery method to the continuous evolving needs of users
b) standardization of the SW products and services in order to encourage take up by a wide user community
c) assured long term access to data
d) use of validated models in order to provide quality indicator to the user
e) development of tools to improve operators ability to explore data through the use of advanced data analysis techniques

f) raise awareness of space weather issues and educate users about their effects and what can be done for warning and mitigation.

Valuable tools that support these requirements are the data e-infrastructures that have been developed or are under development by European space science communities, able to provide access to homogenized and standardized space data through e-science tools. These data platforms should be systematically exploited from the European space weather community to further meet the requirements of the users and to provide assured services in long term.

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Biographies

Anna Belehaki received a Ph.D. on Space Physics in 1992 from the National and Kapodistrian University of Athens and immediately after, she joined Prof. Gordon Rostoker’s group in the Canadian Network for Space Research of the University of Alberta in Canada as post doctoral fellow. In 1995 she was elected in a research position in the National Observatory of Athens and since 2007 she is research director and head of the Ionospheric Group. Anna Belehaki has a long term experience on ionospheric experiments and monitoring techniques, on space weather prediction and forecast models for ionospheric effects, on the development of operational space weather services and on the study of solar wind-magnetospheric-ionospheric interactions for the modeling of the topside ionosphere and the plasmasphere. Anna Belehaki is the PI of the Athens Digisonde project, coordinator of the DIAS project (the European Digital Upper Atmosphere Server, funded by the EC, eContent Programme) and scientific manager of the ESPAS project (Near-Earth Space Data

Infrastructure of e-Science, funded by the EC, FP7-eInfrastructures). She is the chair of the Management Committee of the COST Action ES0803 “Developing Space Weather Products and Services in Europe”, a network among 26 countries where 85 experts from all over the world participate. From 2009 to 2012 she is co-chairing the European Space Weather Weeks. She has published more than 70 papers in peer review international scientific journals and participated to more than 120 scientific conferences. In 2010 together with the core group of COST Action ES0803 she established the Journal for Space Weather and Space Climate – SWSC, for which she is serving as Editor in Chief.