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Defining and Characterising Heliospheric Weather and Climate

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Abstract. At large distance scales, space exploration in the last decades has significantly helped in better locating the boundaries of the Heliosphere and outlining its shape as well as in probing the various plasma domains that separate the inner heliospheric region from the interstellar one. At shorter distance scales, a fleet of spacecraft has been probing the outer and inner Solar System plasma with a high level of detail.

This monitoring, complemented by space- and ground-based observations of processes relevant to the Heliosphere, has pointed out a series both of intrinsic and extrinsic perturbations that characterise the physical state of heliospheric plasmas both at small and large spatial scales and on short and long temporal scales.

By means of concept maps that schematise the association among concepts, in this work we will present a new domain ontology for the definition and characterisation of Heliospheric Weather and Climate.

Keywords. Solar-terrestrial relations, solar system: general, Galaxy: general, galaxies: general

1. Introduction

Many definitions of Space Weather exist. Are such definitions using a terminology, which is correct both from a physical and from a semantic point of view? What can be a possible approach to correctly match the requirements for knowledge coding? In the following, we will concisely consider a holistic approach to the definition of Heliospheric Weather and Climate, entirely based on concept maps.

2. A European definition for Space Weather

A number of definitions for Space Weather has been formulated by different organisations, that are based on the respective missions and goals, often biased by the end user needs. A dedicated working group of COST Action 724 analysed many definitions and elaborated a European definition for Space Weather that is semantically and physically consistent (Lilensten *et al.* (2008)). It reads, "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".

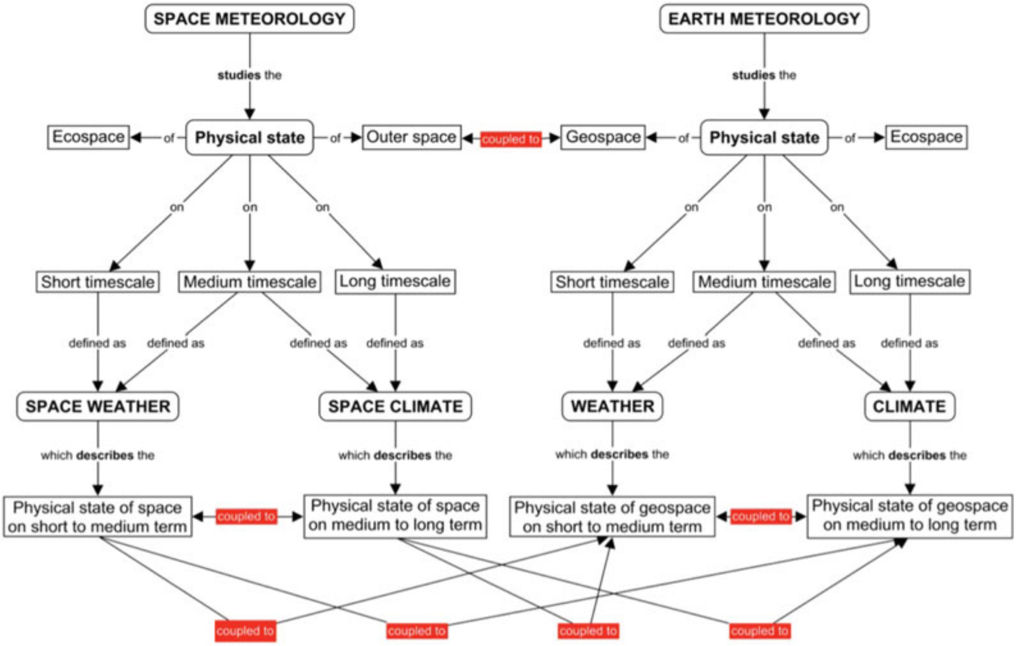

Figure 1. C-map that defines Meteorology of Space and Earth, and their relationships.

3. The ontological approach

Concept maps (c-maps) are conceptual tools that allow a flexible representation of concepts and their relationships, i.e., the schemes for knowledge coding. Hence, c-maps are suitable for building up a domain ontology, such as, e.g., a Space Weather (SWx) ontology (Messerotti (2007), Messerotti (2008), and references therein). Furthermore, c-maps can be used to embed knowledge in scientific data bases as metadata (Messerotti (2002)). In this way, one can define Meteorology of Space as the discipline that studies the physical state both of Ecospace and Outer Space on short timescale (Space Weather) and on long timescale (Space Climate), and, similarly, Meteorology of Earth, by emphasising the interrelationships as in Figure 1.

3.1. *General definition of Meteorology, Weather and Climate*

The term "Meteorology", used in Earth and planetary sciences, refers to the discipline which deals with the atmosphere and its phenomena, and studies the "Weather", i.e., the physical state of the atmosphere at a specific time and place, and the "Climate", i.e., the average state of weather on the long term.

