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Space weather or the solar variability effects on the terrestrial environment: the Italian activities

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Abstract. The near-Earth space is an highly dynamic environment because of the highly variable conditions of the solar wind and interplanetary magnetic field which originate from the Sun. In the last years, human technological systems which operate in this environment have increased and can be affected by such variability; then, it becomes more and more important to understand the solar-terrestrial relation physics in attempting to forecast the near-Earth space conditions. This is the aim of the Space Weather program which links the study of the Sun-Earth system and the development of interaction models to the technical applications in order to minimize the risks for human activities. In the following we first discuss solar phenomena and their effects on the terrestrial environment; then, we summarize the International Initiatives in the Space Weather framework and the Italian resources in terms of continuous observations and analysis of the solar, interplanetary, magnetospheric and ionospheric parameters.

Key words. Sun – Solar Wind – Earth's magnetosphere

1. Solar sources of terrestrial disturbances

The Earth is completely embedded in the ionized outer atmosphere of the Sun, the solar wind, which flows around the magnetosphere; as a consequence, it is subject to the extremely variable conditions on the Sun. The main effects on the terrestrial environment are due to solar originated interplanetary structures and to enhancements of energetic particle flux and electromagnetic radiation (Daly 2002); they consist in dramatic changes in the magnetospheric-ionospheric current systems and particle populations. Geomagnetic storms represent a well known manifestation of the solar wind-Earth interaction and are characterized by a main phase during which the magnetic field on the Earth's surface is largely depressed. They occur when the interplanetary magnetic field is southwardly directed for a sufficiently long time interval (>= 3 hrs for a major storm) (Tsurutani & Gonzalez 1995) and the solar wind

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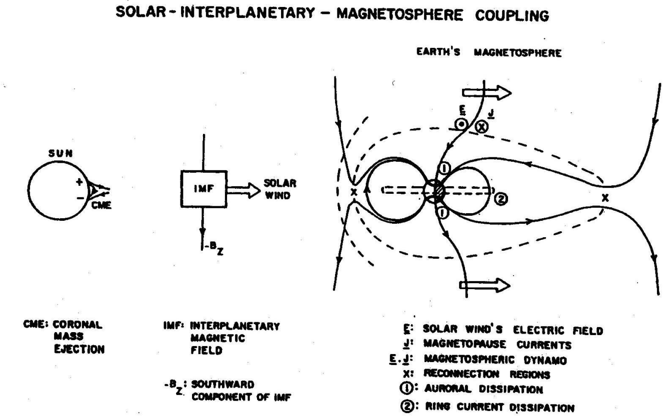

Fig. 1. The interplanetary-magnetospheric coupling showing the reconnection process (from Gonzalez & Tsurutani 1992)

