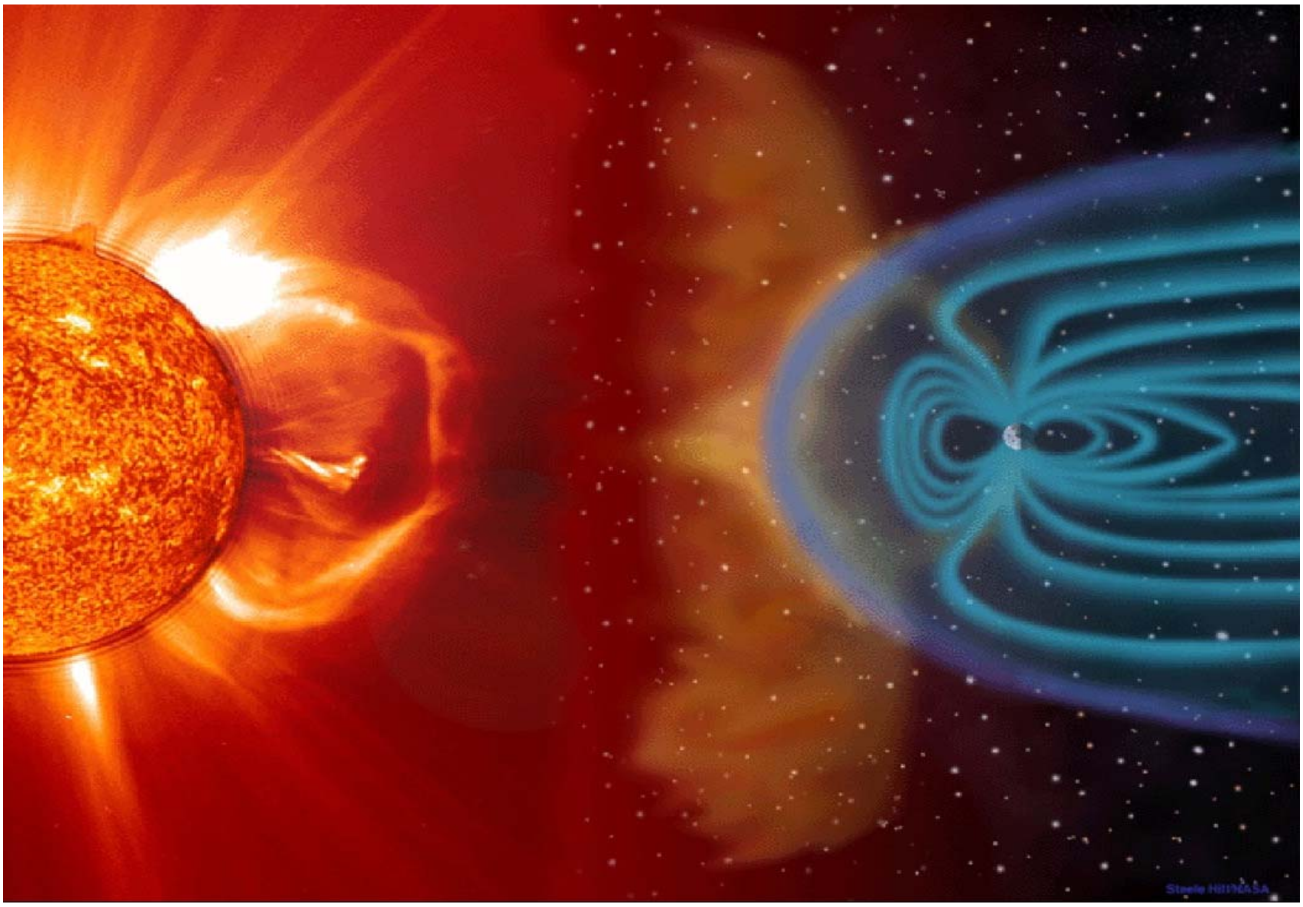
JRC Scientific and Technical Reports

The Space-Weather Awareness Dialogue: Findings and Outlook

An event hosted by the European Commission's Joint Research Centre
and co-hosted by the Directorate-General Enterprise and Industry
25-26 October, 2011, Brussels, Belgium

Elisabeth Krausmann



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European Commission
Joint Research Centre
Institute for the Protection and Security of the Citizen

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An event hosted by the European Commission's Joint Research Centre
and co-hosted by the Directorate-General Enterprise and Industry

25-26 October, Brussels, Belgium

Elisabeth Krausmann

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Executive summary

Our modern technological infrastructures on the ground and in space are vulnerable to the effects of natural hazards. Of increasing concern are extreme space-weather events such as geomagnetic storms - a recurring natural hazard caused by solar activity - that can have serious impacts on space- or ground-based infrastructures such as electrical power grids, telecommunication, navigation, transport or banking.

