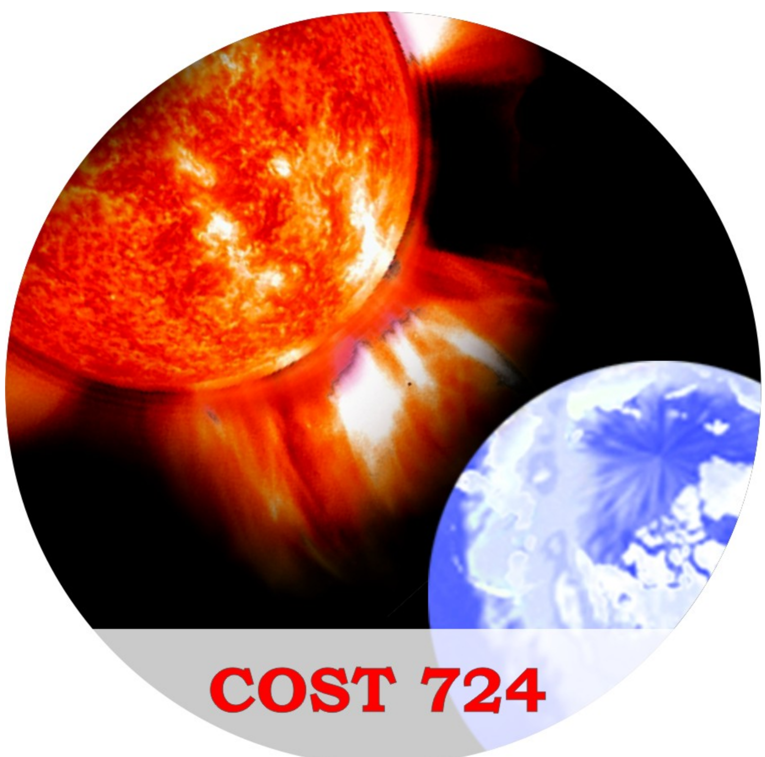
# COST 724 final report

## Developing the scientific basis for monitoring, modelling and predicting Space Weather

J. Lilensten[1], A. Belehaki[2], M. Messerotti[3], R. Vainio[4], J. Waterman[5], S. Poedts[6]

[1] Laboratoire de Planetologie de Grenoble, Observatoire des Sciences de l'Univers de Grenoble,CNRS-UJF,France
[2] Institute for Space Applications and Remote Sensing, National Observatory of Athens, Greece
[3] Department of Physics, University of Trieste, Italy
[4] Department of Physical Sciences, University of Helsinki, Finland
[5] Geomagnetism and Space Physics Program, Danish Meteorological Institute, Denmark
[6] Centre for Plasma Astrophysics, K.U.Leuven, Belgium



# A European definition for Space Weather

J. Lilensten[1], B. Sanahuja[2], and M. Messerotti[3]

[1] Laboratoire de Planetologie de Grenoble, OSUG-CNRS, France jean.lilensten@obs.ujf-grenoble.fr
[2] Dept. Astronomica i Meteorologia, Universitat de Barcelona, Spain Blai.Sanahuja@ub.edu
[3] INAF Trieste and Dept. of Physics, Univ. of Trieste, Italy messerotti@oats.inaf.it

**Summary.** Our action has devoted a lot of efforts to define properly space weather and get one -or several- European definitions. In this paper, we will explain how we handled the task, what difficulties we came with, and how we managed to converge toward the following European space weather definition:
*Space weather is the physical and phenomenological state of natural space environments. The associated discipline aims, through observation, monitoring, analysis and modelling, 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.*

## 1 Why a new 'Space weather' definition?

During the 3rd Management Committee (MC) meeting in Trieste, on November 2004, the MC considered that there were two main problems with this unofficially but widely accepted USNSWP definition of Space Weather:

1. The statement that it "can endanger human life or health" which is true under certain (exceptional) circumstances, it is often felt too strong and not at the same level of relevancy than the other effects.
2. The fact that this definition is much oriented toward effects instead of science.

The preparatory work and the debate at the MC meeting could not lead immediately to a consensual definition. Therefore, it was decided to set-up a working group which would summarise the issue, analyse the problems and propose a procedure.

