CHAPTER 47

AFFECTS: Advanced Forecast For Ensuring Communications Through Space

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ABSTRACT

AFFECTS is a space research project under the seventh framework programme of the European Union. The natural hazards of space weather have the potential to catastrophically disrupt the operations of technological systems. In the AFFECTS project European and US scientists are developing an advanced prototype space weather warning system to safeguard the operation of telecommunication and navigation systems on Earth against the threat of solar storms in the timeline of March 2011 until February 2014. The project website is hosted at http://www.affects-fp7.eu

- Solar activity affects the entire Earth environment from the magnetosphere down to the ionosphere, and even to the lower atmosphere climate system. The natural hazards of space weather do not only modify the atmosphere. They also have the potential to catastrophically disrupt the operations of many technological systems, such as communication systems and power grids on Earth. Figure 1 summarises the different effects of space weather on the Earth's environment. Hence the impact of space weather for people's lives and jobs is very real, and as we approach solar maximum around the end of 2012, such risks increase. In the AFFECTS project, European and US scientists are developing an advanced prototype space weather warning system to help mitigate space weather effects on the operation of telecommunication and navigation systems.

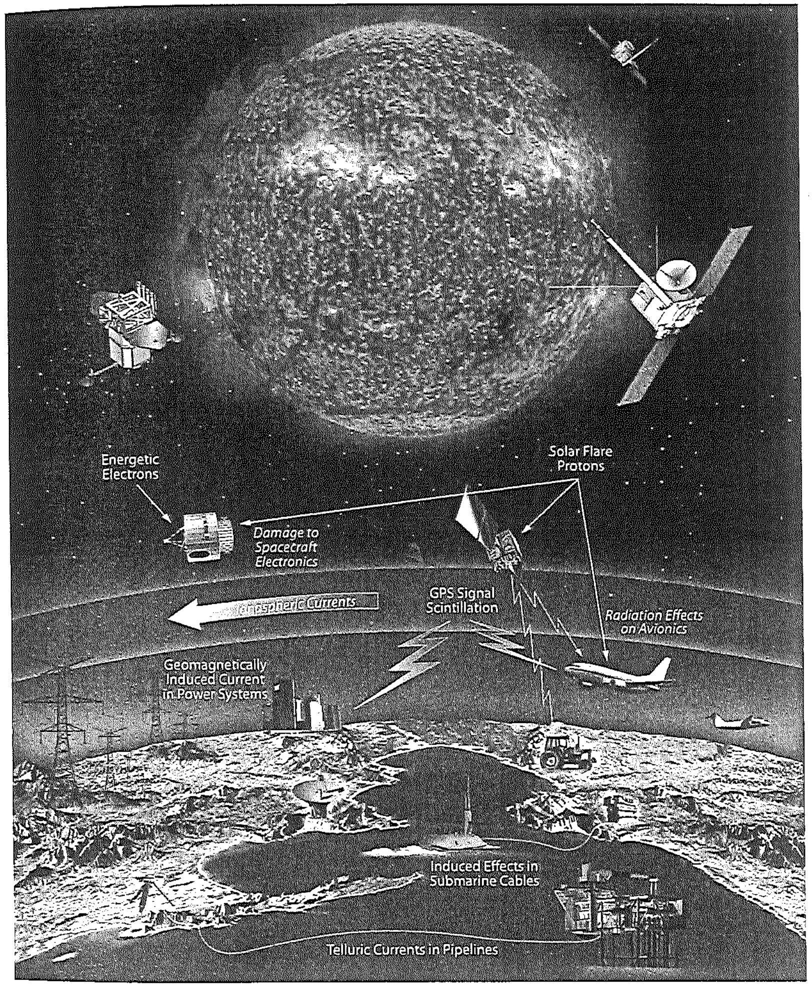

Figure 1. Summary of space weather on the terrestrial environment. Courtesy: NASA.

The key objectives of the AFFECTS project are:

- state-of-the-art analysis and modelling of the Sun–Earth Chain of Effects on the Earth's ionosphere and their subsequent impacts on communication systems based on multipoint space observations and complementary ground-based data;
- development of a prototype space weather early warning system and reliable space weather forecasts, with specific emphasis on ionospheric applications;
- dissemination of new space weather products and services to end users, the scientific community and the general public.