Similarly, one can define as "Meteorology of Space" the discipline which deals with the Space Domain and its phenomena, and their impacts on Earth and planetary environments. It studies, respectively, "Space Weather", i.e., the physical state of the Space Domain at a specific time and place, and "Space Climate", i.e., the average state of Space Weather on the long term.

3.2. *Description of the physics*

The c-map approach is quite effective in describing the physics of processes from the highest level of abstraction, which depicts the commonalities in physical system triggering, response, and relaxation (e.g., Figure 2), to a higher level of detail (e.g., Figure 3).

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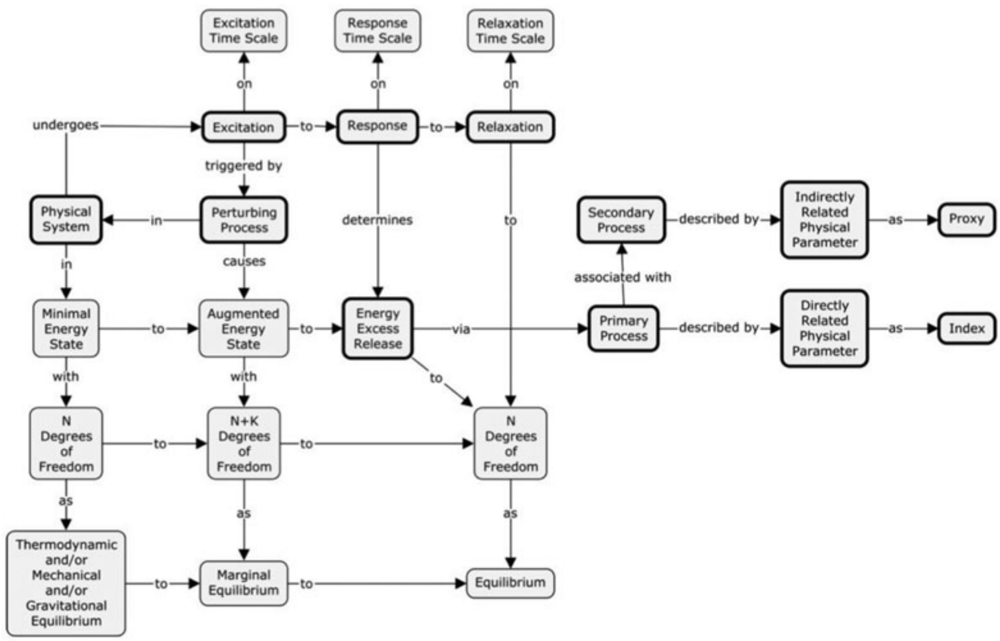

Figure 2. C-map that outlines physical system triggering, response, and relaxation.

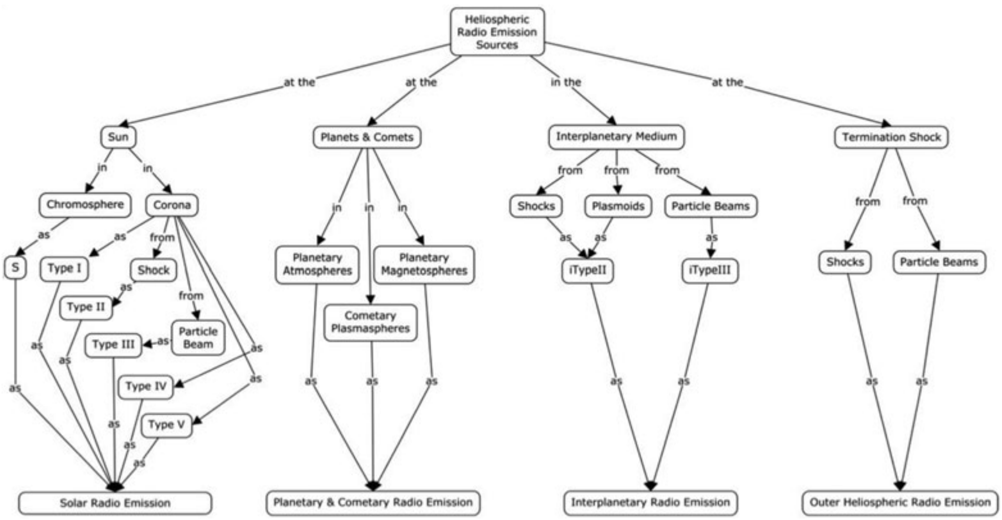

Figure 3. C-map that summarises heliospheric radio emission sources (Messerotti (2011)).

4. Semantics of Meteorology of Space

As stressed in Section 3.1, Space Weather refers to the physical state of space and planetary environments as perturbed by energetic photons and particles from both the Sun and outside the solar environment, and the discipline that studies Space Weather is Meteorology of Space.