In view of the risk of catastrophic technological failure and the upcoming solar maximum expected in early 2013, the European Commission's Joint Research Centre together with the Directorate-General Enterprise and Industry organised a high-level 'Space-Weather Awareness Dialogue' in Brussels, Belgium, on 25-26 October 2011. The aim of the event was to raise awareness of the potential impact of space weather on critical infrastructures in space and on the ground, to identify scientific, operational and policy challenges for reducing the risk to susceptible critical infrastructures and services, and to recommend concrete actions to better protect them. This should address the full disaster-management cycle, including prevention, preparedness and response.

The Space-Weather Awareness Dialogue brought together about 70 high-level representatives from national organisations and authorities, international organisations with assets possibly affected by space weather, operators of critical infrastructures, academia, and European Union institutions. In the course of the discussions **consensus was reached on the following points**:

- Space weather is a threat to our critical infrastructures that needs to be addressed.
- The analysis of the space-weather threat to ground-based critical infrastructure (power grid, aviation, telecommunications, etc.) is of equal importance as the study of space-based infrastructures.
- There is no central entity that takes the lead in the space-weather community.
- The assessment of space-weather impact on critical infrastructures requires a multidisciplinary effort from all stakeholders (scientists, engineers, infrastructure operators, policy makers).
- Ageing satellites that monitor space weather need to be replaced.
- A framework for better structured communication between the stakeholders is required.
- Open space-weather data sharing is necessary for improving early warning and impact models.
- While there is some preparedness for normal space weather in some infrastructure sectors, nobody is fully prepared for extreme events.
- The topic of space-weather impacts would benefit from cross-sectoral discussion.
- Emergency exercises could help raise awareness of space-weather impact.
- International cooperation is required to cope with the problem as response capabilities may be beyond the capacity of individual countries.

With respect to the many facets of the threat of space weather the JRC will continue and enhance its coordinating efforts and scientific activities.

The US proposal of a virtual institute on "Society and Space Weather" will have to be assessed and a collaborative transatlantic approach for tackling both the space dimension and the critical-infrastructure dimension of space weather will be sought.

Background

Our modern technological infrastructures on the ground and in space are vulnerable to the effects of natural hazards. Of increasing concern are extreme space-weather events such as geomagnetic storms - a recurring natural hazard caused by solar activity - that can have serious impacts on space- or ground-based infrastructures such as electrical power grids, telecommunication, navigation, transport or banking. A recent study on the impact of a severe geomagnetic storm (1921 superstorm) on the US power grid showed that in a worst-case scenario extensive damage to or failure of the power grid could be expected due to geomagnetically-induced currents[1]. In terms of power-grid assets damage to high-voltage transformers is a likely outcome. With manufacture lead times of 12 months or more, this could be the bottleneck in the restoration process. Moreover, through cascading effects power outages could have a ripple effect and impact other services reliant on electrical power, leading to e.g. the disruption of communication, transport, the distribution of potable water, lack of refrigeration possibly resulting in a loss of food and medication etc[1]. For the simulated geomagnetic-storm impact scenario the societal and economic costs were estimated to be of the order of 1-2 trillion $US in the first year alone, and recovery times of 4-10 years depending on the suffered damage.

The European Commission Joint Research Centre's (JRC) research activities are dedicated to supporting the agenda Europe 2020 where space is one of the key elements of the flagship initiative "An industrial policy for the globalisation era". For this reason and in view of the upcoming solar maximum expected in early 2013, the JRC together with the Directorate-General Enterprise and Industry organised a high-level 'Space-Weather Awareness Dialogue' in Brussels, Belgium, on 25-26 October 2011. The aim of the event was to raise awareness of the potential impact of space weather on critical infrastructures in space and on the ground, to identify scientific, operational and policy challenges for reducing the risk to susceptible critical infrastructures and services, and to recommend concrete actions to better protect them. These actions should address the full disaster-management cycle, including prevention, preparedness and response.

The Space-Weather Awareness Dialogue brought together about 70 high-level representatives from national organisations and authorities, international organisations with assets possibly affected by space weather (ESA, WMO, EUMETSAT), operators of critical infrastructures, academia, and European Union institutions. The Dialogue was actively supported by senior officials of the JRC, Directorate-General Enterprise and Industry, Directorate-General Mobility and Transport, Directorate-General Humanitarian Aid & Civil Protection, and the US National Oceanic and Atmospheric Administration (NOAA). The programme and the list of participants are provided in Annex 1 and 2.

Summary of topical key findings

The event was structured into six sessions organised as panel discussions with more than 40 panellists over the two-day programme. The first day featured an introduction to the space-weather phenomena, as well as panel discussions on the impact of extreme solar activity on ground- and space-based infrastructures and services. The sessions of the second day addressed the challenges of forecasting the severity, time of impact and geographical coverage of space-weather events and subsequently the preparedness of operators and public services and their management of possible damage to infrastructures. The final session collected the main messages from the foregoing sessions and tried to establish a roadmap tracing the route from awareness to action at EU policy level and beyond.

[1] Severe space weather events – understanding societal and economic impacts, A workshop report, US National Research Council, The National Academies Press, Washington, D.C., ISBN: 0-309-12770-X, 2008.