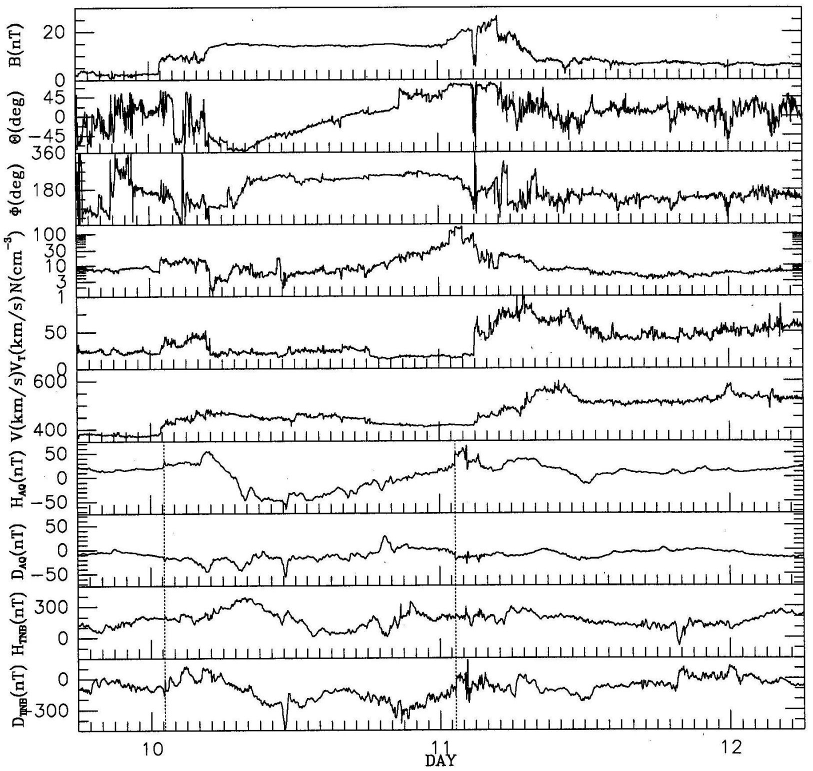

Fig. 2. Interplanetary magnetic field and plasma parameters from Wind and the geomagnetic field H component at L'Aquila and Terra Nova Bay (Antarctica) during the January 10-11, 1992 magnetic cloud (from Villante et al. 1998)

speed is high; an enhanced magnetospheric convection occurs which drives ions from the tail to the inner magnetosphere and causes strong ionospheric and magnetospheric currents (Fig.1). Solar wind structures which are responsible for geomagnetic storms are mainly magnetic clouds and high speed streams (from Gonzalez et al. 1999). Magnetic clouds are generated by coronal mass ejections (CMEs) which occur, more frequently at the solar maximum, in correspondence to active regions associated to visible spots and are bright in the EUV and X rays region; a magnetic cloud is characterized by high speed plasma and complex magnetic field structure which often shows a strong southward component causing very intense geomagnetic storms. In Fig. 2 it is shown, as an example, the January 10-11, 1997 magnetic cloud and the corresponding storm observed at L'Aquila Geomagnetic Observatory and at the Italian station of Terra Nova Bay in Antarctica. High speed solar wind streams come from coronal holes which appear as dark regions in the EUV and X emission; they are localized at polar latitudes during the solar maximum phase and move toward equatorial regions approaching solar minimum: for this reason the high speed streams are mostly observed during the low solar activity phase. In addition, since the coronal holes last for several solar rotations, the continuously emerging streams appear to corotate with the Sun (Fig. 3). Their interaction with slow solar wind generates a turbulent region (Corotating Interaction Region, CIR) which is characterized by compressed and distorted plasma and magnetic field; when this region impacts the Earth's magnetosphere, it drives geomagnetic storms generally recurrent with a 27 days period, observed expecially during the solar cycle minimum. Other effects on the terrestrial environment are due to intense X and UV rays emission during solar flares and to the Earth's arrival of energetic particles. Both solar flares and acceleration of solar energetic particles (5-50 MeV) occur in association with CMEs; solar flares effects are almost immediately seen while energetic particles arrive at the Earth orbit within 1 hour and can reach the inner magnetosphere flowing along the geomagnetic field lines in the polar regions. Also cosmic rays, i.e. very energetic particles (up to several GeV) of galactic origin, can penetrate to the ground, also at equatorial latitudes; these events occur less frequently at the maximum of the solar cycle when the more frequent disturbances of solar origin in the interplanetary space shields the flux of cosmic rays reaching the Earth.

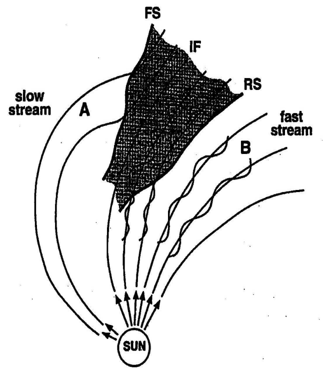

Fig. 3. Schematic of the formation of a corotating interaction region (from Gonzalez et al. 1999)