## 2 The working group. The procedure.

The members of the working group specifically dedicated to work on a new space weather definition included 6 colleagues from our action and from ESTEC, under chairmanship of Blai Sanahuja (coordinator). The MC asked the working group to try to the reach a space weather definition, or a reasonably space weather definition draft with qualifications to be presented and discussed in a MC meeting. To reach this issue, the following actions were programmed:

- To produce a document summarizing the relevant points of discussion on the subject.
- To make a list of constraints we put in the SW definition.
- To define a procedure that can lead to the SWDf (with possible alternatives).

## 3 To produce a document summarizing the relevant points of discussion on the subject

The important issues identified by the working group, with respect the USNSWP definition are: (1) It is the most widely used so far (including in COST programme of work and ESA space weather pilot project). In addition, it seems that COST community will be in practice working on a concept which is not fundamentally different from the US agencies and from the ESA pilot project. (2) It is criticised for its excessive emphasis on hazardous SW effect on human health. (3) It is criticised for the lack of reference to scientific activities.

To solve problems regarding point (1) the only requirement is that effort is made such that the new definition is compatible with the definition of USNSWP. From the discussions that took place at MC meeting the technical problems with the definitions are points (2) and (3) above. Regarding point (2), it seems that the statement that space weather can endanger human life or health is considered to be too strong. It is recognised, however, that ionising radiation has statistically health impact on astronauts and air crew if certain threshold are exceeded. So the statement is not wrong but it should be softened. Regarding point (3), the working group examined the analogy with atmospheric weather and found out that in all definitions the weather is defined by its effect on human activities and that there is no need to make reference to any of the related science (e.g., atmospheric science, meteorology, climatology, etc.). The working group decided that an equivalent approach should be used for the definition of space weather which is a concept which can be the subject of scientific study but is not a scientific activity per se.

From the above discussion, the working group identified the following constraints and set of guidelines for the definition of space weather to be elaborated.

## 4 Proposed constraints by the working group for the definition of space weather

Constraint 1. It should be compatible with the USNSWP definition (i.e., it must appear clearly that they describe the same concept). Constraint 2. It should soften the statement that Space weather can endanger human life or health but must be compatible with it. Constraint 3. The definition must have an analogy with the ‘weather’ definition hereby reflecting the analogy of the two concepts. This implies the following points 5 and 6 below. Constraint 4. It should mention effects on human activity and technology. Constraint 5. The space weather should be made as a concept independent of the scientific research.

Furthermore, the working group recommended the following additional constraints on the definition: Constraint 6. It must be compatible with all well recognised space weather effects. Constraint 7. It should not mention only negative effects of space weather. Constraint 8. It should refer to the solar variability. Constraint 9. It should be understandable by an audience broader than the scientific community.

## 5 Procedure to perform to present and, eventually, to approve a definition of space weather.

The working group approved to prepare a list of twelve definitions, divided in two groups, to be presented in the 5th MC meeting in Vienna, on April 2005. The idea was to reduce the number of potential definitions in order to simplify and speed up the final discussion. The first group (six items) contained the most suitable definitions, as understood by the working group, while the second subset gathers the definition of space weather finally discarded.

The working group approved to propose a procedure to select a definition of space weather, subject to the approval of the MC and to the decision by the MC to go ahead with such selection. There were three steps: (1) After discussion, approval by the MC of the list of constraints presented by the working group (2) After discussion, approval by the MC of the list of possible definitions of SWDf (3) After discussion, if proceeds, selection of a definition from the list previously approved, with a final voting by the MC members.

This procedure had to be approved by the MC. The working group understood that if at the end of the process there were an extended consensus was reached on a given definition, the form of this definition could be modified in order to improve it or to make it more understandable.

Based on these criteria, 5 definitions were approved by the working group.

- *SWDf2*: Space Weather describes physical conditions in the Earth's environment which are ultimately determined by the variable solar activity. Space weather manifests itself through various physical phenomena which are observed in the Earth's environment comprising space and ground.
- *SWDf8*: Space Weather describes the physical processes induced by solar activity that have impact on our terrestrial and space environment, on ground based and space technological systems, and on human activities and health. The main goals of space weather are establishing the scientific basis to understand such phenomena and developing operational tools to predict and forecast them.
- *SWDf10*: The conditions and processes occurring in space which have the potential to affect the near Earth environment. Space Weather processes can include changes in the interplanetary magnetic field, coronal mass ejections from the sun, and disturbances in the Earth's magnetic field. The effects can range from damage to satellites to disruption of power grids on Earth.
- *SWDf11*: Space Weather describes physical conditions in the Earth's environment which are ultimately determined by the variable solar activity and which may affect human activities in space and on Earth. Space weather activities include: scientific research, operational observations and modeling, forecast and specification services.