Session 1: Space weather today

The five panellists of the first session discussed the basics of space-weather phenomena and introduced the potentially disastrous impacts on critical infrastructures on and around the Earth. Generally, from a solar-physics point of view great progress had been made in understanding the solar processes which are at the origin of space weather. However, their predictability is still very poor. This is on the one hand due to space weather manifesting itself in multiple ways, such as e.g. radio bursts, solar energetic particles, coronal mass ejections, etc. The extremes of these phenomena need to be better understood, as well as any possible correlation between them. On the other hand, the data used for model development and validation go back only 20 to 40 years which is too short a timescale for reliable model development and validation. A problem mentioned in this context is the reliance of data collection on an ageing fleet of satellites. In the US no replacements are currently foreseen e.g. for ACE and SOHO, and ESA would be welcome to complement NASA satellites. This was also echoed during the ensuing discussions where the development of a European capacity for forecasting purposes was called for to improve the reliability of predictions and reduce the likelihood of false alarms. The EC was asked to play a key role in supporting any such initiative.

The panellists agreed that space- and ground-based systems could be severely affected by space weather and that awareness of this risk needs to be raised in order not to be surprised. The US is very concerned about the possible impact of space weather on critical infrastructures and hence on the society and economy. The greatest risk in this context appear to be geomagnetically-induced currents (GIC) that can wreak havoc with the power grid. With longer and longer power lines to transport electricity over big distances, the power grid’s vulnerability is increasing. For getting a true measure of the risk, credible impact scenarios are required so that associated mitigation measures can be defined.

There was agreement that a major space-weather event could happen anytime although most big events would be expected to occur around the solar maximum and shortly afterwards in the declining phase of the cycle. Continued preparedness is therefore paramount. Overall, a lack of operational procedures for rapidly protecting infrastructures (similar to procedures against space debris) was indicated and the wish was expressed that the EC play a role in facilitating the development of harmonised procedures.

There are several national initiatives that address the threat of space weather, and examples were given for France, Germany and the US. Mostly, these initiatives focus on the provision of operational services to end-users relying on precise navigation services using GPS (off-shore drilling, aviation, etc.), such as the Space Weather Application Centre Ionosphere (SWACI) in Germany, or to prevent space-weather impact during space-craft launches (Meudon Observatory in France). In order to address the multidisciplinary problems related to the space-weather threat, the US are contemplating the idea of establishing a dedicated international (virtual) space-weather institute pulling together all relevant stakeholders.

The main conclusions from Session 1 are:

- The space-weather hazard has always existed, but the **vulnerability of the society is increasing**.
- Many **infrastructures and the services** they provide are recognised as **susceptible to space weather**.
- Extreme space-weather events are **low-probability/high-consequence events** for which risk assessment is difficult.
- There are **uncertainties in models** forecasting space-weather events, modelling the impact on critical infrastructures and in the definition of countermeasures to be adopted.

- There is a **lack of impact scenarios and likelihood estimates** necessary for preparedness.
- The dynamics and complex interaction of space weather with infrastructures should be **catalogued** for lessons-learning purposes by **collecting data on incidents for post-event analysis**. Data ownership needs to be clarified and possible problems of data sensitivity overcome.
- There are some national space-weather related initiatives but **international cooperation** is deemed a necessity for successfully tackling the problem. In this context the US is contemplating the setting up of an international virtual "Society and Space Weather" Institute.
- A concerted effort is needed for **improving predictability and infrastructure impact models**.
- Prediction is largely dependent on data from an **ageing fleet of satellites** launched for scientific purposes. While noting the need to replace outdated systems, a need was voiced for a European operational monitoring system.
- A forward-looking strategy for risk mitigation is needed that keeps pace with the development of new vulnerable technologies (**future-proof structure**).

Session 2: Impact on space-based infrastructures and services

This session and its seven panellists aimed at shedding light on the potential impact of space weather on space-based infrastructures, such as e.g. those required for satellite navigation, communications, broadcasting, earth observation, meteorological services, etc. Politically, space infrastructures are of increasing importance as many services they provide, e.g. communication and navigation, are critical for society and the economy. Satellite operators and manufacturers are well aware of the space-weather threat and address the problem through robust satellite design and integration. They feel that the associated risks are manageable. Current satellites are hardened to resist space-weather events with a severity similar to those of the recent past, and they have built-in redundancies to cope with space-weather related anomalies. Unless there is a total systems failure, operators can preserve compromised services by moving them to adjacent satellites. A better understanding of the effects of space weather could help to optimise designs and harden the satellite in a cost-effective way.

Although satellites in general tend to outlive their planned service life there have been space-weather related incidents. The main effects on the space infrastructure itself are due to e.g. electrostatic charging, degradation of electronics and solar-cell damage, memory bit-flips, atmospheric drag that affects the satellite's orbit, loss of stability (star tracking), etc. The services provided can be heavily influenced by ionospheric disturbances that affect the signal transmission from the satellite to the ground receivers. This can affect, for instance, GNSS signals that in turn can impact other services (aviation, offshore exploration, time stamping, etc.). Due to the sensitivity of GNSS receivers they are a powerful tool to monitor space-weather effects in the ionosphere. It was pointed out that usually multiple space-weather impacts take place during the same solar storm.

