WORKING GROUP 2: FORECASTING SPACE WEATHER - SCIENTIFIC ROAD MAP

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ABSTRACT

This paper is a summary of the ideas and conclusions that came out of 3.5 hours of open floor discussion on Friday the 13 November 1998 at the 'ESA Workshop on Space Weather'. The Statement of Work for Working Group 2 was defined as: Forecasting Space Weather - Scientific Road Map: what is needed as operational models, observations (both real-time and past data), theoretical breakthrough (model development next 2-5 years in Europe). It was stressed that these plannings should also address the needs of potential users. In terms of Space Weather forecasts, we address mainly the actual forecasting and not atmospheric research. Conclusions of the working group indicate that observers and modellers have much to contribute in the Space Weather arena in the new millenium.

Key words: Space Weather, scientific road map, observations, models.

1. INTRODUCTION

Working group 2 consisted of approximately 70 participants, equally divided between observers and modellers. The goal of the working group was that everybody should have a possibility to make comments, give suggestions and input during this session. The outcome of the discussion is summarised in this paper.

The first part of the session consisted of defining the major questions about effects of the Sun on the interplanetary space, its coupling with the magnetosphere and its effects at Earth. After a fruitful discussion a list of open questions was formulated:

1. Who are the potential users/customers for our statement of work?
2. What are the most important effects of Space Weather conditions on spacecraft and ground based systems?
3. What are the Space Weather phenomena that cause these effects?
4. When, how far ahead, and how accurate do we want to predict these phenomena?
5. What is required in Solar-Terrestrial Physics to predict Space Weather?
6. How can we establish reliable prediction techniques?
7. Which funding services can be envisaged to finance these services?

These questions are addressed in Sections 2–6, except for question 7, which was not discussed due to a lack of time. The paper ends with a conclusion of the outcome of the Friday morning discussions.

2. WHO ARE THE USERS?

We decided, according to the main goals of the Space Weather workshop to discuss the statement of work from the potential user/customer point of view. Basically the users can be divided into 'technical users' and 'biological users'. Figure 1 presents a schematic overview of the potential user community.

2.1. Technical Users

There is a multitude of potential technical users/customers both for space and Earth purposes, many of which have common interests. For example, spacecraft problems may cause disturbances in transmission to Earth and thus affect our daily life on Earth.

Spacecraft operators need reliable predictions of events that can cause anomalies or failures in order to schedule operations or take protective action.