- *SWDf12*: Processes in the solar wind and Earth environment induced by solar variability (variable conditions on the Sun). Particular consideration is given to their impact on space-born and ground-based technological systems and human healthProcesses in the solar wind and Earth environment induced by solar variability (variable conditions on the Sun). Particular consideration is given to their impact on space-born and ground-based technological systems and human health

The definitions that were discarded are

- *SWDf1*: Space Weather describes physical conditions in the Earth's environment which are ultimately determined by the variable solar activity.
- *SWDf3*: Space Weather Research aims at the understanding and quantification of physical processes associated with solar activity which affect the coupled Sun-Earth system in all aspects.
- *SWDf4*: The goal of space weather research is the establishment of the scientific basis needed to develop the capability to forecast solar activity and its effect on geospace, the biological manifold, and technological systems.
- *SWDf5*: Space environment changes (essentially electromagnetic and particulates with natural origin) and their related effects (especially on human activities in space and on Earth).
- *SWDf6*: Space Weather is the physical and phenomenological state of Ecospace, the region where human activities interact with the terrestrial and space environments. Space Meteorology is aimed at the observation, the study and the prediction of Sun- and non-Sun-driven perturbations in Ecospace, which affect both biological and technological systems.
- *SWDf7*: Space Weather is the science of the composition and dynamics of the space environment of the Earth, from its upper atmosphere to the heliosphere. It aims at understanding the mostly solar origin of the space environment and all the interactions inside the space environment predicting and quantifying the energy inputs due to solar activity and cosmic radiations and their impact on the space environment predicting and quantifying the consequences of these variations on the ecospace, defined as the region where human activities interact with the terrestrial and space environments
- *SWDf9*: Sun activity that acts on the biosystem

## 6 Development and discussion at the 5th MC meeting

The discussion was very warm. Discarded definitions were considered by some colleagues as the bests, some wanted to have more emphasis on science, some on technology. In spite of the working group efforts to set up a rationale working way, the criteria were soon forgotten. The reactions reflected in many ways our cultural differences, showing how interesting, but how difficult it is to build Europe! The working group tried to convince the Management Committee that we can even come with three definitions adapted to different tasks: it turned out to be totally impossible. It looked very much as a dead end.

## 7 A European definition for space weather

During the 9th MCM in Sofia (May 2007), we decided to restart the process. Dr. Messerotti gave a semantic grid to analyse our definitions. We restarted the discussion from SWDf6. We understood that there should not be a definition inside of a definition (ecospace must not be explained inside of the space weather definition), and that there is a difference between the space weather itself and the associated discipline. We created a discussion group that gathered 30 participants. Each word was discussed. Finally, we converged to the following definition, which constitutes therefore the European definition for Space Weather:
***Space weather is the physical and phenomenological state of natural space environments. The associated discipline aims, through observation, monitoring, analysis and modelling, 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.***

## References

US National Space Weather Program: Implementation Plan, FCM-P31-1997, Office of the Federal Coordinator For Meteorological Services and Supporting Research, Silver Spring, Md., 1997; http://www.ofcm.gov/nswp-sp/text/a-cover.htm

# Concept Maps for a Space Weather Ontology

M. Messerotti[1,2]

[1] INAF-Astronomical Observatory of Trieste, Loc. Basovizza n. 302, 34012 Trieste, Italy
messerotti@oats.inaf.it
[2] Deptartment of Physics, University of Trieste, Via A. Valerio n. 2, 34127 Trieste, Italy
Mauro.Messerotti@ts.infn.it

**Summary.** We present a first attempt aimed at building an ontology for Space Weather based on a graphical representation of knowledge. For this purpose, the IHMC Concept Maps sofware toolkit was used as a quite flexible and effective development environment. The preliminary set of Concept Maps is shown and briefly commented as well as the future perspectives.

## 1 Introduction

A clear definition of the concepts relevant to Space Weather and its operational field is needed due to many conceptual ambiguities introduced by the common practice. Therefore the construction of an ontology is the appropriate way to solve ambiguities, to emphasize relationships and to set the basis for defining a Space Weather knowledge model. In Section 2 we outline a semantic model for knowledge and in Section 3 we explain how knowledge can be represented in graphical form by Concept Maps. In Section 4 we define the foundation ontology and in Section 5 we outline the Space Weather ontology building process and we comment the basic Cmaps. The conclusions are drawn in Section 6.