In terms of data availability or generation a need for a coordinated standardised system for data sharing was expressed (there exist already several national systems). This requires the establishment of international data-exchange protocols and a data policy that ensures the commercial confidentiality of data. Several satellite operators have their own space-environment sensors aboard their infrastructures, and this information is shared in the frame of the Space Data Association (SDA). The information received by the SDA is translated into a standard format and then transmitted to all SDA members for warning purposes. Currently, about 300 satellites are tracked in SDA. It was suggested that space-weather data could be included in the GEOSS initiative. A number of ESA SSA space-weather segment services support the mitigation of impacts.

Overall, it was felt that Europe needs to invest in more research on better understanding the space environment and space-based sensors (hosted payloads) while at the same time exploiting all existing assets in orbit for impact monitoring. This research should lead to operational services which require, however, sustainable funding, a data policy that facilitates the exchange of existing data while protecting sensitive information, and dedicated operators. In this context the role of the EU (as owner of assets) and of the EU Member States needs to be clarified.

The main findings from Session 2 are:

- Space infrastructures have a strong political importance considering that many **space-based services are critical** for the smooth functioning of society.
- **Current satellites have built-in redundancies to resist** the effects of space weather as experienced during the last 20 years.
- The understanding of space-weather effects should be improved to help **optimise designs** (i.e. avoiding costly ‘over design’). **Resilience could be obtained through better engineering** (cost-effective hardening and redundancy).
- Space weather can **affect the space infrastructure itself or the service it provides** (communication, navigation). As a consequence, GNSS disturbances can affect other services and infrastructure that depend on GNSS services, possibly leading to **potential cascading effects** in telecom networks, power grids, aviation, etc.
- GNSS receivers are **powerful tools to monitor space-weather** effects in the ionosphere.
- **Risk-assessment** and data-sharing capabilities similar to the existing practices for space debris should also be developed for space weather.
- **Standards for data exchange** should be developed or existing ones updated to guarantee reliable data provision and data-sharing among stakeholders. This requires a data policy regarding sensitive data.
- **Improved modelling and model validation** are necessary to better understand space-weather phenomena and their potential impact on GNSS.
- A **greater number of sensors** should be deployed and all possible assets in orbit be exploited to monitor space-weather impact. Hosting SSA sensors on other payloads should be considered where possible.

Session 3: Impact on ground-based infrastructures

The six panellists in this session highlighted the potential direct or indirect effects of space-weather phenomena on ground-based infrastructures. Representatives from various sectors discussed space weather and power-grid operations, aviation safety and air traffic control, and underground pipelines. Some minor problems were experienced by the Swedish (2003) and the UK power grids (1989). Due to the increasing understanding of the physics of GIC and its effects on the grid, and building on the experience with space weather in the past, the Swedish transmission system has implemented some protective measures and should be able to handle the space-weather levels encountered in the recent past. There is, however, concern on how to cope with more extreme space weather (e.g. a 100 or 500 yr-event). SCADA systems may increase the reliability of the power grid. In the UK the worst incident saw two high-voltage transformers damaged which had to be replaced. Several operational measures for responding to space-weather impact are available but depend on timely and reliable advance warning.

GIC forecasting is, however, still in its infancy, and current warning times may not be sufficient to bring transformers back from maintenance or spare transformers online. The 7th FP EUROGISC project (European Risk from Geomagnetically Induced Currents) aims at producing the first European-wide real-time prototype forecast service of GIC in power systems, based on in-situ solar wind observations and comprehensive simulations of the Earth's magnetosphere.

The vulnerability of aviation is increasing due to a growth in air traffic and the inherent susceptibility of certain trajectories during space-weather events (polar routes). The aviation sector has experienced the 2003 events and has since been implementing the lessons learned. In the UK there is an open discussion on the scale of the problems space weather could cause. Air traffic control depends on many infrastructures, e.g. navigation, power and communication. Resilience has been implemented through redundancy in the UK, with e.g. spare frequencies, two networks, diversity of function, alternative ways for communication over the Atlantic if HF fails during space-weather events, etc. Moreover, big aircraft are required to have alternative terrestrial navigation capability in case GPS becomes unreliable. The air-traffic sector is regulated and requires the preparation of safety cases by the operator.

While several ground-based infrastructure sectors have experienced (minor) space-weather effects, and consequently some knowledge and best practices for risk reduction exist, there is no exchange of lessons learned or views between the vulnerable sectors. Generally, the industry at large may not be aware of the problem and may be running risks. Moreover, with the development of new and possibly susceptible technologies that may be even more interconnected, more robustness and redundancies may be required in the future.