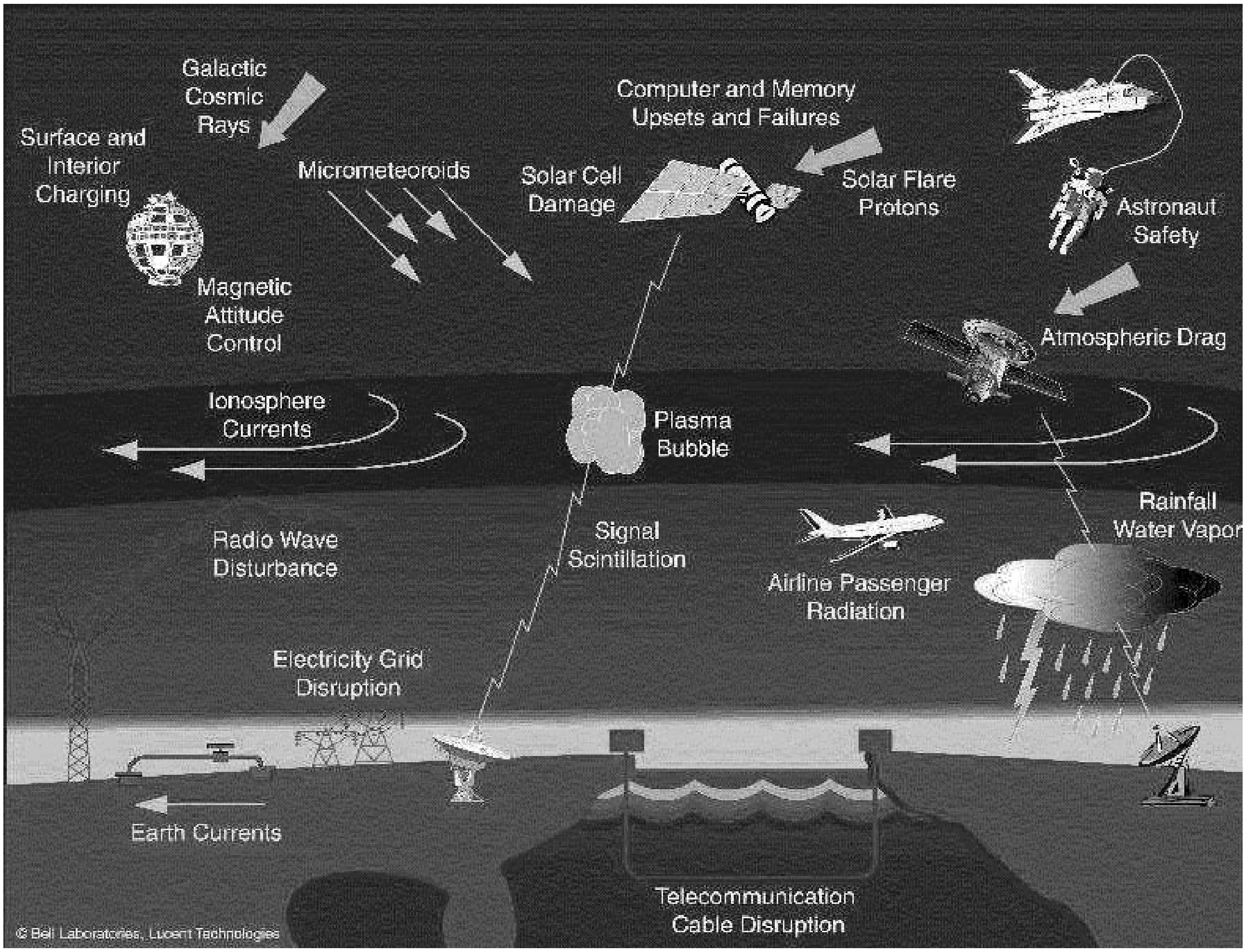

Figure 1. Overview of the user community for Space Weather products (Courtesy of Bell Laboratories Lucent Technologies)

Potential ground based customers are powerline companies, oil companies and telecommunication industry. Technical problems affecting network transmission, localisation, radar, positioning, communication problems effects on synthetic aperture radar systems, global positioning systems (GPS), geomagnetic surveys, powerline failures and corrosion effects observed in pipelines on Earth are important. However, it is not always clear if Space Weather prediction techniques are sufficiently reliable to warrant shutdowns of systems or rescheduling of activities: false alarms can obviously cause unnecessary loss of productivity, wheras failure to predict events can lead to damage in systems. The potential customer has to decide whether he needs Space Weather predictions or not, but the Space Weather community has to provide more information on the accuracy of predictions if reliable cost effectiveness studies are to be carried out. For more information see (Lanzerotti, L., Thomson, D., Maclennan, C., 1997).

2.2. Biological Users

For future extended missions such as the International Space Station, the protection of astronauts from Space Weather effects, for example, from solar proton particle events is crucial. There must be ample time to reach protection during extravehicular activity (EVA) as emphasised by Michael Golightly in his review talk (these proceedings). Furthermore, aircraft crew and passengers are under risk of radiation especially on polar routes. Thus airlines are potential Space Weather customers before a plane takes off and even during flight. As cancellation of a flight requires clear threshold limits an international definition of permitted doses for manned missions and aircraft has to be investigated.