## 2 A Semantic Model for Knowledge

A semantic model for knowledge is based on a set of propositions, each one expressing the relationship between concepts. A concept is a pattern of regularities in objects which are descriptive knowledge elements. A relationships is a logical action link, i.e., an inferencing knowledge element. It is therefore possible to graphically represent a certain knowledge on a topic or sub-topic by drawing a graph with blocks connected by lines to describe the relevant propositions. A similar representation is defined as a Concept Map (Cmap) (Messerotti (2002) and references therein).

## 3 Representing Knowledge via Concept Maps

The knowledge representation outlined in the previous section can be achieved by constructing Cmaps as graphical schemes of knowledge in organized form. Various software tools exist for this purpose, but we claim that the most user-friendly and, at the same time, the most advanced for its capabilities to export knowledge in machine-readable format is the Cmap Tools Knowledge Modelling Kit, a multi-platform client developed by the Institute for Human and Machine Cognition (IHMC, Florida, USA) that allows the interactive drawing of a Cmap and its eventual publication on a local or remote Cmap server. In the latter case, the published Cmaps become accessible: (a) at human level via a conventional web client (like e.g. Microsoft Internet Explorer or Mozilla Firefox) for reading only or for remote collaborative editing upon authentication; (b) at machine level via specific web services for knowledge manipulation, as a Cmap can be parsed and exported as an XML file which codes the concepts and their relationships (Messerotti, 2006, 2007). This software tool is freely available for non-commmercial purposes and can be downloaded upon registration at the URL http://cmap.ihmc.us/. A Cmap is a quite flexible representation as external resources such as other Cmaps, hyperlinks, scripts, etc, can be associated with concepts, so that a set of Cmaps published on a Cmap server can be navigated to explore the coded knowledge.

For the publication of the Cmaps developed in the framework of CA724, a dedicated Cmap server was installed and active at the INAF-Astronomical Observatory of Trieste. It is reachable at the URL http://imhotep.oats.inaf.it:3000/.

A sample Cmap is shown in Fig. 1. By selecting an adequate layout, the vertical location of the concept blocks with respect to each other can rank the conceptual hierarchy in terms of inclusivity, being the most inclusive concepts at the top of the graph and the less inclusive ones at the bottom. Similarly, the relative horizontal location can be associated with the generalization level. The adoption of such layout schemes is not mandatory and it depends on the specific nature of the Cmap, i.e., on the knowledge framework it describes.

## 4 Definition of a Foundation Ontology

An ontology describes the knowledge on a general subject (foundation ontology) or on a specific topic (domain ontology) and it is the formulation of a conceptual scheme about e.g. a domain that is constructed by:

- Defining the precise meaning of domain entities (Semantics).
- Identifying the relationships between entities (Associativity).
- Stating the rules between entities and set of entities (Operativity).

The formulation of a foundation ontology for Space Weather is needed for a series of reasons:

- There is no clear definition of the terminology and many ambiguities exist.
- There is no clear definition of the physical domains.
- The interrelationships are defined only on a fragmentary basis and are typically limited to subdomains. 1item The development of Semantic Virtual Observatories need the existence of ontologies to incorporate the relevant knowledge models and to properly operate knowledge handling and knowledge discovery on data sets.

## 5 Ontology of Space Meteorology

For the reasons considered in the previous section, we preliminarily started the process of building a foundation ontology for Space Weather (Messerotti, 2007) by: (a) identifying the elementary concepts

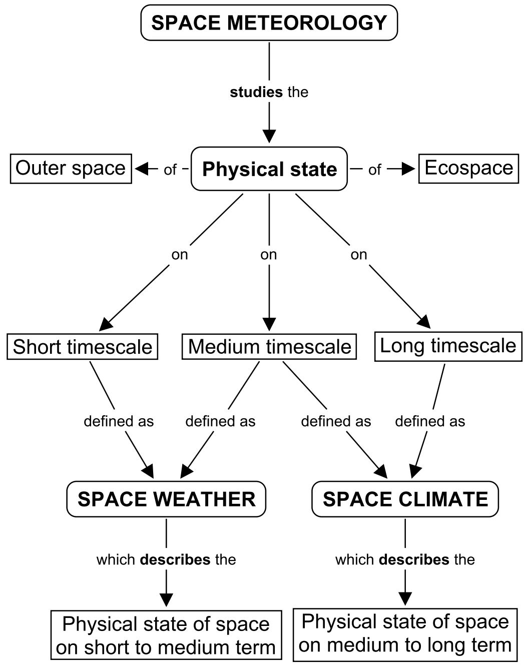



**Fig. 1.** Cmap that defines the domain of Space Meteorology

according to the available knowledge and performing a careful analysis of the related terminology to define the semantics ; (b) identifying the relationships among elementary concepts according to the available knowledge of the underpinning physics, that characterize the associativity and (c) stating the rules between concepts and set of concepts to define the operativity framework.