2. Effects on the magnetosphere-ionosphere system

During a geomagnetic storm, energetic charged particles are accelerated from the tail into the inner magnetosphere and intense electrical currents circulate in the near-Earth space. One of the effects is the induction of currents (geomagnetically induced currents, GICs) on the ground and in man-made conductors, expecially at high latitudes. For example, power transmission systems can be affected by GICs causing voltage drops, transformer heating and, in extreme cases, power blackouts such as occurred in Quebec during the March 13, 1989 storm, when 6 million people were without power for 9 hours (Daly 2002). Other problems can arise for oil and gas pipelines, where GICs increase the corrosion processes, and for long communication cables. The dramatic changes occurring in the ionospheric particle populations during a geomagnetic storm or due to the increase of X and UV emission from solar flares can degrade the performance of the navigation and communication radio systems. Indeed, these changes affect both signals which use the ionosphere as a reflecting surface ($3 < f < 30 MHz$, ground-to-ground communications) and signals which need to pass through the ionosphere ($f > 30 MHz$, satellite-based communications) and produce unexpected absorptions or reflections. The arrival at the Earth's orbit of energetic particles causes serious damages to materials and electronics components on spacecraft; moreover, the density increase in the upper atmosphere and ionosphere disrupt the stability of low altitude satellites and accelerate their decay. The magnetosphere and atmosphere provide efficient shielding for cosmic rays and solar energetic particles; nevertheless, radiation can affect aircraft passengers at high latitudes and astronauts, in particular on the International Space Station, due to the long permanence in the space.

3. The International and Italian activities

From the above considerations, it emerges that for a Space Weather research it is necessary a continuous monitoring of the solar wind, magnetospheric and geomagnetic field, i.e. the availability of continuous measurements from space and on the ground. Through data analysis a new understanding of the interaction phenomena can be achieved in order to improve models and forecasting. Interest and activity in this field is now increasing and many countries are involved in national research programs and international cooperations. In the Unites States, the NASA started in 1995 the National Space Weather Program (NSWP) and more recently the "Living with a Star" project (Withbroe 2001). This is a space weather-focused and applications-driven research program which addresses to the study of the physics and dynamics of the Sun-Earth system over the 11-years solar cycle, to understand the effects of solar variability on terrestrial climate changes, to forecast energetic particle events that affect the man safety, communication and transportation systems. In Europe, between 1999-2001 ESA supported two parallel studies led by ALCATEL Space (France) and RAL (Rutherford Appleton Laboratories, United Kingdom) in order to investigate the needs and benefits of an European program of Space Weather application, to establish the detailed data supply requirements and to provide inputs for a possible program proposal. These studies have clearly demonstrated that Europe has very strong assets that could be usefully used such as ground and space observatories, modeling capability and strong expertise in Space Weather effects (Hapgood 2002), (Pick 2002). Now, ESA has taken the initiative to establish a Space Weather Application Pilot Project (2002-2004) to develop and extend the Space Weather user community through limited development of targeted services, provided by a network of service providers, supported by a common infrastructure and using data from existing or easily adaptable assets. In Italy, the scientific community having a long experience in the framework of the Sun-Earth relationship, is now interested to the development of Space Weather activities. In 1999, in particular, the Italian Space Weather Initiatives in ESA has started under the IFSI-CNR coordination (Messerotti & Candidi 2002) and has been supported by ASI and MIUR (2000-2001). It involves mainly four topics:

- the study of phenomena generated on the Sun;

- the evolution of the above phenomena in space;

- the interaction of this phenomena with the Earth's magnetosphere;
- the effects of the above interaction with the Earth's ionosphere. The research is based on:
- Solar observations from the ground (optical and radio telescopes) and from space (SOHO),
- Solar wind measurements (CLUSTER, WIND),
- Magnetospheric field measurements (CLUSTER),
- Geomagnetic field measurements (SEGMA array and antarctic stations),
- Ionospheric measurements (ionosondes, riometers, all-sky camera, radar SuperDARN).

The research institutes which are involved in this initiative are:
- the Catania, Naples, Rome, Turin and Trieste Astronomical Observatories for the solar observations;
- IFSI-CNR for solar wind and magnetospheric measurements and for all-sky camera Artic and Antarctic observations;
- the University of L'Aquila for the geomagnetic field measurements through the newly established longitudinal array at low latitudes SEGMA and in Antarctica;
- INGV for ionospheric data at Rome and Gibilmanna (Palermo)

INGV also participates to the COST Action 271 (2000-2004) regarding the effects of upper atmosphere on terrestrial and Earth-space communications. Finally, it is important to mention the new initiative of SCOSTEP. The international SCOSTEP's mission is to implement research programs in solar-terrestrial physics that can benefit from international participation: for example the STEP program in 1990-95. CAWSES (Climate and Weather of the Sun-Earth System) is a major future program to be implemented in the period 2004 -2008 (Schmieder et al. 2002). It will provide a scientific approach to understand the short term (Space Weather) and long term (Space Climate) variability of the integrated solar-terrestrial environment and its societal applications.

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