2.3. Summary

One participant asked a question that poses other questions for debate: Do users need forecasts or just measurements, for example: Are “forecasts” of cosmic rays arriving at Earth necessary or is local cosmic ray monitoring (neutron monitors) sufficient? We as a scientific community need to know in precise detail what it is the users want! We also need to ask the question: Which effects can we predict? This is important because the connection between the effect, the space environment, and the actual cause (phenomenon) has to be defined, which led us to the topic of the next section.

3. SPACE WEATHER PHENOMENA AND EFFECTS

In this section, we present a list of the main effects of Space Weather on satellites and ground systems, and the phenomena that cause them (see also the review talk paper by Clive Dyer in these proceedings). This list is not exhaustive, as in general different environments contribute to one type of effect, and many anomalies and failures are caused by a combination of effects. A better understanding of the effects of Space Weather could be achieved if more information were available on anomalies and failures of commercial and military systems.

The list below is presented in terms of environments, and their respective effects (descriptions of effects in parentheses are not repeated):

- cosmic radiation (protons and highly ionising heavier nuclei):
  - SEEs in electronics
  - background noise in sensor systems
  - effects in aircraft systems and sea level electronics through production of atmospheric secondaries
- inner radiation belt (energetic protons and electrons):
  - ionising dose damage (life expectancy reduction of electronics, cancerogenic dose in humans)
  - non-ionising energy loss (degradation of solar panels and CCDs, detector noise)
  - SEEs in electronics
  - surface charging anomalies
- outer radiation belt (energetic electrons)
  - cumulative dose and damage effects
  - deep dielectric charging (responsible for numerous anomalies and some losses)
  - surface charging anomalies
- solar particle events:
  - increased rates of SEUs
  - contribution to ionising dose and non-ionising energy deposit
  - communication disruptions
  - significant enhancements in radiation at supersonic aircraft altitudes
- geomagnetic storms:
  - communication and radionavigation disruptions
  - ionospheric scintillation (degradation of GPS accuracy)
  - overloads in power systems and railway networks
  - corrosion of pipelines
  - offshore drilling (drill bit alignment using geomagnetic field direction)
- solar activity:
  - changes in atmospheric drag (potential loss of tracking)
  - radar fade-outs during X-ray flares

It was pointed out that meteroids and debris can also be included in the 'Space Weather' debate. This is a question that should be looked at more seriously as the particulate component of the space environment is affected by solar activity.

For system operations and scheduling the primary concern is to be able to predict the occurence of harmful events, whereas predictions of effects such as drag and dose are of second order. What are the phenomena in the Solar-Terrestrial enviroment that cause the main problems for users: the arrival of X-rays (or cosmic radiation), solar particle events, solar wind alterations in the interplanetary medium, or solar wind induced variations in the inner and outer radiation belts, etc.?

From the Sun itself a wealth of energetic manifestations, for example, particles, radiation, and coronal mass ejections (CMEs), are constantly entering the interplanetary medium. There was a general agreement that CMEs and not solar flares are the troublemakers and the cause of the strongest energetic interplanetary particle events that can cause hazardous radiation effects. It was noted that not only CMEs, but also coronal holes (origin of the fast solar wind) and interaction regions of the fast and slow solar wind (co-rotating interaction regions) need to be observed.

CMEs are undoubtedly the most powerful solar wind drivers of magnetospheric processes at the Earth. In the inner magnetosphere, they produce a deep and long-lasting enhancement of highly relativistic electrons (HREs) that are partly responsible for satellite failures. However, CMEs are not the only phenomenon to be predicted as stated above. A mild solar wind also drives energy to the magnetosphere depending on its velocity and, especially, on its magnetic field strength and orientation. This leads to substorm activity that may be harmful, for example, for polar orbiting satellites traversing the auroral region.

The cause and effect of each potential 'canditate' described above depends on the user's interest and what may be important to one user may be irrelevant to another user. Thus it is important to define a time frame for predictions for each effect, which is treated in the next section.