The Cmap at the highest generalization level, which describe the basic definitions of Space Weather and Space Climate according to their operational framework, is shown in Fig. 1. A terminology issue becomes immediately evident and it is related to the term ”Space Meteorology”, which is used with different meanings in different contexts. In fact, it can be interpreted e.g. either in terms of ”terrestrial meteorology from space” or ”meteorology of space”. We claim that a detailed analysis of the semantics leads to the selection of the second meaning for close analogy with the terrestrial meteorology, whereas the first meaning, notwithstanding its large use in some scientific communities, should be rejected in the construction of the foundation semantics, which has, in fact, the role to operate disambiguation where needed as in this case. In fact, a fundamental rule is that the common use of a term cannot bias its correct definition in a domain, as this would propagate throughout the whole domain semantics having eventually unpredictable conceptual side effects.

Definition of outer space, whose physical conditions are studied by Space Meteorology, and its physical environments (galactic, local and interplanetary) with their own population properties is reported in Fig. 2.

Fig. 3 shows the typical drivers which characterize the physical state of space at different spatial scales.

Fig. 4 shows the typical timescales on which the drivers are known to operate.

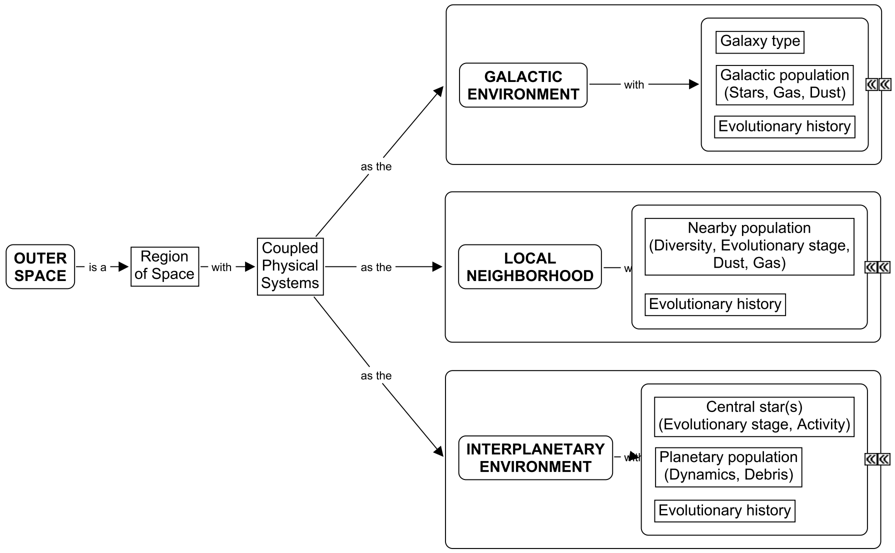



**Fig. 2.** Cmap that defines the outer space and its physical constituents

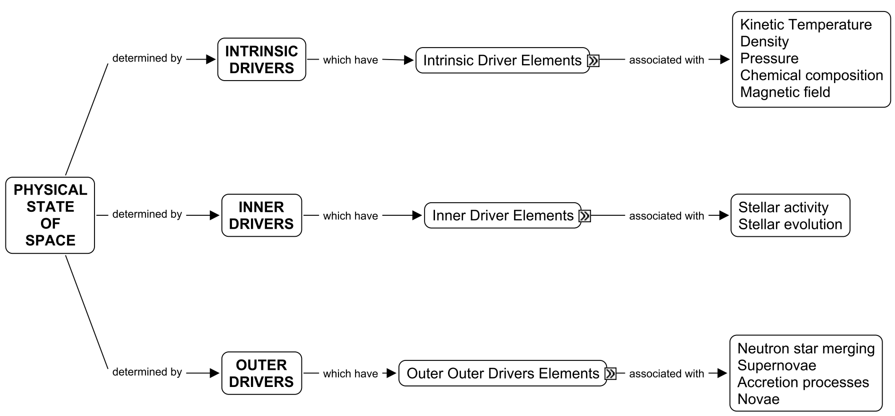



**Fig. 3.** Cmap that show the intrinsic, inner and outer drivers of the physical state of space

Fig. 5 details the typical impacts of space climate and Space Weather with special attention to the physics of the living matter. In particular, the technological and environmental effects of Space Weather are categorized in Fig. 6, which shows the relevant entities of Fig. 5 at a higher level of detail.