Solar storms are a consequence of sudden eruptions of magnetised gas in the Sun's outer atmosphere. Often such storms start with a sudden release of electromagnetic energy lasting for some minutes, accompanied by an eruption of a giant cloud of magnetised plasma — a coronal mass ejection (CME). The fastest of these 'space hurricanes' are accelerated to speeds of 10 million kilometres per hour and, if heading in the direction of Earth, reach our home planet at a distance of 150 million km in less than a day. Figure 2 provides a generic sketch of the phenomenon.

The impact of the coronal mass ejection on the Earth's magnetosphere causes a geomagnetic storm if the magnetic field of the coronal mass ejection is oriented antiparallel to the direction of the Earth magnetic field. Through the reconnection of the magnetic fields large-scale current systems are driven in the Earth magnetosphere causing severe space weather. Polar lights become visible even at equatorial latitudes, astronauts and airline crews and passengers become exposed to enhanced radiation doses in the form of energetic particles up to GeV energies, satellites in low Earth orbit experience enhanced orbital drag and can lose hundred of metres in height, navigation and telecommunication systems are affected or may even become completely disrupted locally. Power grid transformers can be severely damaged causing power outages, such as in Quebec in 1989 or in Malmö in 2003. For an overview on the subject the reader is referred to the book Space Weather — Physics and Effects by Bothmer and Daglis (eds., Springer/Praxis, 2007).

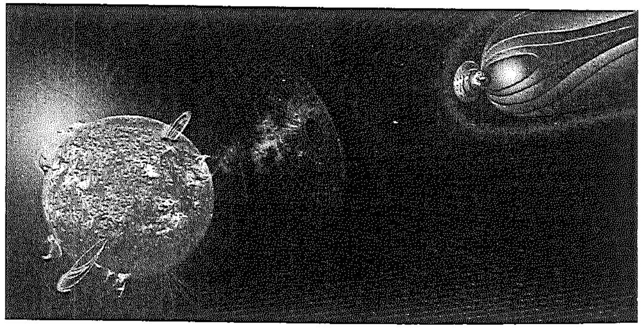

Figure 2. Sketch of a coronal mass ejection propagating towards Earth. Courtesy: NASA.

PROJECT STRUCTURE AND ACHIEVEMENTS IN YEAR ONE

The AFFECTS project has successfully completed its first year. The project is organised in the following six dedicated working packages (WPs):

- WP 1 Administrative, financial and legal management of the project.
- WP 2 Management of the flow of raw and calibrated data required for WPs 3 and 4 as input for early warning and for establishing beyond the state of the art tools and modelling. Maintenance of instruments and data sets and support of detector development. Definition of common data formats to be used for ionospheric, thermospheric and space weather modelling activities.
- WP 3 Development of an early space weather warning system.
- WP 4 Provision of tools to forecast geomagnetic indices for TEC (total electron content) maps. Mid-term forecast, modelling improvement and services for overall forecasting system/dissemination.
- WP 5 Development of an ionospheric forecast system for end users providing early warnings and forecasts

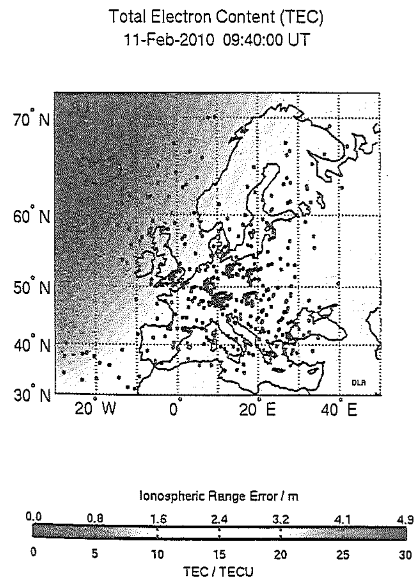

Figure 3. Map of Europe showing the ionospheric TEC conditions on 11 February 2010 and the corresponding ionospheric range error. Courtesy: DLR, SWACI (Space Weather Application Center Ionosphere, http://swaciweb.dlr.de).

of expected ionospheric perturbations deduced from analysis of solar, geomagnetic and ionospheric GNSS (Global Navigation Satellite System) data (see Figure 3).

- WP 6 Provision of overall space weather data and in particular early warnings and forecasts to end users, scientific community, and general public. Organisation of a user workshop.

Figure 4 summarises the working package activities, institutional responsibilities and interfaces between individual working packages, and also the general workflow of the project.

During the first year, the management of the project has successfully been set up according to the plans of WP1.

WP2 has the overall function to establish and maintain the pipeline of state-of-the-art data from instrumentation in the field, including both satellite and ground-based data to WP3 (early warning) and WP4 (Forecasting Tools and Modelling). For these purposes,

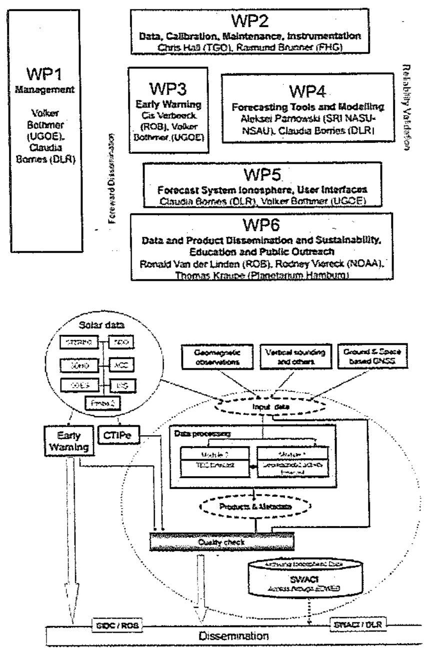

Figure 4. AFFECTS working package structure, institutional responsibilities and project workflow.

Web-Interface for EUV data, the L1 solar wind and geomagnetic indices database, AE activity monitoring and local indices and GNSS based ionospheric data, including vertical sounding data from auroral zone and polar cap ionosondes, have been established. The stream of data from instruments on board STEREO, SOHO, SDO, Proba2, ACE, GOES and ISS, and the ground-based magnetometer and ionosonde stations is smoothly maintained by the AFFECTS partners. Full magnetometer records are accessible since February 2012 to the project members to help study auroral space weather effects.

WP3 has as its main objective to help establish and maintain an early space weather warning system, with specific emphasis on ionospheric applications. The layout for the Early Warning System for GNSS Users has been designed. NOAA-SWPC provides 24/7 flare warnings, but during certain time intervals, the GOES instrument suffers from data gaps. Through a specific analysis of data from the Proba2 instrument, LYRA data can now be used to bridge these gaps with a measurement accuracy of about 10 %. Coronal mass ejection characteristics were derived from stereoscopic modelling and tracking of CMEs detected with STEREO/SECCHI. The results serve as input for the ENLIL CME simulation code in collaboration with NOAA-SWPC and D. Odstrcil at NASA/GSFC to help estimate proper arrival times for solar storms propagating to Earth since most CMEs are considerably decelerated en route to Earth, with the fastest ones having initial speeds above 2 000 km/s but substantially below 2 000 km/s at 1 AU. The alert time in extreme events can decrease to less than a day. Multiple events from individual active regions play a major role for extreme space weather as exemplified through solar activity on 1 August 2010 (Temmer at al. 2012). During the October 2003 storm the dTEC variation of about 30 TECU within several minutes (Tsurutani et al. 2006), corresponding to range errors of several tens of m. Convection of enhanced TEC fronts from the polar zones over Europe took place in less than an hour. Further quantitative event studies are under way.

The role of WP4 is to develop the core components of forecasting modules for integration in the Forecast System Ionosphere developed in WP5. The prototype software tools for forecasting geomagnetic indices Dst and Kp as indicators of CMEs impact on Earth (i.e. their geoeffectiveness) with three hours lead time have been developed (Parnowski 2011). Currently the maximum lead time which can be achieved is four hours in advance of solar storms. Alerts from the L1 ACE solar wind data allow 15–30 minute warnings.

WP5 has its objectives in reducing the impact of space weather phenomena on telecommunication and navigation systems through quantitative forecasts of ionospheric perturbations based on solar, geomagnetic and ionospheric data up to 24 hours in advance (Forecast System Ionosphere (FSI)). For this system, the architecture has been designed and processor modules are implemented and currently in their test phase. Online dissemination of TEC maps is under implementation at the SWACI AFFECTS website at http://swaciweb.dlr.de/affects/ and comparisons with the NOAA SWPC CTIPe (Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics model) are undertaken.

WP6 objectives are to disseminate overall space weather data and generated products, including early warnings, reports and forecasts to end users, the scientific community, and general public and the organisation of a user workshop. A dedicated website for data dissemination has been established in the environment of the DLR SWACI web service (see link provided under WP5). The website incorporates a solar, geomagnetic and ionospheric database. Additionally, it provides equivalent slab thickness products retrieved from vertical sounding data (UoT) and TEC data (DLR). AFFECTS analyses of several major space weather events have received overwhelming media coverage (newspapers, radio, journals, TV) since the start of the project in March 2011. The AFFECTS forecasts provided to the media have helped avoid deleterious warnings in these cases, based on determination of the CME speeds and directions of propagation. The layout of the early warning system has been completed and collaboration for dissemination of space weather reports to the general public has been established with the RTL media group through infoNetwork GmbH, Cologne, Germany. The SWACI TEC maps can be consulted in the NASA Space Weather App. for mobile phones. The AFFECTS project is featured through 'The Sun in 3D' DVD/blue-ray booklet and red and blue stereo glasses. The AFFECTS logo and trailer have been established and are available through the AFFECTS website at http://www.affects-fp7.eu.

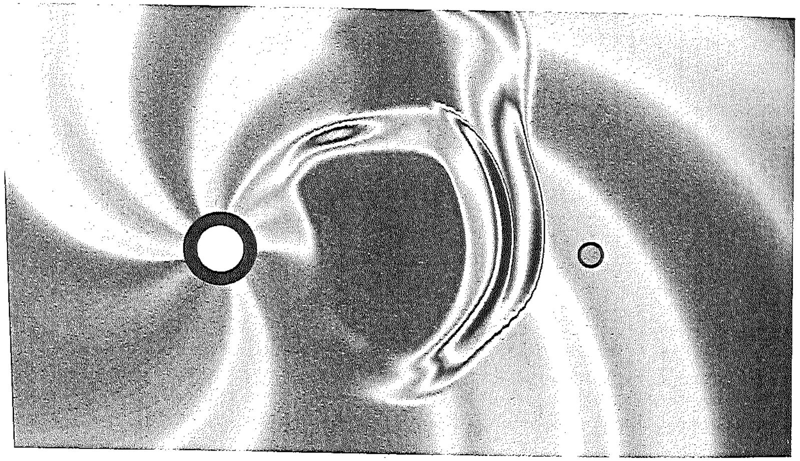

Figure 5. Simulation of the solar wind stream structure between Sun and Earth for a CME event approaching Earth in an 'onto the ecliptic view'. The different colours represent different solar wind densities, with red colours denoting high and blue colours denoting low plasma densities. The CME can be identified from its reddish shell-like pattern in front of the Earth, labelled as filled green circle.

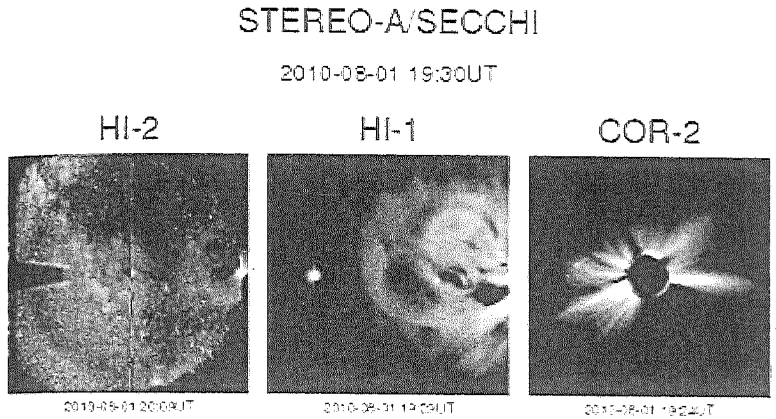

Figure 6. CME tracked from Sun to Earth on 1 August 2010 by the STEREO/SECCHI telescopes on board spacecraft A. Courtesy: STEREO SECCHI Consortium, RAL, NASA. The Sun is hidden by the external COR-2 telescope occulter. The CME is seen in the HI-1 image in the middle. The Earth is the small bright point in the center of the HI-2 image to the right. Bright spots in the HI-1 and HI-2 images are Mercury and Venus.

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