From the Sun to the terrestrial surface: understanding the chain

Proposal to ISSI, International Teams Programme

Applicant

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Abstract

Space Weather discipline aims, through the observation, monitoring, analysis and modeling, at understanding and predicting the state of the Sun, the interplanetary and planetary environment and the solar driven perturbations that affect them (from the COST724 action definition of the Space Weather term). Reviewing current scientific journals, one can find lots of studies about theoretical modeling of evolving coronal mass ejections (CMEs), solar activity observations, interplanetary magnetic topologies, or terrestrial disturbances measured by geomagnetic indices or by their imprints from the ionosphere and the thermosphere down to the troposphere. However, only a few papers relate some of the links which make up the chain from the Sun to the Earth. Moreover, when they do, they usually only relate events measured with different data sets, and just a selected number of papers provide a joint analysis of both (or several) datasets, contributing in that way to a significant advance in the understanding of the chain from the Sun to the terrestrial surface.

The next solar maximum should peak around year 2010. Solar activity cycle 24 is expected to be much higher than average with a maximum sunspot number of 160±30 [Hathaway and Wilson, 2006]. Then, lots of geomagnetic disturbances are expected to take place soon in the terrestrial environment, and effects on technological systems in general could take place. On the other hand, several spacecrafts and terrestrial telescopes are gathering data with extraordinary resolution in space and time. Among these, the STEREO (Solar Terrestrial Relations Observatory) mission, launched in October 2006, with two identical observatories –one ahead of Earth in its orbit, the other trailing behind- will follow the mass ejections from the solar corona to the L1 point with a unique side-viewing perspective.

Considering this extraordinary opportunity both, from the data coverage and from the importance of the events expected, the present proposal joins scientists with expertise in the different stages from the solar atmosphere to the terrestrial surface. The results obtained could allow us to advance in the task of forecasting geomagnetic storms. However, the primary goal of the present study is not dedicated to the technological point of view, but mainly to the scientific one. Then, the goal of the proposal is to integrate the different stages to accomplish the task of understanding the whole chain.

Scientific rationale, goals of the project and its timeliness

This proposal arises as a continuation of the project started at 2005 with a proposal titled 'The stages of the Sun-Earth connection'. From year 2005, when ISSI allowed this team to start a joint analysis of different stages from the Sun to the Earth of selected events, the activity of the team has not ceased. Results are now starting to be published, showing that a joint analysis of different stages is necessary to fully understand an event.

Following this line, several aims have been selected for this project:

1) The first aim of the team is dedicated to the *modelling of the corona*.
   Vector magnetograms combined with photospheric velocity profiles will be used as boundary conditions in simulations of the dynamics of coronal structures in an attempt to model the onset of CMEs and their early-stage development (up to 30 R_sun)
2) The second aim is to *compare solar observations with 'in-situ' observations*.
   H-alpha and X-ray solar disk images (from Hinode) together with coronagraph images make up the set of solar observations of coronal mass ejections (CMEs) from their initial phase. On the other hand, magnetic field, solar wind plasma and energetic particle data at L1 and other locations in the heliosphere, will form the datasets used to observe interplanetary CMEs (ICMEs).
   In this task, two aspects will be analyzed:
   a. Relationship between solar and interplanetary events.
   During the last project, the filament on the solar surface observed on 2005 May 12, and the magnetic cloud (MC)[1] observed on May 15 at 1AU where related (Dasso et al., 2008). Only a few cases in the literature have been successful in such task. The possibility of relating a filament with its interplanetary counterparts involves, not only solar or interplanetary observations, but also theoretical modelling of magnetic topologies as flux ropes. This implies that, we not only analyze the relation between the direction of the filament and the flux rope axis, but are also interested in quantifying magnitudes such as magnetic fluxes and helicity. Then, the analysis of selected isolated events from both datasets (solar and in situ) is the aim of this part of the project.
   b. Events observed at different locations
   The location of Ulysses at different latitudes, longitudes and distances from the Sun, together with spacecrafts such as ACE and Wind at L1 point, provides the opportunity to relate magnetic clouds at different locations in the heliosphere. During the last project we compared two magnetic clouds (Rodriguez et al., 2008), one observed in November 2001 and the other one in January 2005. In one case, Ulysses was located above the Northern solar pole, and then, its measurements together with those from ACE at L1, let us analyze the 3D topology of the MC. In the other, Ulysses and ACE were almost radially aligned, and then, we had the extraordinary possibility to study the expansion of MCs. The experience of the team analyzing the global topology of MCs has an extraordinary value in order to continue in this line during this project, including those events which are being and will be observed by STEREO mission.
3) The final aim is dedicated to the *geoeffectiveness*.

[1] Magnetic cloud is the term used for a special type of CMEs when they travel through the interplanetary medium and have a characteristic magnetic field configuration [Burlaga et al., 1981]

The last stage of the chain is the response of the terrestrial environment. EISCAT radars monitoring ionospheric parameters, the CHAMP satellite measuring total neutral density around 400km and the different geomagnetic indices, PC, AE, m, aa and Kp, Dst, SYM and ASY (see Menvielle and Berthelier, 1991 for a review) as well as newly developed planetary and longitude sector indices with a time resolution better than 3 hours (Menvielle, 2003), will be used in the analysis of the last link of the chain. They monitor magnetic signatures of the magnetosphere and ionosphere convection in response to solar wind and interplanetary magnetic field variations at Earth.