## 6 Conclusions

We described the preliminary work carried out to build a foundation ontology for Space Weather based on a careful analysis of the domain terminology and of the physical framework. The use of IHMC Cmaps proved to be an appropriate choice both for organizing the relevant knowledge in graphical form

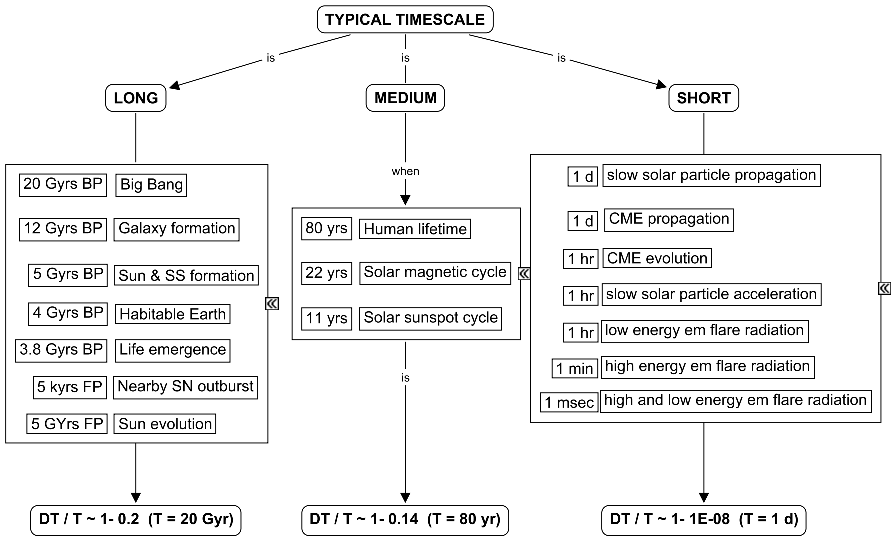



**Fig. 4.** Cmap which describe the typical timescales

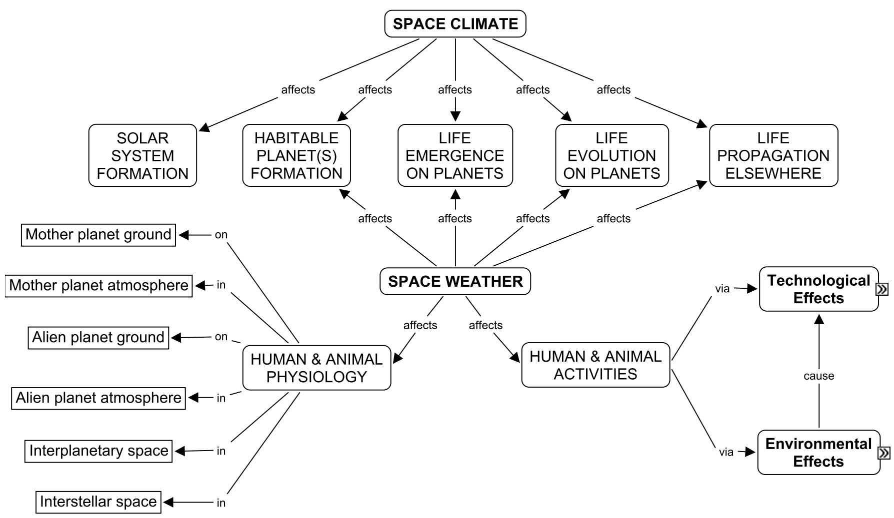



**Fig. 5.** Cmap of space climate and Space Weather impacts

via a multi-platform, flexible software tool and for making coding this knowledge in a machine-readable format suitable to be processed in a VO environment. The main aim was to clearly set the definitions and the operational and physical domains as a first step towards a Space Weather ontology and to the building of a Space Weather knowledge model. The first set of Cmaps has been publishing on a dedicated Cmap server in order to share them and to stimulate their fine tuning and their extension by the Space Weather community. A significant amount of work has anyway to be performed as a joint, multi-disciplinary