The main conclusions from Session 3 are:

- Space weather is an **emerging risk**.
- A systematic **mapping of all possibly affected infrastructures and services** may be necessary.
- Some sectors and operators within these sectors seem aware of the problems of normal space weather (which should be verified) but they are **not prepared for an extreme event**.
- The **scale of impact of an extreme event is unknown**.
- There is **increasing vulnerability** due to network design and growing interdependencies.
- There is concern that ground-based infrastructure operators are **collectively unprepared for extreme events**.
- Space weather could be **included as an additional hazard in the risk assessment** against other natural hazards.
- Some strictly regulated sectors, such as aviation, have **backup systems** in case GPS navigation fails, while other transport sectors, like maritime traffic, do not.
- There is **no cross-sectoral discussion and communication**.
- In the absence of impact scenarios increased **financing** for improving preparedness is difficult to argue.

Session 4: Early warning

This session and its six panellists addressed the challenges in forecasting space-weather events and possible gaps that need to be tackled to ensure reliable and timely warning for infrastructure operators.

Despite best efforts the forecasting capability is practically nil due to a need for improving our predictive modelling and because the effects of some solar events (EUV radiation or X-rays) hit the earth already 8 minutes after their creation. Solar energetic particles have arrival times of 10-30 minutes. There is more lead time for predicting geomagnetic storms caused by coronal mass ejections (18-96 hrs) and this is being used for warning power-grid operators. This service is commercialised in the US where operators of power grids and the Department of Defence pay for obtaining the relevant data. Possibly implemented measures following early warning are e.g. deferring maintenance for power grids or avoiding polar routes for the aviation sector. It was mentioned during the discussions that while we may not be able to say with any certainty when an event will happen, we can say with some confidence that nothing (or nothing substantial) is going to happen within a certain period of time. This could already be useful information for an end-user.

Predictive modelling can be improved by more scientific research and validation of existing models against latest data, facilitating the sharing of data (efficient mechanisms for global data exchange are in place), and collaboration between stakeholders within the EU but also internationally. This would also help get the various stakeholder groups to work together which would already be an important first step in tackling the problem. An important obstacle that may hamper these efforts is the fact that many national governments or operators do not fully appreciate the risks posed by space weather or understand possible mitigation strategies. It may require a high-impact event for governments or industry to take action.

Early-warning capabilities also depend on the availability of space-weather assets (satellites/missions) that provide continuous, timely and reliable observational information that addresses the needs of the end-users. Discussions are underway internationally on whether and how to replace the ageing observational infrastructures. Decisions for future payloads or missions targeted towards space weather need to be taken now. ESA is analysing the existing assets for fulfilling space-weather related user requirements in the frame of the ESA-SSA programme. If needs are identified the a proposal for improving capabilities will be made.

The discussions also highlighted that early warning in itself is not enough. The users of forecasting services need to be involved in tailoring them as e.g. engineers in power companies need to know how to react to the early-warning information that is provided to them. Guidelines for industry could be helpful in clarifying how to use the provided information.

The key findings from Session 4 are:

- The space-weather **forecasting capability is very limited** despite best efforts.
- Further scientific research including validation is required to improve predictive modelling.
- Due to ageing, scientific observational infrastructure **dedicated to space-weather and associated payloads and missions are needed**.
- Many **stakeholders do not understand the risks** presented by space weather, let alone the mitigation measures. This needs to be addressed.
- Early-warning information provided to the users must be **timely, reliable and useful**.
- Industry needs **guidelines** on how to use and take advantage of early-warning information.
- **Stress tests and emergency drills** are important to identify gaps in scientific models, vulnerabilities of impacted infrastructures, and weaknesses in response procedures.
- **Data sharing** is essential.

Session 5: Risk management and preparedness

In this session five experts in risk management and risk governance discussed preparedness aspects for space-weather events and their consequences on critical infrastructures. The reinsurance industry is interested in the definition of worst-case scenarios as there is too much uncertainty regarding the occurrence probability of an extreme space-weather event. The risk of common-failure modes and hence the ripple effect of space weather to many sectors within a relatively short time frame is high, which could lead to the accumulation of losses if the baseline scenarios are too optimistic. The pre-conditions for e.g. a black-out need to be identified, the associated impact scenarios defined, and the insurance coverage situation overlaid. In addition, the impact of risk prevention and mitigation measures also needs to be quantified.

From the space-insurance perspective space weather is currently perceived a low concern with only few claims due to space-weather related damage. An explanation could be that anomalies may not have been claimed, as satellites have redundant systems, or that space weather was not recognised as the root cause of damage. During the severe space weather in 2003 reportedly 45 satellites were affected with 1 science satellite being a total loss. However, no claims were filed with the insurer. Generally, space insurance believes that preparedness levels are low. Satellites may have been designed to resist events of the magnitude of the 1989 and 2003 events but not for the 1921 or the 1859 Carrington event.

From a crisis-management point of view science is a necessary ingredient for building preparedness but it is not sufficient. There are a number of institutional and governance issues that are of equal importance. For one thing responsibilities and lines of communication need to be defined before an event happens so that everybody knows when and how to react in the case of a warning. Consequently, emergency-response protocols need to be ready and tested before severe space-weather strikes. This can be achieved by civil scenario-based exercises or drills (stress tests) that help raise awareness of the stakeholders (whole-society approach) and to identify gaps and weaknesses in the emergency procedures. The unalterable fact that there will always be budget constraints requiring a setting of priorities can be bypassed by to the greatest extent possible building generic and not necessarily specific response capacities that can then be applied to several domains. This is valid in general for impossible trade-off situations.

The European Commission is tasked with establishing a list of the risks the EU is facing now, as well as emerging risks. Moreover, the Member States are committed to undertaking a national risk assessment based on guidance from the European Commission. Including space weather into the list of emerging risks could help increase the communication of hazards and associated risks and improve preparedness. Social media can play an important role in communicating risks effectively to give a warning without causing panic.

The main key points from Session 5 are:

- There are **high economic stakes** involved.
- The insurance industry needs worst-case scenarios for **exposure assessment**.
- Many **uncertainties** in managing the space-weather risk are **not related to science but to institutional/governance issues**.
- Input on risk management is required not only from physical science but also from **social science**.
- Risk management of space-weather impacts requires a **multidisciplinary, international effort**.

- The concepts of risk perception and risk acceptability are important: **emergency exercises** could help the raising of awareness and to test institutional emergency procedures.
- G**eneric** and not necessarily specific **risk management capacities** should be built that can be applied to several domains. This can help avoid impossible trade-off situations.
- It is important to **learn from past events** to build capacities.
- **Social media** can play an important role for disseminating information on the space-weather threat.

Main conclusions of the space-weather awareness dialogue

The final session wrapped up the previous sessions by focusing on the key messages from the foregoing dialogue and by discussing them in more detail while trying to achieve a reconciliation of the different views. The issue of data availability and sharing was brought up again, confirming previously mentioned ideas and opinions. All possible sources of relevant data should be exploited (including in Russia, and observation capabilities in Armenia and Tajikistan). It was added that it is essential to define which data needs to be shared as not all data will be of equal relevance for tackling the problem of space-weather impact on infrastructures. It was also mentioned that some data-sharing coordination mechanisms exist already and these should be exploited before coming up with something completely new. This is also valid for data-sharing standards which are available but might have to be updated to accommodate the requirements of space-weather data users. While decisions in the past to build science satellites that deliver data on solar activity are helping us through the current solar cycle, it is now time to decide on new missions from which we will benefit in the future.

On the infrastructure-impact side worst-case scenarios for extreme space weather but also realistic scenarios for average space weather have to be defined for impact assessment. Currently, there is a lack of detailed knowledge on how space weather can affect certain infrastructures and what the consequences will be. Consequently, there is also a gap in the development of adequate and cost-effective mitigation measures. This has resulted in different levels of preparedness across the various infrastructure sectors. In general, preparedness is, however, considered low. There is a clear need for this issue to be addressed with some urgency.

The civil-protection community, which needs to be involved in any effort to manage the risk from severe space weather, is reliant on scenarios and guidance from scientists, engineers and operators. A holistic view is therefore required that brings together all these disciplines and includes also governance issues. In order to move forward it was suggested to move along four tracks, which are 1) understanding extreme space weather (which is of particular concern for insurance), 2) effects of normal and extreme space weather on space- and ground-based infrastructures to understand weaknesses, 3) preparedness which requires a link with policy-making institutions, and 4) data, which is necessary but not sufficient.

With all participants agreeing that space weather can severely impact our critical infrastructures and with the problem possibly being beyond the coping capacity of single nations it was suggested to create a network of all stakeholder organisations (science, industry, operators, policy makers) that come together regularly to exchange views and discuss progress made. Starting from this Space-Weather Awareness dialogue a more permanent discussion process that will shed light on all aspects of the space-weather hazard should be established.

The participants of the Space-Weather Awareness Dialogue highly appreciated the initiative of the European Commission to organise this event and its involvement in space-weather activities. They agreed that this forum was an excellent opportunity to bring together all relevant stakeholders, from solar scientists to grid operators and policy makers, who previously did not have the opportunity to meet. The momentum from this event should be used to define if and how the EC can help continue the started dialogue in which **consensus was reached on the following points**:

- Space weather is a threat to our critical infrastructures that needs to be addressed.
- The analysis of the space-weather threat to ground-based critical infrastructure (power grid, aviation, telecommunications, etc.) is of equal importance as the study of space-based infrastructures.
- There is no central entity that takes the lead in the space-weather community.
- The assessment of space-weather impact on critical infrastructures requires a multidisciplinary effort from all stakeholders (scientists, engineers, infrastructure operators, policy makers).
- Ageing satellites that monitor space weather need to be replaced.
- A framework for better structured communication between the stakeholders is required.
- Open space-weather data sharing is necessary for improving early warning and impact models.
- While there is some preparedness for normal space weather in some infrastructure sectors, nobody is fully prepared for extreme events.
- The topic of space-weather impacts would benefit from cross-sectoral discussion.
- Emergency exercises could help raise awareness of space-weather impact.
- International cooperation is required to cope with the problem as response capabilities may be beyond the capacity of individual countries.

Outlook

Space weather is a concrete and recurring threat to critical infrastructures, be they based in space or on the ground; therefore, concerted action is required to achieve adequate levels of global preparedness. Contrary to the notion that space weather primarily affects space-based infrastructures and services, possible impacts on the ground are of equal importance, whereas space-based assets seem reasonably resilient to space-weather impact.

Several participants of the Space-Weather Awareness Dialogue expressed the hope that the EC would take the lead in facilitating a more permanent discussion process on the space-weather threat that would include all concerned stakeholders. In addition, the EC was called upon to coordinate possibly fragmented activities that would eventually lead to increased preparedness including efficient data exchange, model improvements and validation, impact-scenario development, and guidance for accident prevention and mitigation. The EC is well positioned to take on this challenge due to the availability of its own independent science service, the JRC, and its natural interest and duty in assessing the impact of hazards , including space weather, on European Union policies, such as e.g. on the European Critical Infrastructure Directive which is currently under review.

With respect to the many facets of the threat of space weather the JRC will continue and enhance its coordinating efforts and scientific activities.

The US proposal of a virtual institute on “Society and Space Weather” will have to be assessed and a collaborative transatlantic approach for tackling both the space dimension and the critical-infrastructure dimension of space weather will be sought.

ANNEX 1

PROGRAMME OF THE SPACE-WEATHER AWARENESS DIALOGUE

Space-Weather Awareness Dialogue

European Commission, Berlaymont Bldg., Schuman Room, Rue de la Loi 200, Brussels, Belgium

PROGRAMME (DAY 1) - 25 OCTOBER 2011

Registration of participants (9:30 – 10:20)

Opening of the Space-Weather Awareness Dialogue

Duration: 30 minutes (10:30 – 11:00)

- **Dominique Ristori**, **Director General**, Joint Research Centre, European Commission and **host of the event**
- **Marco Malacarne**, **Acting Director**, Space Security and GMES, Directorate-General Enterprise and Industry, European Commission, and **co-host of the event**

Session 1: Space Weather Today – Introduction

Duration: 1.5 hours (11:00 – 12:30)

Moderator: **Stephan Lechner**, Director, IPSC, Joint Research Centre, European Commission.
Rapporteur: Elisabeth Krausmann, Senior Scientist, Joint Research Centre, European Commission.

Panellists:
1) **Norbert Jakowski**, Team Leader, Institute of Communications and Navigation, DLR, Germany
2) **Mike Hapgood**, Head, Space Environment Group, RAL Space, UK
3) **Patrice Brudieu**, Deputy Director, Directorate for Strategy, Programmes and International Affairs, CNES, France
4) **Stephanie R. Langhoff**, Chief Scientist, NASA Ames Research Centre, USA
5) **Volker Bothmer**, Senior Lecturer and Project Lead Stereo/Corona, University of Göttingen, Germany

Lunch (12:30 – 14:00)

Session 2: Impact on Space-Based Services and Infrastructures

Duration: 2 hours (14:00 – 16:00)

Moderator: **Reinhard Schulte-Braucks**, Head of Unit, Space Research and Development, Directorate-General Enterprise and Industry, European Commission
Rapporteur: Pravir Chawdhry, Senior Scientist, Joint Research Centre, European Commission

Panellists:

1) **Mikael Rattenborg**, Director of Operations, EUMETSAT
2) **Nicolas Bobrinsky**, Head, SSA Programme Office, ESA/ESAC
3) **René Oosterlinck**, Adviser to the DG of ESA and State University of Ghent, Belgium
4) **Aarti Holla-Maini**, Secretary General, European Satellite Operators' Association
5) **Olivier Lemaitre**, Head of Brussels office, ASD-Eurospace
6) **Joaquim Fortuny-Guasch**, Senior Scientist, Joint Research Centre, European Commission
7) **Gerald Braun**, Deputy Head, Space Situational Awareness Centre, Federal Armed Forces, Germany

Coffee break (16:00 – 16:30)

Session 3: Impact on Ground-Based Infrastructures

Duration: 2 hours (16:30 – 18:30)

Moderator: **Paul Verhoef**, Head of Unit, Research and Innovative Transport Systems, Directorate-General Mobility and Transport, European Commission
Rapporteur: Alois J. Sieber, Head of Unit, Security Technology Assessment, Joint Research Centre, European Commission

Panellists:

1) **Mikael Odenberg**, Director General, Swedish National Grid
2) **John Vincent**, Deputy Director Strategic Safety, European Aviation Safety Agency
3) **Ken Ashton**, Head of Navigation and Spectrum, NATS En-route Ltd., UK
4) **Phil Lawton**, Grid Operations 2020 Manager, National Grid plc, UK
5) **Aleksandar Jovanovic**, CEO, European Virtual Institute for Integrated Risk Management, Germany
6) **Ari Viljanen**, Senior Scientist, Finnish Meteorological Institute

Dinner (19:30) on invitation by the host

PROGRAMME (DAY 2) - 26 OCTOBER 2011

Session 4: Early Warning

Duration: 1.5 hours (9:00 – 10:30)

Moderator: **Delilah Al-Khudhairy**, Head of Unit Global Security and Crisis Management, Joint Research Centre, European Commission
Rapporteur: Alessandro Annunziato**,** Senior Scientist, Joint Research Centre, European Commission

Panellists:

1) **Tom Bogdan**, Director, Space Weather Prediction Center, NOAA, USA

2) **Mark Gibbs**, Government Service Manager, UK Met Office
3) **Juha-Pekka Luntama**, Head, SSA-SWE Segment, ESA
4) **Ronald van der Linden**, Director General, Royal Observatory of Belgium
5) **Barbara J. Ryan**, Director, WMO Space Programme, World Meteorological Organisation
6) **Chris Davis**, Head, Solar Stormwatch, UK

Coffee break (10:30 – 11:00)

Session 5: Risk Management and Preparedness

Duration: 1.5 hours (11:00 – 12:30)

Moderator: **Tom Bogdan,** Director, Space Weather Prediction Center, NOAA, Boulder, USA
Rapporteur: Elisabeth Krausmann, Senior Scientist, Joint Research Centre, European Commission

Panellists:
1) **Reto Schneider**, Director, Swiss Reinsurance Company Ltd.
2) **David Wade**, Chief Space Underwriter, Atrium Space Insurance Consortium
3) **Bengt Sundelius**, Special Adviser, Swedish Civil Contingencies Agency
4) **Ian Clark**, Head of Unit, Civil Protection Policy, Prevention, Preparedness and Disaster Risk, Directorate-General Humanitarian Aid & Civil Protection, European Commission
5) **Zarko Sivcev**, Adviser COO, Directorate Network Management, Eurocontrol

Lunch (12:30 – 14:00)

Session 6: From Awareness to Action

Duration: 1.5 hours (14:00 – 15:30)

Moderator: **Alois J. Sieber**, Head of Unit, Security Technology Assessment, Joint Research Centre, European Commission
Rapporteur: Pravir Chawdhry, Senior Scientist, Joint Research Centre, European Commission

Panellists: Moderators for Sessions 1-5

Closing of the Space-Weather Awareness Dialogue (15:30-16:00)

ANNEX 2

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SPACE WEATHER

Awareness Dialogue

25-26 October 2011

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Abstract
Our modern technological infrastructures on the ground and in space are vulnerable to the effects of natural hazards. Of increasing concern are extreme space-weather events such as geomagnetic storms - a recurring natural hazard caused by solar activity - that can have serious impacts on space- or ground-based infrastructures such as electrical power grids, telecommunication, navigation, transport or banking.

In view of the risk of catastrophic technological failure and the upcoming solar maximum expected in early 2013, the European Commission's Joint Research Centre together with the Directorate-General Enterprise and Industry organised a high-level 'Space-Weather Awareness Dialogue' in Brussels, Belgium, on 25-26 October 2011. The aim of the event was to raise awareness of the potential impact of space weather on critical infrastructures in space and on the ground, to identify scientific, operational and policy challenges for reducing the risk to susceptible critical infrastructures and services, and to recommend concrete actions to better protect them. This should address the full disaster-management cycle, including prevention, preparedness and response. The Space-Weather Awareness Dialogue brought together about 70 high-level representatives from national organisations and authorities, international organisations with assets possibly affected by space weather, operators of critical infrastructures, academia, and European Union institutions. In the course of the discussions a consensus was reached on the following points:

- Space weather is a threat to our critical infrastructures that needs to be addressed.
- The analysis of the space-weather threat to ground-based critical infrastructure (power grid, aviation, telecommunications, etc.) is of equal importance as the study of space-based infrastructures.
- There is no central entity that takes the lead in the space-weather community.
- The assessment of space-weather impact on critical infrastructures requires a multidisciplinary effort from all stakeholders (scientists, engineers, infrastructure operators, policy makers).
- Ageing satellites that monitor space weather need to be replaced.
- A framework for better structured communication between the stakeholders is required.
- Open space-weather data sharing is necessary for improving early warning and impact models.
- While there is some preparedness for normal space weather in some infrastructure sectors, nobody is fully prepared for extreme events.
- The topic of space-weather impacts would benefit from cross-sectoral discussion.
- Emergency exercises could help raise awareness of space-weather impact.
- International cooperation is required to cope with the problem as response capabilities may be beyond the capacity of individual countries.

With respect to the many facets of the threat of space weather the JRC will continue and enhance its coordinating efforts and scientific activities.

The US proposal of a virtual institute on "Society and Space Weather" will have to be assessed and a collaborative transatlantic approach for tackling both the space dimension and the critical-infrastructure dimension of space weather will be sought.

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The mission of the JRC is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.

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