4. WHEN, HOW FAR AHEAD, AND HOW ACCURATE DO WE WANT TO PREDICT THE SPACE WEATHER PHENOMENA?

The requirements for the time scales and precision of predictions are to be set by the future users of Space Weather forecasting services. However, as a short reference, we give here some time scales that were identified in the discussions during the workshop.

Power companies ask for the probability of a geomagnetic storm the day before maintenance and if there is a storm they postpone maintenance. The Advanced Composition Explorer (ACE) satellite that was launched in 1997 provides warnings one hour ahead for power companies to shift loads or grounds in transformers. When scheduling geomagnetic surveys, a 27-day forecast is desired two to four weeks in advance. Off-shore drilling uses the geomagnetic field to orient drill bits and that drilling stops at Kp greater than 7. X-ray flares have to be predicted 1–3 days in advance for fade-outs (this has to be refined, as the size of the predicted flares is important). Other time scales from the potential users are 0–24 hrs for telecommunications, real time in ionospheric maps, 0–2 hrs for navigation, and 1 day for drag effects.

Satellite operators want to know about anomalies about one day ahead, but for mission planning longer time scales are needed. For magnetic storm effects, the time scales vary from one day to one week depending on the particle populations considered. For example, spacecraft internal charging events occur in about one day, whereas surface charging may happen in minutes or seconds (it was pointed out that low energy electrons constitute a fluence problem in spacecraft charging and that build-up takes days before effects happen, so that keeping track of conditions is important). Scintillation effects for GPS users are difficult to correct for, and should have a prediction time of a couple of hours.

5. WHAT IS REQUIRED IN SOLAR-TERRESTRIAL PHYSICS FOR PREDICTIONS?

The essential driver of Space Weather (at geospace, the Earth's orbit, etc.) is the continuous variability of the solar activity along with the more distinctive 11-year solar cycle. Therefore, when we discuss solar-terrestrial physics we are in fact referring to the Sun-Earth connection. Solar activity manifestations propagate from the solar surface, through the interplanetary medium to the Earth orbit, interacting with the magnetosphere and with subsequent ionospheric and atmospheric consequences.

Variations of the solar wind conditions can trigger unwanted effects. However, the forecast time from the L_1 point is too short compared to the time scales given in the previous section. Forecasts from conditions on the Sun would result in longer forecasting times, but in order to achieve this capability theoretical breakthroughs and comprehensive overviews of events are needed. Observations are needed! The future STEREO mission will predict CMEs towards Earth (forewarning is 1.5-5 days). In this section, we discuss first theory and models, and then observations and data.

5.1. Theory and Models

To predict radiation belts one day ahead both solar wind parameters (pressure, velocity, and IMF orientation) and planetary indices (Kp and Dst) are required. Thus these have to be defined through modelling conditions a day ahead. Predictions of the global index Kp directly from solar wind parameters is now possible. For the solar wind parameters this means continuous monitoring of solar wind conditions or continuous coronal observations and MHD modelling for the solar wind output at Earth's orbit. Planetary indices are difficult to provide in short term, but can be done if there is any specific need. Along with the Kp index, current directions are needed as well: it should be possible to derive them from $B_{\rm imf}$ directions in real time and to develop a model.

Modelling of the ionosphere-plasmaphere electron density height profile is essential in ionospheric Space Weather forecasting. Emphasis was placed on the relevance of the COST project for this purpose. For navigation purposes, total electron count (TEC) maps and scintillation index S_4 are important. It was pointed out that the storm time evolution of the ionosphere has to be known better (polar cap boundary/solar protons).

Reliable atmospheric models are crucial:

1. they form a boundary condition for the radiation belt and inner magnetosphere models;
2. increased atmospheric temperature must be considered during the launch and re-entry phases of spacecraft;
3. Space Weather may have long-term effects on the Earth's climate (relevant to whole population).