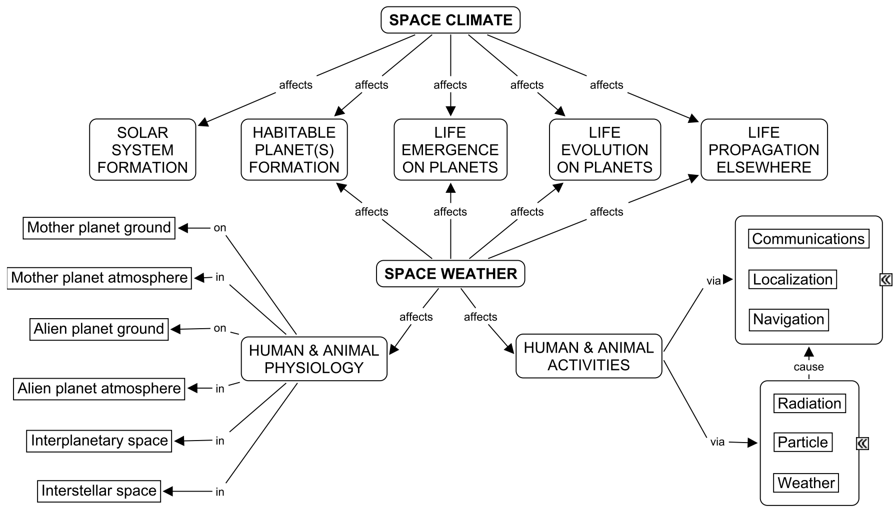



**Fig. 6.** Cmaps of space climate and Space Weather with a higher level of details

effort to consolidate the ontology to an operational level, which is a must for the incorporation in new generation semantic applications.

**Acknowledgements:** This work has been carried out in the framework of COST Action 724 and it has been partially supported by the Italian Space Agency (ASI) under contract ”Analisi dati sole e plasma”, WP 2700 - SOHO/Ground based joint analysis.

## References

Messerotti, M.: Embedding knowledge in scientific databases via concept maps as metadata. In: Sawaya-Lacoste, H. (ed) Proc. of the Second Solar Cycle and Space Weather Euroconference, 24–29 September 2001, Vico Equense, Italy. ESA SP-477, Noordwijk: ESA Publications Division, ISBN 92-9092-749-6, 607–610 (2002)

Messerotti, M.: Virtual Observatories and Virtual Grids: The Interplay in Fully Exploiting Solar-Terrestrial Data, CODATA 2006, Beijing, China, October 2006, http://www.codata.org/06conf/presentations/F1/F1_Messerotti/VirtualObservatories.pdf

Messerotti, M.: Building a Foundation Ontology for Solar Space Weather. In: Lundstedt, H. (ed) Proc. of Workshop on Solar Activity: Exploration, Understanding and Prediction, 19–21 September 2005, Lund, Sweden. ESA CDROM, Noordwijk: ESA Publications Division (2007)

Messerotti, M.: Advancing Virtual Observatories via Knowledge Management, IUGG Meeting 2007, Perugia, Italy, 2-13 July 2007. http://www.iugg2007perugia.it/

# Part VI

# Conclusion

# COST724: Conclusions and way ahead

A. Belehaki[1] and J. Lilensten[2]

[1] Ionospheric Group, Institute for Space Applications and Remote Sensing, National Observatory of Athens, Metaxa and Vas. Pavlou, 15236 Palaia Penteli, Greece belehaki@space.noa.gr
[2] Laboratoire de Planetologie de Grenoble, OSUG-CNRS, France
jean.lilensten@obs.ujf-grenoble.fr