Anyway, it must be noticed that quite often Space Weather is used to mean both the physical state of the environment and the discipline which studies it, but we stress that this is a misuse from an ontological and linguistic point of view. With regard to

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that, a never-ending discussion has been in progress, due to the widespread misuse and the concern for not being understood, e.g., by end-users as they are familiar with the wording Space Weather, and a change could be source of confusion. Notwithstanding, we are convinced that this is not an argument to justify a distortion of the terminology.

4.1. *The acronym for Space Weather*

Following a coherent approach, we consider the acronym for Space Weather as follows.

In particular, we emphasise that the universal acronym for "Weather" is "WX", i.e., the Morse code shorthand for the word "Weather", which is used as such in all messaging systems.

By analogy, the acronym for "Space Weather" should be "SWX" or "SWx". In fact, The World Meteorological Organisation (WMO) is organising a global SWx service for aviation safety according to the requirements by ICAO (International Civil Aviation Organization), and it will be operational in 2018.

Hence, the adoption of SWx as acronym for Space Weather in the messaging is a natural extension of the meteorological framework and unambiguous.

Other acronyms are misleading, such as, e.g., SWE (Society of Women Engineers) and SW typically used to mean "Solar Wind" in solar and heliospheric physics.

5. The Space Weather workflow: basic assumptions

SWx activities can be subdivided into three categories: (1) SWx monitoring; (2) SWx science; and (3) SWx operations.

Despite that there is a natural overlapping of the three categories, they can be clearly identified and should not be interchanged to properly focus the different roles. This consideration applies both to data sets and to observing facilities.

For instance, a non-active (closed) data set is useful for SWx science, but not for SWx operations, and a spacecraft that provides data with a latency of days to months has not been designed for SWx operations. Similarly, a science model has to be transitioned to an operational model through a long process of testing and validation.

6. The Space Domain as coupled astrophysical domains

The Space Domain is a complex physical system, which consists of a nonlinearly coupled complex subsystems. This structure extends in spacetime at increasing time, space, and energy scales. Hence, the sources of SWx have to be identified respectively in cluster of galaxies, galaxies, the Galaxy (Milky Way), the solar neighbourhood, the Heliosphere, and the Sun. In fact, high energy phenomena occur, e.g., in the Milky Way, where Magnetars, Hypernovae, and Supernovae outbursts contribute to Galactic Cosmic Rays (GCRs) and originate Gamma Ray Bursts (GRBs), which perturb the physical state of the Heliosphere. Hence, it is justified to define and consider the "extragalactic" and "galactic" climate, which are studied by "cosmoclimatology", being the relevant phenomena evolving on quite long timescales. Cosmoclimatology is still at a very preliminary stage.

7. Definition of Heliospheric and Solar Weather and Climate

Instead of using the term SWx for any domain, like, e.g., SWx in the Heliosphere, it is more appropriate to define the terms "Heliospheric Weather" (HSWx) and "Heliospheric Climate" (HSC) as a natural extension of Heliophysics (Messerotti (2011)). These definitions are reported in Figure 4, where the outer and inner forcing agents are listed.

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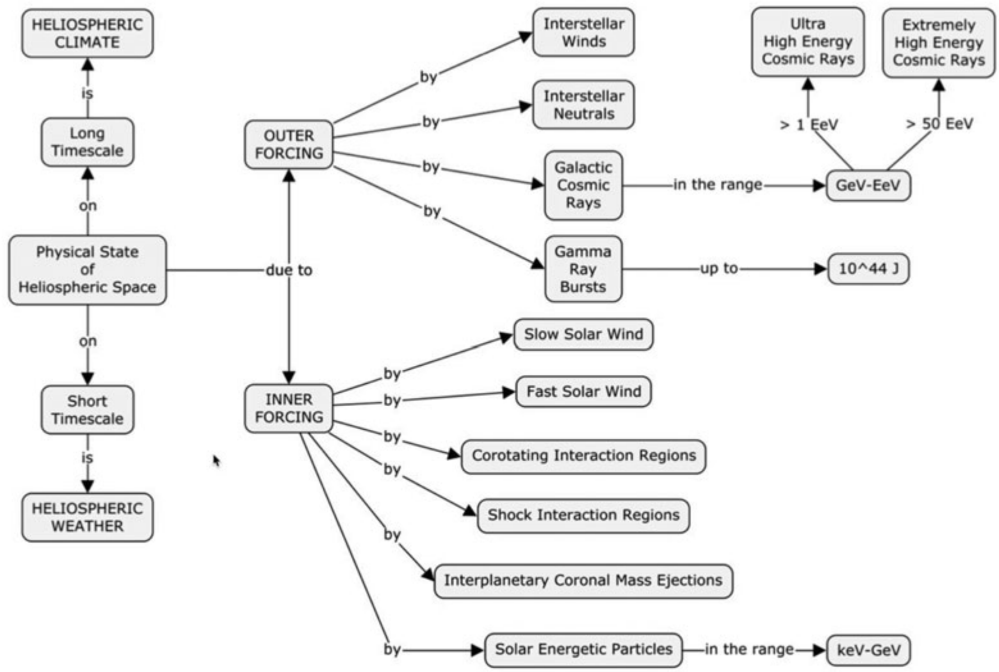

Figure 4. C-map that defines Heliospheric Weather and Climate.