Intense geomagnetic storms have been related to high velocity halo CMEs from active regions close to central meridian. However, these results come from statistical analysis and are not able to explain particular events. In our previous project we have analyzed the geoeffectiveness of three fast halo CMEs (manuscript in preparation). Our results show that the most geoeffective event was the one closest to the solar limb and that the one initiated close to central meridian was non-geoeffective. However, interplanetary data explained the observations at the terrestrial environment. Then, in this project, we will relate geomagnetic indices and ionospheric/thermospheric data data to interplanetary data.

The response of the terrestrial environment to solar wind disturbances depends on the interplanetary magnetic field and solar wind density and velocity. However, to relate interplanetary measurements at L1 and terrestrial measurements, a temporal shift is necessary. This shift depends, not only, but mainly, on the solar wind velocity, which changes from time to time. Detailed analysis of selected events and coresponding time shifts will be made.

References

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Collaboration and division of tasks

The participation of the group members is mainly defined by the link on the chain in which they are experts. The different stages from the Sun to Earth analyzed, instruments /data used and participants involved in the tasks are described below:

- Solar observations and models: pre-corona, flares and CMEs (SECCHI–STEREO, EIT and LASCO–SOHO, THEMIS magnetometer).
  - *Hebe Cremades, Cristina Mandrini, Stefaan Poedts, Brigitte Schmieder and Andrei Zhukov*
- In-situ (interplanetary) observations and models:
  - Magnetic field and solar wind plasma (IMPACT-STEREO, MFI and SWE-WIND, MAG and SWEPAM-ACE):
    - *Yolanda Cerrato, Consuelo Cid, Cid, Sergio Dasso, Luciano Rodríguez, Elena Saiz and Andrei Zhukov,*
  - Energetic particles (EPAM-ACE, EPS-GOES, ERNE-SOHO, IMPACT-STEREO): *Angels Aran and Blai Sanahuja*
- Terrestrial environment observations and models:
  - Ionosphere and thermosphere (EISCAT and CHAMP)
    - *Chantal Lathuillère and Michel Menvielle*
  - Ground based observations (geomagnetic indices):
    - *Yolanda Cerrato, Consuelo Cid, Michel Menvielle and Elena Saiz*

Expected output

- Scientific results will be announced in contributions to conferences and published in conference proceeding papers.
- Major scientific results will be submitted for publication in leading scientific journals accessible to the whole community interested in Solar Physics, Interplanetary Physics, Geophysics and Space Weather. We expect to submit three or four papers describing in detail the most interesting events.

Why does ISSI qualify as preferred implementation site?

Most of the members have been at least once at ISSI. We believe it offers a great working environment and it provides us with a good geographic location.

List of confirmed members

- SPAIN:
  - Universidad de Alcalá (Space Research Group): *Consuelo Cid, Yolanda Cerrato and Elena Saiz*
  - Universitat de Barcelona (Departament d'Astronomia i Meteorología): *Angels Aran and Blai Sanahuja*
- ARGENTINA

    - Instituto de Astronomía y Física del Espacio, Universidad de Buenos Aires y Consejo Nacional de Investigaciones Científicas y Técnicas: *Sergio Dasso and, Cristina Mandrini*
    - Universidad Tecnológica Nacional, Mendoza, y Consejo Nacional de Investigaciones Científicas y Técnicas: *Hebe Cremades*

- BELGIUM:
    - The Centre for Plasma Astrophysics (CPA) of the K.U.Leuven: *Stefaan Poedts*
    - Royal Observatory of Belgium: *Luciano Rodríguez and Andrei Zhukov*
- FRANCE
    - Département d'Astronomie Solaire de l'Observatoire de Paris (DASOP): *Brigitte Schmieder*
    - Centre d'Etudes des Enviroments Terrestre et Planétaires: *Michel Menvielle*
    - Laboratoire de Planétologie de Grenoble: *Chantal Lathuillère*

Schedule of the project

- Before first meeting: Preparation of the material by each group in its Institution. Every team member shall provide two events that he/she is able to analyze but that need other inputs, such as data analysis or modelling that can help to advance in the understanding of the event.
- First meeting (three-four days on September-October 2008): Joint analysis of the proposed events. Who can help who? Which are the most interesting events? Selection of the most relevant events to analyze and starting point of the joint analysis.
- October 2008 - February 2009: Study of the selected cases in every Institution, providing results through the ISSI web page to all team members.
- Second meeting (three-four days on February-April 2009): Comparison of obtained results and preparation of publications.
- Third meeting (October-November 2009): Preparation of final version of manuscripts to be submitted.

Facilities required

- Two meeting rooms (one big for the whole team and one small for splinter meetings) with projection facilities.
- One desktop computer with printer connection.
- Internet access for laptops.

Financial support requested of ISSI

- Per diem to individual Team members to cover living expenses while in Bern.
- Team leader travel costs.

Appended material: brief CVS (including addresses).