As stated in Section 3, CMEs are the prime trouble-makers for users. Unfortunately, they are also the trouble-makers for Space Weather forecasting and related research. Thus CMEs are one central topic in Space Weather related solar-terrestrial research (e.g. provide predictions on CME onset, speed relative to solar wind, and mass). Precursors to CMEs have to be found. The direction of CME propagation and orientation of its magnetic field are vital. These topics still require basic research in addition to predictions.

The signatures of the solar activity are directly linked between the 'cause' of these signatures and their 'effects'. It was stated that we need to be able to predict high speed solar wind streams. Interplanetary scintillation measurements can be used to model the speed and density of propagating mass.

The modelling of the solar corona is still a very hot topic. New observations from various spacecraft (Yohkoh, SOHO, Ulysses, TRACE, ACE, etc.) are providing us with a wealth of information concerning the complicated physics of the Sun. It was pointed out (see review talk paper by Volker Bothmer in these proceedings) that future missions (e.g. STEREO, Solar Orbiter) will provide us with many of the essential parameters that are necessary to obtain realistic models of the structure of the corona and heliosphere and for the first time it will become possible to directly observe solar disturbances from the Sun to Earth. Furthermore missions such as STEREO will help in the understanding of the onset, structure and evolution of CMEs.

5.2. Observation and Data Availablity

The ideal situation is continous monitoring of the Sun, solar wind, radiation belts, and ionosphere.

At present there is much data available (both from space-borne and ground-based observatories). However, the old databases need extensions not only for prediction purposes, but also for better calibration with other databases. Existing but not well-known databases can perhaps give us new information using new analysis techniques and/or comparisons with new models.

It was emphasised that Russia has a large set of real-time data that is available for use by the community. The importance of collecting long, uninterrupted time series of data and of keeping ground stations operational was stressed. The goal of the COST project is that data from different stations should be gathered and distributed in centra, ideally in real time.

Cosmic Ray variations give information about interplanetary conditions and there exists a large network of more than 40 stations.

Rapid dissemination of data is vital and therefore data should be available not only on the satellite, but also in the relevant data centres. Long data series for all fields are needed!

We need to understand the onset of CMEs, flares, the source of the solar wind and magnetic field structure. To accomplish this, solar wind parameters (density, duration, velocity) are essential. Also, global changes, for example in the solar corona, must be understood to give us an overview picture of what is going on on a smaller scale (spatial and time). These goals can only be reached by coordinated efforts between the modellers and the observers, i.e. by 'teamwork'.

6. HOW WILL WE KNOW THAT WE ARE IMPROVING?

In order to measure progress in establishing reliable prediction techniques, an evaluation process has to be defined to regularly compare current prediction accuracies with older methods. Naturally, new forecasting methods cannot be validated with historical methods.

Continuous monitoring of the Sun, solar wind, radiation belts and ionosphere was emphasised strongly by this working group. This is possible with a few polar, elliptical, geo-stationary and heliocentric satellites. But we should not forget ground-based observations either.

Finally we need to see if our models are getting better in predicting what will happen (i.e. if the error bars on time scale and precision get reduced).

It is important to stress that Space Weather research is an interdisciplinary science which strongly enhances understanding the links in the chain of physical processes between the Sun (corona, solar wind, interior) and the Earth's magentoshere, ionosphere, etc.

7. CONCLUSIONS

All participants agreed that good models and continuous data are needed, especially continuous monitoring of the Sun, solar wind, radiation belts and ionosphere. To achieve this, we need a fleet of well-equipped satellites in different orbits (polar, elliptical, geostationary, heliocentric).

The main conclusions of the session are:

1. Space Weather forecasting is not the same as Solar-Terrestrial research;
2. the ability to predict the occurence of harmful events is primordial, whereas predictions of effects such as drag and dose are of second order importance;
3. long data series are important;
4. Friday 13$^{\text{th}}$ is a nice day for working group sessions in Space Weather studies.

Finally, let us not forget that perturbations of systems can give information about Space Weather. Thus what sometimes may seem like an undesired effect may in fact indirectly help us in the understanding of the dynamic space environment.

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REFERENCES

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