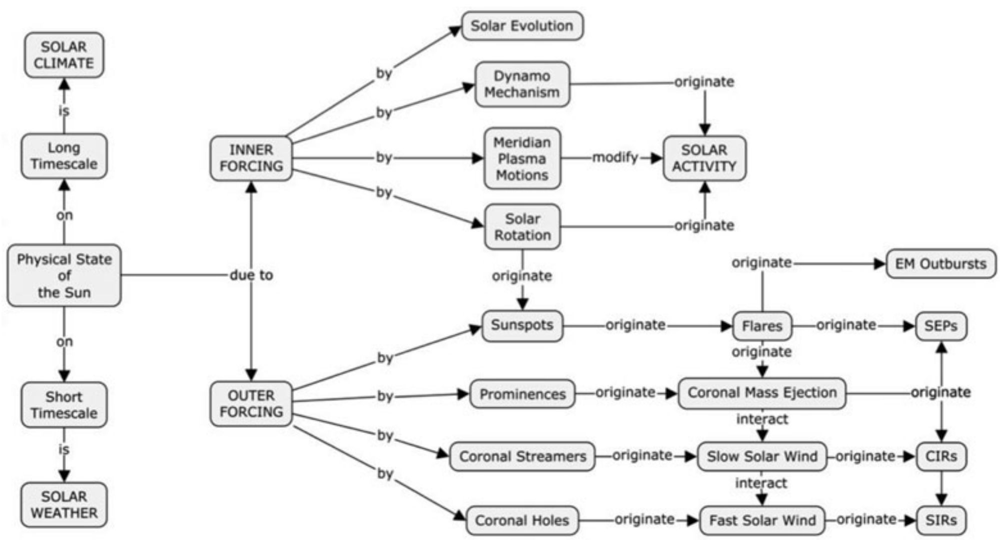

Figure 5. C-map that defines Solar Weather and Climate.

Among the former ones, GCRs and GRBs are considered, whereas the latter ones include Solar Wind structures (CIRs, SIRs), Interplanetary Coronal Mass Ejections (ICMEs), and Solar Energetic Paricles (SEPs).

Energy ranges span from GeV to EeV (CRs), up to 10^{44} J (GRBs), and keV to Gev (SPEs). The characteristic times span from milliseconds to days.

Ultra and Extremely High-Energy Cosmic Rays are quite rare, but they cannot be disregarded, as potential sources of impacts on biological and technological systems.

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7.1. Definition of Solar Weather and Climate

Analogously, Solar Weather and Climate are the physical state of the Sun on short and long timescales, respectively (Figure 5). SWx impacts on Earth and planets are originated by perturbations that occur at the Sun as manifestations of its physical state, in turn, determined by inner and outer forcing processes (see, e.g., Messerotti *et al.* 2008, 2009). The inner forcing agents span from the Sun's evolution, dynamo mechanism, and meridional plasma motions to solar rotation, which originate and modulate solar activity. Outer forcing agents are the activity manifestations like photospheric sunspots, chromospheric and coronal prominences, coronal streamers, and Coronal Holes, which originate flares, CMEs, slow and fast Solar Wind streams, SEPs, CIRs, and SIRs.

8. Conclusions

The Heliosphere is the most relevant domain for the human beings and its perturbations affect both technological and biological systems.

Notwithstanding, it is just a physical domain nonlinearly coupled with all other domains in the Universe, whose physical state, despite of their distance, significantly biases the Heliospheric Weather and Climate.

Hence, outer high energy sources must be taken into account when assessing Heliospheric Weather and Climate, in the framework of Cosmoclimatology.

This poses the issue of a multi-disciplinary approach that spans over many astrophysical subjects, related to events that occur on cosmic timescales and for which a detailed climatology does not exist yet.

An approach based on knowledge coding by concept maps can help in defining the physical domains, the phenomenology and the involved physical processes, and their relationships, according to correct physical and semantic approaches.

Furthermore, this approach is quite promising in advanced data handling and knowledge discovery applications, as it provides correct terms and attributes for metadata in advanced data models.

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