## 1 Conclusion

European institutes active on space physics have a long tradition on monitoring and modeling space phenomena leading to space weather effects. The contribution of these institutes to advance our knowledge in space research was often pioneering. Nevertheless until recently there was a total lack of coordination of research activities in the field of space weather phenomena monitoring, model and prediction in Europe causing several barriers in the transformation of the European know-how to space weather products, required by the users' community, including the European industry. On the other hand related activities in the US have been systematically coordinated and supported by national funding agents. COST Action 724 "Developing the scientific basis for monitoring, modeling and predicting Space Weather" achieved to coordinate, for the first time, the existing national activities in Europe with the involvement of 28 countries. Over the last four years, COST Action 724 established a strong European community around space weather, through the organization of working meetings, management committee meetings, regular workshops and international conferences (European Space Weather Week), international schools and important publications in books, special issues and peer review journals. In addition, COST Action 724 developed the first prototype of the operational pan-European Space Weather Portal that offers access to the most important space weather servers operated by European research institutes and Regional Warning Centers and hosts multi-lingual public outreach pages.
Within the Action's life time significant progress has been achieved on fundamental topics related to the deeper understanding of physical processes underpinning space weather and to their modeling and prediction, through the activities performed by the three working groups of the Action.
Working Group 1 was active on monitoring and prediction of solar activity. Important contributions have been made on the identification, analysis and development of models relevant to solar activity as driver of Space Weather effects. The available information is organized in concept maps for deeper understanding of the interrelationships. Finally an extensive work has been carrying out for the definition of a foundation ontology of Space Meteorology to properly define the concepts of Space Weather, Space Climate and their drivers in the broadest scientific context.
Working Group 2 was focused on the studies related to the Earth's radiation environment and its effects on the magnetosphere, ionosphere, atmosphere, technological systems and human health. Important contributions have been made, including: the development of a comprehensive model of the interaction of cosmic rays (CR) of solar and galactic origin with the Earth's magnetosphere; studies of interactions of the CR particles with the Earth atmosphere and validation of CR induced ionization models, applicable to different heights in the atmosphere; development of a Real Time Database of Neutron Monitor Obser-

vations; development of probabilistic models of Solar Energetic Particle fluxes and fluences as well as SEP event forecasting models; development of techniques and instrumentation for using CR intensities and anisotropies for forecasting large space weather events; satellite measurements of plasma waves and neutral and charged-particle radiation in the ionosphere, magnetosphere and solar wind; development of models for trapped particle radiation and its interaction with the magnetospheric plasma waves were developed; investigation of the effects of space radiation on human health by carrying out an extensive campaign of dose measurements at spacecraft and aircraft altitudes; review of radiation effects on technology on-board spacecraft and compilation of a list of reported spacecraft anomalies due to space weather events.

Working Group 3 has focused on analyzing, modeling and predicting the physical response of geospace (comprising the Earth's magnetosphere, the ionized and neutral atmosphere and the ground) to certain types of solar disturbances, primarily CME. This involved modeling the evolution of transient events (ICME and SEP) through interplanetary space and their interaction with the Earth environment. Plasma-physical models of the propagation of CMEs on various background solar wind categories have been developed using an MHD concept. The dynamics of the magnetosphere-ionosphere system in response to the arrival of bursty solar events has been modeled, the variable state of the magnetosphere during geomagnetic storms has been modeled physically and empirically, and physical models describing the dynamics of the thermosphere (neutral and ionized) have been developed, including the impact of geomagnetic storms on the thermosphere. Semi-empirical models of solar wind-geospace interaction (mostly based on a neural network approach) have been developed with the objective to facilitate the construction of operational space weather forecast schemes (concentrating on geomagnetic activity forecast).

In order to fulfill the objectives of this COST Action for the coordination of the European effort in the development of space weather services, several activities were carried out in the frames of Working Group 4 leading to the development of the first prototype version of the European Space Weather Web Portal (ESWWP) reached in the address http://www.spaceweather.eu. This Portal provides access to the following facilities: a) an archiving facility that has been set up, for the interactive storage, search and retrieval of the available models with a full description and references and of data information via a united web interface, b) a catalogue devoted to the European web sites related to space weather, c) a model interface web portal, which provides access to a prototype implementation of remote model and data base access tools.

The Action's results had strong impact in the European scientific scene. The Action achieved to demonstrate to the decision makers in Europe that space weather phenomena and their effects have scientific and societal impact that needs to be taken into account in order to have reliable technological systems operated in space and to secure the modern society from potential problems due to space weather (i.e electric power failures, health problems due to radiation effects, communication and broadcast problems). This is a requirement not only because European researches deserves systematic support to achieve scientific advances in this field that will lead to reliable space weather services but also because Europe has to meet the challenge of the US space research and industrial development.

## 2 The way ahead

The heightened sensitivity of increasingly sophisticated technology to fluctuations in the solar-terrestrial environment and the effects of the radiation environment in humans' health makes it increasingly important to be able to forecast adverse conditions, or analyze the features of the disturbed system that cause operational problems. In the next future, the European space weather community ought to concentrate on the following issues: