ESTEC/Contract No. 14069/99/NL/SB
European Space Weather Programme (ESWP) Study
WP 410 System Requirements Definition

European Space Weather Programme System Requirements Definition

ESWP-DER-SR-0001
Issue 1.0 April 20th, 2001

DERA report no. DERA/KIS/SPACE/CR010157

Cover + x + 86 pages

February 2001

Authors : Lesley M.Murphy, David J.Rodgers

ESA Technical Officer : Dr. A.Hilgers, D/TOS (TOS-EMA)

This document is subject to the release conditions printed on the reverse of this page

DERA

DERA is an Agency of the UK Ministry of Defence

Customer Information	
Customer Reference Number	ESWP-DER-SR-0001
Project Title	European Space Weather Programme Study
Customer Name	European Space Agency (ESA)
Customer Contact	Dr.A.Hilgers, D/TOS, TOS-EMA
Contract Number	ESTEC contract no. 14069/99/NL/SB
Milestone Number	Not applicable
Date Due	16/02/2001

This document was produced by DERA for the European Space Agency under Order/Contract reference 14069/99/NL/SB

Authorisation

Prepared by	L.M.Murphy
Title	Project Manager
Signature	
Date	
Location	DERA Farnborough

Principal authors

Name	L.M.Murphy
Appointment	Project Manager
Location	DERA Farnborough

Name	Dr. D.J.Rodgers
Appointment	Senior Scientist
Location	DERA Farnborough

Record of changes

Issue	Date	Detail of Changes
0.1	29/01/01	First draft for internal review
0.2	09/02/01	Second draft addressing comments from internal review
1.0	20/04/01	First issue addressing customer comments and further internal review comments on previous draft

Abstract

This document first presents a set of User Requirements for a possible future European Space Weather System (ESWS). It then presents a set of System Measurement Requirements (SMRs) derived from, and traceable to, each individual User Requirement. Since many User Requirements result in the same (or very similar) System Measurement Requirements, a final consolidation process is carried out to remove duplicate requirements. The end result, ie. the consolidated set of System Measurement Requirements, is recommended as the starting point for detailed definition of ESWS design concepts.

Executive summary

This document presents a set of system measurement requirements that may be used as a starting point for the definition of a future European Space Weather System (ESWS). It is envisaged that the ESWS would form part of a potentially wide-ranging European Space Weather Programme (ESWP) which would encompass other activities such as basic scientific research and model development. The work presented in this report forms part of a pre-feasibility study of a potential ESWP, sponsored by the European Space Agency (ESA).

In developing the system measurement requirements, a key consideration has been to ensure traceability to an underlying set of user requirements. The main foundation for the user requirements was a market analysis exercise carried out in an earlier phase of this study which included a series of interviews with potential users of space weather information and services. Because of the differing viewpoints of the interviewees, careful consideration of the market interview findings was necessary in some cases to ensure the correct interpretation. The table of user requirements presented in this report provides traceability to the market interviews as well as necessary comments on their interpretation.

The system measurement requirements are presented in a set of tables (one table for each relevant user requirement). These tables provide a guide to the type of information needed to meet each user requirement as well as the model processes needed to generate that information. A comment on the availability and/or maturity of the necessary model process is also included. In general, each identified model process generates a number of system measurement requirements, depending on the input data it requires. Each system measurement requirement comprises a concise statement of the physical parameter to be measured and the necessary spatial and temporal sampling.

The system measurement requirements (SMRs) have been captured and presented separately for each user requirement in order to ensure traceability. However because the same space weather data can often meet the needs of several users, there is inevitably a considerable amount of repetition in the individual SMRs. For ease of reference, a consolidated version of the SMR tables is therefore presented in which the duplicated requirements have been removed.

It is recommended that the consolidated system measurement requirements be used as the foundation for the ESWS space and ground segment definition work to be carried out in the next phase of this study. However, since the size and scope of the proposed ESWP has yet to be decided, it is not possible at this stage to present a definitive set of ESWS requirements. This will depend on key decisions regarding the size and scope of the ESWP (assuming such a programme is approved), and in particular on whether a small, medium or large scale programme is to be pursued.

List of contents

List of Tables

List of Figures

1 Introduction

1.1 Purpose

1.1.1 The purpose of this document is to specify a set of *system measurement requirements* that may be used as a starting point for definition of a future European Space Weather System (ESWS).

1.1.2 The idea behind ESWS is to establish a European system or service to support user requirements for space weather information that are not adequately met by current systems or whose future provision cannot be guaranteed. It is envisaged that this would form part of a wider European Space Weather Programme (ESWP) which would encompass other activities such as basic scientific research and model development. A rationale for the overall programme is presented in [1].

1.1.3 This document has been produced for the European Space Agency (ESA) as part of study to investigate the potential benefits, technical feasibility, cost and programmatic issues surrounding the development of a ESWP. The requirements for this study [2] include consideration of a number of programmes of different scale (in terms of technical complexity, level of benefit to users and cost). In particular the study requirements call for consideration of at least three space segment options, viz.

- A ‘full scale’ space segment requiring development of new instruments and spacecraft platforms.
- A concept based on the addition of ‘hitchhiker’ space weather payloads (standard plasma, field or radiation environment monitors) to planned European spacecraft.
- Use of existing and planned space assets developed under the space programmes of ESA member states, with no supplementary hardware development.

1.1.4 A key objective has been to ensure that the system measurement requirements are traceable to user requirements which have been established through an earlier market analysis exercise [3].

1.1.5 The scale of the proposed future ESWP has yet to be decided (indeed one of the purposes of this study is to provide input to the decision-making process). Clearly, if it is decided to pursue a small scale programme using only existing and planned space assets, then the ESWS system requirements will not include any *new* measurement requirements. However there will still be a need to define which of the existing or planned data sources are to be exploited by the system. A medium scale programme based on the use of hitchhiker payloads would be expected to address at least some of the system measurement requirements specified in this document. In order to justify the higher costs of a large scale programme involving the development of new instruments and spacecraft, it will be necessary to demonstrate that the ESWS meets a greater number of user requirements (compared to a medium scale programme). This will imply a need to meet more (though not necessarily all) of the system measurements requirements specified here. Whatever the size of the ESWP programme, some required measurements may be obtained through international co-operation agreements.

1.1.6 An ideal ESWS would address the full set of system measurements requirements specified in this document, thereby meeting all identified user needs. However, in practice this may not be possible due to cost and/or technical constraints. The system measurement requirements presented here are therefore intended to provide a guideline for the space and ground segment definition tasks (Work Packages 420 and 430 of this study) but should not be interpreted as firm system requirements at this stage. It is anticipated that a subset of the requirements will be selected following completion of the space and ground segment definition work.

1.2 Scope

1.2.1 This document considers only the ESWS system *measurement* requirements derived from underlying user requirements. Specification of more general ESWS system requirements (such as requirements relating to the ground segment processing, data distribution, etc.) are outside the scope of the task as set out in the proposal [4].

1.3 Structure of this document

1.3.1 This document is structured as follows.

1.3.2 Section 2 provides an overview of the methodology used to develop the system measurement requirements.

1.3.3 Section 3 discusses the definition of a set of User Requirements (URs) which are based largely on the findings of the market interviews described in [3]. The User Requirements are presented in tabular form in Appendix A.

1.3.4 Section 4 discusses the definition of the System Measurement Requirements (SMRs). These requirements are presented in a set of tables (one for the SMRs associated with each UR) in Appendix B.

1.3.5 Appendix C presents a final consolidated set of System Measurement Requirements formed from the individual tables in Appendix B.

2 Overview of methodology

2.1 This section outlines the method that has been used to generate a consolidated set of system measurement requirements for use in subsequent space and ground segment definition studies. The main stages of the process are illustrated in Figure 1.

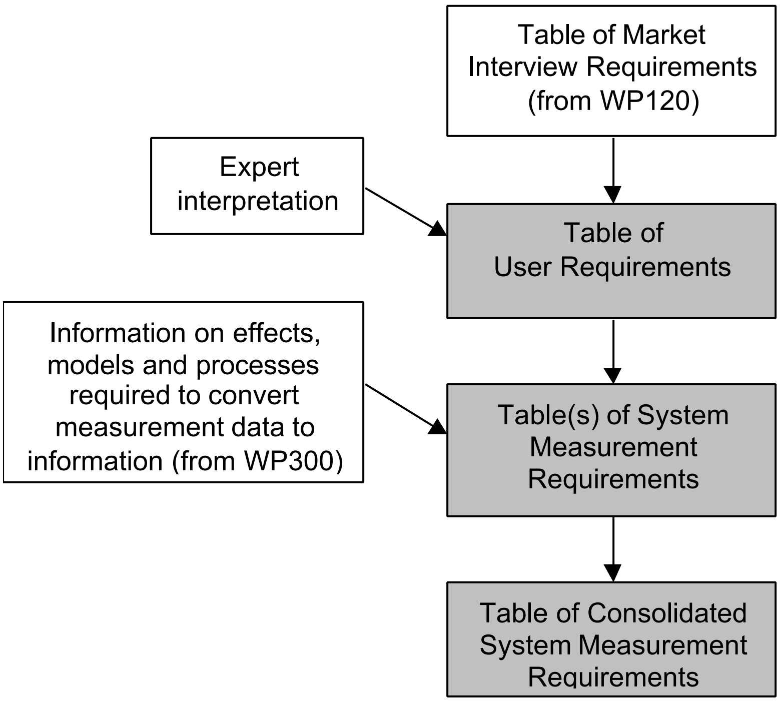

Figure 1; Stages in the requirements definition process

2.2 The first step was to establish a set of user requirements that could be used as the basis for the system requirements definition. The main input to the user requirements definition was the market analysis exercise described in [3], one of the outputs of which was a table of Market Interview Requirements (MIRs).

2.3 Although the MIRs cover most of the key user requirements, they are not in themselves adequate as a statement of the user requirements. The main problem with the MIRs as established in the market interviews is a tendency to mix both top-level and more detailed data requirements. (Note: This is not intended as a criticism of the market interview exercise but is simply a reflection of the fact that the exercise captured the views of a range of potential users who are not themselves experts in space weather and who have differing levels of understanding of the subject). It was found necessary to apply some expert interpretation to the MIRs in order to generate a consistent and comprehensive set of user requirements. Details of this process are discussed in section 3.

2.4 For traceability purposes, each user requirement has been assigned a 'UR' number and the MIRs to which it is related recorded in the User Requirements (UR) table.

2.5 Having established a reasonably consistent and comprehensive set of User

Requirements, the next step in the process involved identification of the System Measurement Requirements needed to meet each UR. This was a detailed process requiring information on the effects, models and processes required to convert measurement data to information. The Effects Catalogue [5] and Rationale report [1] produced under WP300 of this project provided the main source of information for this analysis.

2.6 The process described above resulted in a table of System Measurement Requirements (SMRs) for each User Requirement with the exception of URs 23, 24 and 25 which are general requirements, ie. unrelated to specific measurement requirements. Details of the SMR table structure are presented in section 4.2.

2.7 The reason for separately identifying the SMRs associated with each UR is to ensure traceability back to the original user requirements. However this inevitably results in some duplication of SMRs. The final stage in the process is therefore to remove this duplication, resulting in a single table of 'Consolidated' System Measurement Requirements (CSMRs).

2.8 Once again, for traceability purposes each consolidated system measurement requirement is assigned a CSMR number and the SMRs to which it is related are identified in the CSMR table.

2.9 Figure 2 illustrates the mappings that relate the various categories of requirements considered in this analysis.

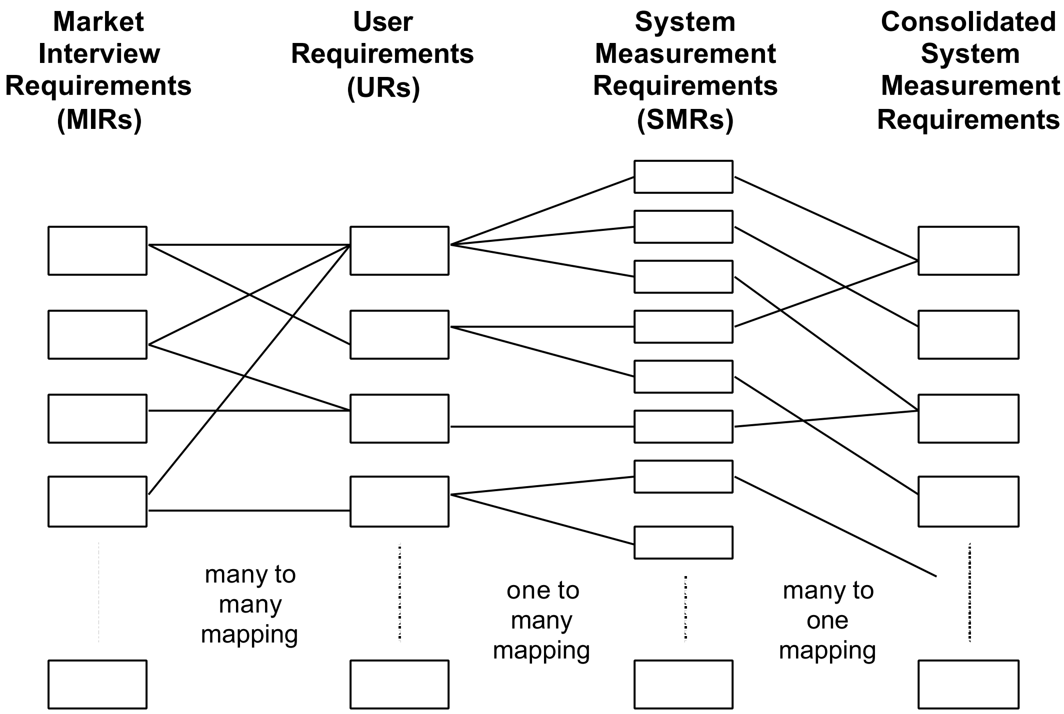

Figure 2; Mappings between requirement

3 User Requirements definition

3.1 Interpretation of the Market Interview Requirements

3.1.1 The market analysis report [3] provides the key input to creating the User Requirements. However the Market Interview Requirements (MIRs) as listed in table 5 of [3] include both top-level and detailed data requirements depending on the viewpoint of the user. In order that these user needs can be used to establish the detailed system requirements, it has been necessary to combine them into a more uniform set of User Requirements (URs). At the same time, duplicated requirements requested by different user groups have been eliminated.

3.1.2 Some additional user groups, not specifically mentioned in the MIRs but identified in the Effects Catalogue [5], have been added where they are expected to share similar requirements. Some MIRs do not specify whether information is required before, during or after real-time. Also, some users who specified a need for forecasts did not state whether now-cast or post-event data were also valuable, in the event that forecast data was unavailable or of insufficient accuracy. (In general, it is to be expected that forecasts will be of much lower accuracy than real-time data). Hence some interpretation of the MIRs has been necessary.

3.1.3 Some of the requirements obtained from the market interviews are *system* rather than *user* requirements, eg. MIR15 refers specifically to proton flux measurements. In this case, the underlying user requirement for information has been captured and the MIR mapped to this requirement (or requirements).

3.1.4 Timeliness indicates how far in advance forecasts should be, how near real-time now-casts should be and how soon after the event post-event information should be. Most MIRs contain a timeliness requirement and some contain more than one. Some interpretation has been necessary to determine which is most relevant and to prevent a physically unachievable timeliness requirement being specified. However, those times should be treated as reasonable goals and not as minimum thresholds for any benefit. Poorer performance can often still have benefits, albeit diminished ones.

3.1.5 From the Effects Catalogue [5], two significant effects were identified for which no MIRs had been specified. These were areas (viz. manned space flight and launchers) where no market interviews had been carried out. Since manned space flight is not yet a commercial market (which was the focus of the market analysis exercise), its absence is not surprising. In the case of launchers, the small number of launch providers within Europe may explain why a suitable interviewee was not identified. However the Benefits Analysis report [6] produced under WP110 of this project has identified that there are significant financial benefits to be generated in both these areas. Hence, even though it has not been established that there is a market for space weather information, user requirements have been specified in both these areas.

3.1.6 Most of the MIRs identified in [3] relate to specific market areas. However MIRs 17-20 are classified as 'general' and require additional comment. MIR17 and MIR18 as given in [3] are essentially direct statements of *system* requirements. The underlying *user* requirements have been interpreted as a user need for continuous data availability during and after extreme events (MIR17) and in the event of premature failure or end-of-life of key space weather systems (MIR18). To this has been added a further user requirement on data distribution and availability. This was implicit in the earlier MIRs but needs to be explicitly stated here to ensure that data handling is given appropriate weight in the system definition phase that follows.

3.1.7 MIR19, which specified prediction timeliness, was too unclear to be translated into a user requirement. It presumably related to a specific problem a user had in obtaining an unspecified type of data. MIR20, which requested storm forecasts without stating which users requested it, was too general to be explicitly converted into a user requirement. However, storm forecasts are an implicit part of all the forecasts that have been specified.

3.2 User Requirements table

3.2.1 The User Requirements have been compiled into a table structured as shown in table 1 below.

UR number	A reference number for the User Requirement
User priority	A priority level reflecting the importance of meeting the requirement in terms of impact on the user's business or operations, defined as: 1 = highest priority (major impact on user's business or operations) *or* 2 = secondary priority (some impact on users' business or operations)
User requirement	A concise statement of the information product required by the user
Timeliness	A guide to the user's timeliness requirement, ie. the time lag between a measurement being made and useful information being received by the user
User	Description of the user by broad market category
Market evidence	Where applicable, a reference to one or more MIR's to which the UR is related
Interpretation	Comments on the interpretation of the MIRs for the purpose of UR definition.

Table 1; User Requirements table structure

3.2.2 It should be noted that User Requirement priorities have been tentatively assigned by the authors on the basis of information gathered during the market assessment and benefits analysis exercises ([3], [6]). The priority scale has been limited to two levels due to the difficulty in justifying a more precise ranking on the limited evidence available at this time.

3.2.3 The User Requirements (UR1-25) are tabulated at Appendix A. Note that UR1-22 are essentially information *product* requirements, in that they entail the provision of certain types of data. UR23-25 are essentially *service* requirements since they relate to data availability, continuity and distribution.

4 System Measurement Requirements

4.1 Development from the User Requirements

4.1.1 The approach taken in this analysis has been to identify the system measurement requirements associated with *each* UR (excluding UR23-25 which are not applicable) before consolidating these measurement requirements into a single set.

4.1.2 The first step in the process is to identify the type of information needed to satisfy the user requirements. These information types are as described in the Effects Catalogue [5] which links effects to space weather parameters. In many cases only one information type is identified for a particular user requirement. However URs may be associated with more than one information type.

4.1.3 For each information type associated with a UR, an information priority is assigned to indicate its importance to meeting the UR. (Note that this is not the same as the User Requirement priority discussed in section 3). Two priority levels are defined as shown in table 2.

Information priority level	Definition
1	Information is essential if the UR is to be fully satisfied
2	Although the information is needed to *fully* satisfy the UR it is of lesser relevance than other parameters and could be omitted in a scaled-down system

Table 2; Definition of information priority levels

4.1.4 Having identified the type(s) of information needed to satisfy a UR, the next step is to determine the models and processes required to generate that information. For example, this may be by mapping measurements from one place to another, interpolating or extrapolating data in space or time, or applying a model that simulates the physical processes involved.

4.1.5 In listing models, account has been taken of models which are either known to exist or known to be in development as well as possible future models based on current understanding of the physical processes involved. However only the types of models required are specified (sometimes with an example).

4.1.6 Three categories have been used to indicate the development status of specific models and processes. These are as follows:

- Mature – Such a model / process has been created although it may not have been implemented.
- Immature – Models / processes like this are under development.
- Speculative – It is believed by some that such a model / process can be produced but the likelihood of success is not well-established.

4.1.7 For ‘mature’ models, a further categorisation has been used to indicate the accuracy of the model in describing the environment required. These categories are:

- Quantitative – Effects predicted by the model (e.g. enhancements to space weather activity) are generally observed and an approximately correct quantitative estimate of their magnitude is provided.

- Qualitative – Effects predicted by the model are generally observed but their magnitude is not adequately modelled.

- Indicative – The model indicates periods when an effect may take place but it often does not occur (i.e. there is a significant false alarm rate).

4.1.8 Having established the models and processes required to generate the required information types, the final step is to specify the measurements that need to be made to provide the necessary inputs to these models and processes. Whilst the objective has been to be as comprehensive as possible, it is impossible to predict precisely what parameters may be found to be useful by future modellers. Hence there is scope for adding other measurements as Space Weather modelling evolves.

4.2 The System Measurement Requirement tables

4.2.1 The System Measurement Requirement tables (one for each of UR1-22) are presented at Appendix B. Each table has the following main column headings:

- Information type.
- Information priority.
- Model processes required to generate information.
- Availability/maturity of model or process.
- Measurement requirements.

4.2.2 The final 'measurement requirements' column is sub-divided into a number of further columns, as follows:

- Note / Ref - Where appropriate, this column includes a) a reference to one of the notes in section 4.3 of this document (below) which provides further details of the requirement, and/or b) a paragraph reference (denoted Rx.x.x) to the Rationale document [1] where an explanation of the need for this measurement may be found. (However not every field includes a reference to [1] since some of the measurements considered useful were not explicitly mentioned in the Rationale document).

- Physical parameter – This column provides a concise description of the physical parameter that needs to be measured.

- Spatial sampling – This column provides a guide to the required spatial sampling of measurement data. Typically the information provided is where, and how closely spaced, measurements need to be made. Many measurements will need to be made only at a single point. For established global indices, such as Kp, the spatial distribution of the input data sets is part of the definition of the index and not something to be defined by this study. Where this is the case, the term 'global index' appears in the table.

- Temporal sampling - This column provides a guide to the required temporal sampling of measurement data. Where coarse sampling is specified for a parameter with significant variation on shorter time scales, the data should represent a mean. In the case of global indices, the time resolution of the index itself is given rather than the data used to construct it. In many cases temporal sampling is driven by the input requirements of models and where existing models are available, their input sampling rates have been used as examples. While these timescales are valid today, the requirements on a future space weather system may well be more demanding.

- SMR number - A final column provides a unique reference number for each identified System Measurement Requirement.

4.2.3 It should be noted that although two information priority levels have been defined (see table 2, section 4.1), in practice almost all the identified information needs have been deemed 'priority 1'. This is perhaps not surprising given that the needs of a wide range of end users have been considered and that information from a number of sources may be essential to meet those needs.

4.3 Notes on the System Measurement Requirements

4.3.1 The notes below provide further expansion of the measurement requirements identified in the System Measurement Requirement tables.

1 EUV / X-ray solar images
Full Sun images in EUV / X-ray wavelengths are required for precursor identification with angular resolution as good as or better than SOHO EIT [7], ie. 5 arc seconds. 1–hour resolution is probably adequate.

2 Visible or UV occulted coronal images
Coronal images show the occurrence of Halo CMEs. Angular resolution as good as SOHO LASCO [8], ie. 11 arc seconds, is desired. The good spectral resolution of LASCO is not essential for a Space Weather application. Interplanetary radio scintillation provides a complementary technique.

3 Visible or UV images of Sun-Earth space
To spot Earth-directed CMEs, stereo viewing from, for example, Earth and L4 or L5 is preferable, with angular resolution of around 30 arc seconds.

4 Auroral images from space
Images should be acquired from over the poles, e.g. from a polar orbiting spacecraft in an elliptical orbit, like the Dynamics Explorer-1 spacecraft (in a 700x25000km orbit). A spatial resolution on the ground of about 50km is required. Measurements over the south pole can be used to infer the auroral activity near the north pole and vice versa.

5 Auroral images from the ground
CCD imaging systems can be used to provide real-time information on the position and intensity of aurorae. A line of cameras extending north-south across the auroral oval could track the aurorae as they move. A spatial separation of around 50km should be sufficient. Multiple lines would enable longitudinally propagating disturbances, such as westward travelling surges, to be tracked. Such instruments are already deployed, e.g. in the Canadian CANOPUS [9] and Scandinavian MIRACLE [10] networks. Image resolution of around 1124x1024 pixels (comparable to the Swedish ALIS system) would be appropriate for this system.

6 Auroral equatorward boundary

The equatorward edge of the diffuse aurora is an optional input to the Magnetospheric Specification and Forecasting Model (MSFM) [1], with hourly resolution. At present this is derived from electron and ion precipitation instruments on polar orbiting spacecraft. However, it is conceivable that auroral imaging could be a substitute.

7 X-ray flux

1 minute resolution of total flux is required to capture X-ray flare onset and magnitude. Spectral measurements like those of GOES [11], ie. 0.1-0.8 nm and 0.05-0.4 nm, are required. Higher spectral resolution than the GOES instrument may be useful, eg. 1-20keV spectral measurements which could be achieved using proportional counters or solid state detectors. Detection of solar radio bursts, from the ground in the 10-1000MHz range, is a possible alternative or complementary measurement.

8 UV flux

This parameter is required for its effect on the ionosphere and upper atmosphere.

9 F10.7 radio flux

F10.7cm is radio flux from the Sun, usually measured every day at Dominion in Canada. It is often equivalent to SSN. Continuous measurements would require several stations around the globe.

10 Cosmic ray secondary neutron flux

The requirement is for measurement by neutron monitors [12] on the ground at a range of rigidities going from the equator to the magnetic pole and at a range of longitudes (to account for directional fluxes). These measurements can be used to infer the neutron flux anywhere on the ground or in the atmosphere and can infer the original interplanetary primary population. Polar zero rigidity measurements are particularly important. Neutrons detected by neutron monitors are secondary products of Cosmic Rays and Solar protons and have energies of several MeV to about 1 GeV. The primaries have the energy range 100MeV and above. 25% accuracy is required. Sampling from 1 to 10GV rigidity in 1GV steps is required.

11 Cosmic ray secondary neutron flux – aircraft measurements

Measurements such as these are rarely made at present. They are best carried out using tissue equivalent proportional counters or solid state detectors. Aircrew dose can be a direct output. Data from a fleet of aircraft may be integrated into a dynamic map of particle fluxes as a function of rigidity and altitude. 5 minute resolution is required to minimise the effects of aircraft motion on the results. 25% accuracy is required.

12 Solar wind velocity - Vsw

Solar wind velocity is a main driver of magnetospheric activity. Measurements usually take the form of energy determination of the proton population, which can be directly converted to velocity since the thermal energy is small. Electron instruments may also be used. Measurements are, at present, best measured at L1 since this gives uninterrupted coverage and around 40 minutes warning of magnetospheric effects. Earlier warnings may be achieved with spacecraft further sunwards, perhaps assisted in station keeping by solar sails. Velocity resolution of around 10km/s is required and dynamic range must go from 200km/s to 1000km/s.

13 Solar wind density – Nsw

This is one of the main drivers of magnetospheric activity. The required measurement range is 0.1 to 100 cm^{-3}. The measurement accuracy requirement is 10% or 0.1 cm^{-3} , whichever is greater.

14 Kp index (Ap)

This 3-hourly ground-based index is a general indicator of magnetospheric activity. It is the primary input to MSFM and can be used to represent 10-100keV electron flux on a statistical basis. Measurements come from a large number of magnetic stations on the ground [13]. Kp has 3-hourly resolution but is not available in near real-time. Provisional values are available, such as those distributed by NOAA [14]. For many purposes the 3-hour resolution of Kp is insufficient to meet user requirements for timeliness. Hence in some measurement requirements the existence of a Kp* pseudo-index with higher time resolution is assumed.

15 Dst index

This index is an indicator of storm-time magnetic disturbances and is biased towards the equator and hence ring-current activity. It has 1-hour resolution. Dst index is an optional input to MSFM and may be input to MHD models. For many purposes the 1-hour resolution of Dst is insufficient to meet user requirements for timeliness. Hence in some measurement requirements the existence of a Dst* pseudo-index with higher time resolution is assumed.

16 AE index

This is a 1-minute ground based index. It is not generally available in near-real time. It may be input to MHD models. CANOPUS CU and CL indices could be used as an alternative. Fluxes of auroral kilometric radiation (AKR) are a possible real-time substitute for such data (see note 39 below).

17 SSN

SSN is the optical number of sunspots according to the international index for sunspots algorithm. This index is routinely maintained by the World Data Center for the Sunspot Index in Brussels [15].

18 IMF (B-field)

The strength and orientation of the interplanetary magnetic field (IMF) are prime drivers of magnetospheric activity. These are at present best measured at L1 since this gives un-interrupted coverage and around 40 minutes warning of magnetospheric effects. Earlier warnings may be achieved with spacecraft positioned further sunwards, perhaps assisted in station keeping by solar sails. For some purposes, only the Bz and By components of the IMF are required; in other cases, all 3 components are needed. Resolution should be around 5% or 0.1nT, whichever is greater. The dynamic range should go from –100nT to +100nT.

For monitoring of spacecraft charging, hourly or 15 minute averages may be sufficient but in general it should be possible to provide higher resolution since data rates will be low, in any case.

Recent work on modelling magnetic structures in the solar wind, such as CMEs, has indicated that knowledge of the magnetic field structure of the Sun at the point of origin may enable the field within the structure to be predicted. Such a link is regarded as still too tenuous to be discussed in this report but it may be a long-term alternative to measurement of the IMF.

19 Magnetospheric magnetic field

Measurements of field components within the magnetosphere are needed to create dynamic magnetospheric models. These are required for calculations of penetration of cosmic rays and solar particles into the magnetosphere. Ideally many measurements throughout the magnetosphere would be taken but a smaller number of measurements would also allow models to be modified in real time.

20 Terrestrial magnetic field – B

Sampling frequency of 10s is required for GIC analysis, including nowcasting. Measurements are required principally of the north (X) and east (Y) components of the horizontal intensity. Also useful are total field intensity (F), the horizontal component (H) and vertical component (Z). These components are generally reported in nanoTesla (nT). Direction may also be represented by declination (D) and inclination (I), in units of degrees. The Earth's magnetic field intensity is roughly between 18,000 - 65,000nT. Since 10% changes may occur due to geomagnetic activity, magnetic field deviations of up to 7000nT may need to be measured.

In the case of hazardous GICs, these are caused by changes in the horizontal component of the Earth's magnetic field which is smaller at the higher latitudes where hazardous GICs occur (around 10,000nT). Hence for the purpose of monitoring GICs, it should only be necessary to measure field deviations of up to 1,000nT in the horizontal component. To obtain information on hazardous GICs, a measurement accuracy of 10nT should be sufficient.

For geological prospecting and the drilling industry, measurements are required of *all* components of the terrestrial magnetic field though principally of the north (X), east (Y) and vertical (Z) components. The total field intensity (F) is also useful and the required sampling frequency is again 10s. For geological prospecting, magnetic field deviations of up to 7000nT may need to be measured and an accuracy of 1nT is required.

ULF waves, detected in these magnetic field variations, are a probable input to mechanisms of acceleration of electrons in the outer radiation belt. Sampling frequency of 10s is required. Measurements at multiple sites to give global ULF activity is desirable.

See [16] and [17] for further information on magnetometer measurements.

21 Interplanetary radio scintillation

Interplanetary scintillation [18] for the detection of coronal mass ejections is complementary to coronagraph images. At present it has technical limitations, e.g. low angular resolution and contamination from ionospheric scintillation, that make it less effective for space weather purposes. Density and velocity of the solar wind are found by this technique. The requirement is for velocity resolution of 10km/s. The density range depends strongly on the distance from the Sun of the feature being observed. Velocity measurements by IPS require multi-station observations.

22 Ionospheric F2 layer critical frequency f_0F2

Measurements of this parameter are made by ionosonde - a combination of transmitter and receiver. Measurements may be vertical above a single site or oblique, between sites. Time resolution, determined typically by the rate of change of the environment, will be 5 minutes for most applications. Higher time resolution can easily be achieved if desired. The dynamic range of the measurements should be 1 to 30 MHz and resolution of 0.1MHz is required. Measurements at a number of sites may be interpolated to form a now-casting model.

23 Ionospheric Total Electron Content (TEC)

Measurements are needed on the ground and may be obtained from GPS signals. Regional measurements may be combined into regional models, or global models may be constructed. Time resolution of 1 hour should follow the diurnal variation quite well and should suit sub-auroral latitudes. Lower time resolution plus some sort of diurnal modelling may be adequate here. In auroral zones and at the polar cap, higher time resolution may be required, down to 5 minutes. Dynamic range should cover 0 to $5x10^4$ e/m^2 with resolution of $1x10^3$ e/m^2.

24 Cross-tail field

This is very closely related to Polar Cap Potential (PCP). The cross-tail field can be measured by electric field measurements or ion drift at ionospheric altitudes. It can be well approximated using IMF measurements. Polar Cap Potential is the same, integrated over the polar cap width. Average E-field or PCP can be used to model drift paths and as an optional input to MSFM. E-field is the key input to models of cold ions in the plasmasphere. High spatial resolution measurements of the E-field itself are not needed since averages are sufficient. However, if measured in polar orbit, rapid E-field or ion drift measurements may be required.

25 Ionospheric ion drift

This can be used to derive the cross tail electric field and polar cap potential. It can also be used to classify the polar cap potential type, which is a speculative approach adopted by MSFM. To resolve the auroral zone and polar cap, measurements every few seconds or less are required. Hourly classifications of type and electric field are required, or possibly more frequently.

26 Cold ions

For polar orbit charging, good coverage of the auroral zone is required, ie. good spatial resolution and hence a time resolution of seconds. Total density is required. Energy resolution is not very important < 50eV. For the rest of the magnetosphere, the important measurement is identification of the plasmapause and a time resolution of 1 minute is sufficient. This can be achieved with GTO observations in 4 orbital planes. As an alternative, remote sounding of the plasmasphere using radio waves from further out could be used. Alternatively, UV imaging of neutral atoms or UV scattering from protons may provide adequate information. 25% accuracy required.

27 1-10keV electrons

The spatial sampling requirement is the same as for 10-100keV electrons. Measurement could be obtained using the same instrument. 10 quasi-logarithmically spaced energies are needed. A 25% accuracy in flux is required.

28 10-100keV electrons

For measurements at GEO, a spatial resolution of 1-hour in local time should be sufficient. If this cannot be achieved by large numbers of spacecraft, fewer (e.g. four) may be used with intermediate values being obtained from nowcast models, fitted to the available data. Values for lower altitudes, e.g. in the GTO range, are obtainable from nowcast models which extrapolate from GEO and are fitted to in-situ measurements. Because of aliasing between time and L-shell, high time resolution of around 1 minute is necessary for measurements made in highly elliptical orbits e.g. GTO. At least 10 quasi-logarithmically spaced energies are required. A 25% accuracy in flux is required.

29 >10MeV ions (SPE/SEPE)

Good spectral information, up to 1 GeV, is required. Mass distribution is required. Measurements are required in space, for example, at L1 or GEO. Measurements can be combined with measurements of 100MeV particles of GCR (Galactic Cosmic Ray) origin. Minimum time resolution should be 1 hour. LET spectrum is required.

30 >10MeV protons (trapped)

Measurements are required in LEO, MEO and GTO. For spacecraft protection, a time resolution of a few hours may be enough. However manned missions require a time resolution of minutes for astronaut protection, the main concern being a sudden temporary injection of new belts during astronaut EVA. Good energy spectrum (LET) resolution is important for shielding calculations. Good pitch angle coverage is needed if projection out of the equatorial plane is required. A single cut through the belt could be achieved with an eccentric equatorial spacecraft with apogee around 2000km. Several spacecraft would be better. At low altitude, directional measurements (E-W asymmetry) are needed. 20% resolution in intensity is required.

31 >100MeV ions
Measurements can be performed with a wide range of instruments, including solid state and Cerenkov detectors and scintillating materials. Energy spectrum is required for transport calculations. Because of geomagnetic shielding, the most consistent measurements are obtained outside the magnetosphere. Measurements in GEO are usually adequate, except at the start of some events where fluxes are very directional. 25% accuracy is required. The minimum requirement is for measurements at 100MeV, 500MeV, 1GeV and 5GeV.

32 Relativistic electrons
For internal charging, measurements at intervals of 1 hour should be adequate (these measurements may subsequently be combined into daily averages). At GEO, the required measurements every 1 hour of local time may be achieved with lower spatial resolution of measurements and physical modelling. For dose calculation at high latitudes (eg. in EVA), a higher time resolution may be needed. Measurements are required over the energy range 0.3 to 5MeV, in ~10 quasi logarithmic steps. Flux accuracy to 10% is required.

33 Atmospheric Scale Height
For monitoring of radiation belts, a temporal sampling interval of 1 day is adequate (although a higher time resolution of under 1 hour would be required for spacecraft drag calculations). Routine direct measurement of Atmospheric Scale Height is not practical but it can be derived by fitting models to orbital perturbation data from LEO spacecraft. Alternatively dynamical models based on UV and Kp could be used. Models such as MSIS may be applicable. An accuracy of around 10km is required.

34 Debris
Debris generally evolves slowly but has a marked solar cycle variation in LEO. Hence 6 month resolution in models or observations is adequate. If it is necessary to respond to single massive explosions produced either accidentally or through deliberate attack, there would need to be much higher resolution (e.g. <1 day). However, this is assumed here to be beyond the scope of a space weather monitoring service. Sizes above 10cm in LEO and 1m in GEO can be monitored by radar. Smaller sizes will require in-orbit detectors like DEBIE or GORID [19]. Total spacecraft failure can be expected with particles measured in grams and over (>1cm). Milligram and over (>1mm) particles penetrate to cause internal damage. Smaller particles cause surface damage. Hence measurement of particles of $>10^{-6}$g is essential and $>10^{-9}$g would be valuable. The full mass ranges of DEBIE and GORID are not essential for this purpose - they reach down to 10^{-14}g and 10^{-15}g. Velocity of impact (0 to 20km/s) and direction are needed. The orbits of most concern are LEO but in the future GEO may be affected and efforts are under way to extend debris models to GEO. At present only the LEO environment is of interest to manned missions.

35 Micrometeoroids
Model updates every 6 months would give adequate timings of recurrent micrometeoroid streams and modelling of random meteoroids. However, intensity in the streams is not

easily quantified and near real-time data is needed to record the flux magnitude. 1 day time resolution is needed for this. Since velocities are higher than for debris, smaller particles may be hazardous and plasma effects can be significant for small particles. Including plasma effects, sizes down to 0.1 microns (> 10^{-15}g) are relevant. Velocities up to 72km/s and direction need to be measured. The same space-based detection instrumentation is used for this purpose as for debris. Astronauts are affected in LEO but similar fluxes would be seen on missions to the moon or Mars.

36 On board dose-rate measurements
Measurements can be performed with a wide range of instruments, including RadFETs and scintillating materials. Usually the same instrument will be sensitive to Galactic Cosmic Rays and Solar Protons. LET spectrum is required for SEE and total dose applications.

37 Personal dosimetry
Personal dosimeters (passive or active) need to be carried by all crew in space.

38 Satellite position
Satellite position measurements are required a few (eg. 3) times per orbit, implying a temporal resolution of around 30 minutes in LEO. The position accuracy required is comparable with users' desired position accuracy after drag effects, eg. 10km. Position can be determined with GNSS, radar or laser ranging.

39 Auroral kilometric radiation (AKR)
This is an indicator of auroral activity and is closely associated with the AE index. Observing spacecraft need to be positioned within the AKR emission cone.

40 Interplanetary radio bursts
Detection of interplanetary waves in the 0.3 to 3MHz range is used to identify interplanetary shocks, such as CMEs. These frequencies are not usually able to penetrate the ionosphere and so measurements must be made in space.

4.4 Consolidation of the System Measurements Requirements

4.4.1 The SMR tables at Appendix B include a considerable amount of repetition. This is to be expected due to the way in which SMRs have been separately captured for *each* User Requirement, many of which are quite similar or have similar underlying physical causes. A consolidated version of the individual SMR tables in which duplicate requirements have been removed is therefore included at Appendix C.

4.4.2 It has yet to be decided whether the proposed ESWS will be aimed at meeting a wide range of user needs or a smaller set of high priority user requirements. To help inform this decision, it is useful to consider the Consolidated System Measurement Requirements (CSMRs) associated with each main user group and also the extent to which any individual CSMR supports the needs of more than one user group. For the purpose of this analysis, 12 main user groups are defined as shown in table 3.

4.4.3 A table listing the CSMRs associated with each main user group is presented at Appendix D. This highlights the fact that a wide range of measurements may be required to meet the needs of some user groups (eg. group H, satellite operators) whereas other user groups may be satisfied by a relatively small set of measurements (eg. group G, GNSS location and radar systems).

User group identifier	User group	Related User Requirements
A	Airlines and air safety organisations	UR1, UR2, UR3
B	Electric power transmission organisations (also pipeline operators and railways and telephone companies)	UR4, UR5, UR6
C	Geological prospectors	UR7, UR8, UR9
D	Drilling industry	UR9
E	Military (target detection and tracking)	UR7, UR8, UR16
F	RF systems (civil and military)	UR10, UR11
G	GNSS location systems and radar systems (civil and military)	UR12
H	Satellite operators (civil and military)	UR13, UR14, UR15, UR16
I	Insurance and financial services (for satellite operations)	UR13
J	Tourism	UR17
K	Space Agencies	UR18, UR19, UR20
L	Launch providers	UR21, UR22

Table 3; Major user groups

4.4.4 A table showing the user group combinations supported by each CSMR is presented at Appendix E. This highlights the fact that some CSMRs support the needs of several user groups while others are relevant to only one such group.

5 Conclusions and recommendations

5.1 This document has defined a set of System Measurement Requirements for application to a possible future European Space Weather System (ESWS). Full traceability to an underlying set of User Requirements has been maintained.

5.2 It is recommended that the consolidated System Measurement Requirements presented in this report be used as the main foundation for the ESWS space and ground segment definition work to be carried out in the next phase of this study.

5.3 The size and scope of the European Space Weather Programme (ESWP) currently under consideration by ESA has yet to be decided. Should it be decided to pursue only a small scale programme using only existing and planned space assets, then the ESWS system will necessarily be unable to meet any *new* measurement requirements. However the requirements presented here will assist in selecting from the available data sources.

5.4 In theory, a large scale programme involving the development of new instruments and spacecraft could be designed to address the full set of system measurements requirements defined in this document, thereby meeting all identified user needs. However, in practice this may not be possible due to cost and/or technical constraints. A medium scale programme based on the use of hitchhiker payloads should address at least some of the measurement requirements defined in this document.

5.5 The system measurement requirements presented here are intended to provide a guideline for the space and ground segment definition tasks but should not be interpreted as firm ESWS system requirements at this stage. It is anticipated that a subset of the requirements will be selected following completion of the space and ground segment definition work.

6 Acknowledgements

The authors would like to thank Dr. Mike Hapgood, Prof. Hannu Koskinen, Dr. Daniel Boscher, Dr. Alain Hilgers and Prof. Clive Dyer for their constructive comments on the draft versions of this report.

7 References

[1] Rationale for a European Space Weather Programme, FMI report produced for ESTEC under contract no. 14069/99NL/SB, ESWS-FMI-RP-0002, issue 2.1, 12th January 2001.

[2] Work Statement and Technical Requirements for an ESA Space Weather Programme study, Appendix 1 to AO/1-3533/99/NL/SB, TOS/EMA/99-008, Issue 1, 17th March 1999.

[3] Space Weather Market Analysis, Astrium Ltd. report produced for ESTEC under contract no. 14069/99/NL/SB, draft issue 4.0, 1st November 2000.

[4] Study for an ESA Space Weather Programme, Proposal in response to ESA ITT AO/1-3533/99/NL/SB, issue 1.1, 28th October 1999.

[5] Space Weather Effects Catalogue, FMI report produced for ESTEC under contract no. 14069/99NL/SB, ESWS-FMI-RP-0001, issue 2.1, 17th December 2000.

[6] Benefits of a European Space Weather Programme, DERA report produced for ESTEC under contract no. 14069/99NL/SB, ESWPS-DER-TN-0001, issue 2.1, 19th December 2000.

[7] http://umbra.nascom.nasa.gov/eit/images/instrument_paper.pdf

[8] http://lasco-www.nrl.navy.mil/handbook/hndbk_3.html

[9] CANOPUS - Canadian Auroral Network for the OPEN Program Unified Study. www.sp-agency.ca/www/canopus_home.html

[10] MIRACLE - Magnetometers, Ionospheric Radars, All-sky Cameras Large Experiment. www.geo.fmi.fi/MIRACLE/

[11] http://www.sec.noaa/

[12] http://ulysses.uchicago.edu/NeutronMonitor/background.html

[13] Maynaud, P.N., “Derivation, Meaning, and Use of Geomagnetic Indices”, AGU (Washington D.C.), 1980.

[14] http://www.sec.noaa.gov/Data/geomag.html

[15] http://www.oma.be/KSB-ORB/SIDC/

[16] http://www.ngdc.noaa.gov/seg/potfld/faqgeom.shtml

[17] http://www.ngdc.noaa.gov/seg/potfld/geomaginfo.shtml

[18] Gapper, G.R., Hewish, A., Purvis, A., Duffett-Smith, P.J., “Observing interplanetary disturbances from the ground”, Nature, vol. 296, Apr. 15, 1982, p. 633-636.

[19] http://www.estec.esa.nl/wmwww/wma/fp_days_99/gd/FP_12_99/sld001.htm

[20] http://www.ses.soton.ac.uk/projects/Astronautics/Gpatrick/gpatrick.html

[21] Størmer, C., Z. Astrophys. 1, 237 (1930).

[22] Shea, M.A., Smart, D.F., 18th International Cosmic Ray Conference, Conference Papers, 3, p.415, 1983.

[23] http://wwwinfo.cern.ch/asd/geant4/geant4.html

[24] http://crsp3.nrl.navy.mil/creme96/

[25] http://www.cami.jccbi.gov/aam-600/610/600radio.html

[26] Lantos, P., "Monitoring equivalent doses received by aircrew", Paper S2-21 presented at The First S-RAMP Conference, Sapporo, October 2000.

[27] http://sec.noaa.gov/rpc/costello/index.html

[28] Chen, J., Cargill, P.J., Palmadesso, P.J., "Real-time identification and prediction of geoeffective solar wind structures", Geophys.Res.Lett., 23, 625, 1996.

[29] Fremouw, E.J., Secan, J.A., "Modeling and scientific application of scintillation results", Radio Sci., 19, 687-0694, 1984.

[30] Catalogue of software for spectrum management, International Telecommunications Union, Geneva, 1997.

[31] ITU-R reference ionospheric characteristics and methods for basic MUF, operational MUF and ray-path predictions, International Telecommunications Union, Geneva, 1997.

[32] http://www1.primushost.com/~cpibos/

[33] Daniell, R.E., Brown, L.D., Anderson, D.M., Fox, M.W., "Parametrized ionospheric model: a global ionospheric parametrization based on first principle models", Radio Science, September-October 1995.

[34] Catalogue of European Space Weather Resources, RAL report produced for ESTEC under contract no. 14069/99NL/SB, ESWS-RAL-RP-0001, issue 1.0, 4th January 2001.

[35] Moorer, D.F., Baker, D.N., "Outer electron belt modeling by assimilation of real-time satellite flux data", International Workshop on Space Radiation Environment Modeling, Moscow, Russia, 7-9 October 1997.

8 List of abbreviations

ACE	Advanced Composition Explorer
ALIS	Auroral Large Imaging System
AE	Auroral Electroject index
AKR	Auroral Kilometric Radiation
Ap	Planetary magnetic activity (A) index
B-field (Bx, By, Bz)	Magnetic field (components)
CANOPUS	Canadian Auroral Network for the OPEN Program Unified Study
CCD	Charge Coupled Device
CIRA	COSPAR International Reference Atmosphere
CME	Coronal Mass Ejection
COSPAR	Committee on Space Research
CRÈME	Cosmic Ray Effects on Micro-Electronics
CSMR	Consolidated System Measurement Requirement
CTIM	Coupled Thermosphere-Ionosphere Model
DERA	Defence Evaluation and Research Agency
Dst	Magnetic storm-time index
E1	E-region (95km-140km) ionospheric layer
E-field	Electric field
EIT	Extreme Ultra-Violet Imaging Telescope
ESA	European Space Agency
ESWP	European Space Weather Programme
ESWS	European Space Weather System
EUV	Extreme Ultra Violet
EVA	Extra Vehicular Activity
F1, F2	F-region ionospheric layers (F1=140-200km, F2= 200-400km)
F10.7	10.7cm radio emission
f_oF2	Ionospheric F2 layer critical frequency
GCR	Galactic Cosmic Rays
GEO	Geostationary Orbit
GIC	Geomagnetically Induced Current
GIM	(GPS) Global Ionospheric Maps
GNSS	Global Navigation Satellite System
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GTO	Geostationary Transfer Orbit
HF	High Frequency
IDES	Integrated Debris Evolution Suite
IMF	Interplanetary Magnetic Field
IPS	Australian radio propagation and space environment service (also, Interplanetary Scintillations)
ITU	International Telecommunications Union
JPL	Jet Propulsion Laboratory
Kp	Planetary magnetic activity (K) index
L1, L4, L5	Sun-Earth Lagrange points
LASCO	Large Angle and Spectrometric Coronagraph
LEO	Low Earth Orbit
LET	Linear Energy Transfer
MHD	Magnetohydrodynamics
MIR	Market Interview Requirement

MIRACLE	Magnetometers, Ionospheric Radars, All-sky Cameras Large Experiment
MSFM	Magnetospheric Specification and Forecasting Model
MSIS	Mass Spectrometer Incoherent Scatter
MUF	Maximum Usable Frequency
NIEL	Non-Ionising Energy Loss
NOAA	National Oceanic and Atmospheric Administration
Nsw	Solar Wind Density
NwRA	Northwest Research Associates
PCP	Polar Cap Potential
PEO	Polar Earth Orbit
PIM	Parameterised Ionospheric Model
POES	Polar Operational Environmental Satellite
PRISM	Parameterised Real-time Ionospheric Specification Model
RadFET	Radiation-sensitive Field-Effect Transistor
RF	Radio Frequency
Salammbo	A dynamic model of energetic protons and electrons in the radiation belts
SEE	Single Event Effect
SEPE	Solar Energetic Particle Event
SMR	System Measurement Requirement
SOHO	Solar and Heliospheric Observatory
SPE	Solar Particle Event
SSN	Sunspot Number
STIF	Short-Term Ionospheric Forecast
TEC	Total Electron Content
TSAR	Time Series Analysis Routines
UR	User Requirement
UV	Ultra Violet
Vsw	Solar Wind Velocity

This page is intentionally blank

Appendix A Table of User Requirements

UR no.	User priority	User requirement	Timeliness	User	Market evidence	Interpretation
UR1	1	Forecasts of hazardous radiation levels at altitudes and on routes used by commercial airlines, that may be dangerous to aircrew or may affect avionics systems.	~18 hours preferred	Airlines and air safety organisations	MIR1	Forecasts need to be early enough to change crew and/or flight-plan. 18 hours ahead was identified as preferred by users in the market interviews but it is anticipated that some appropriate action could be made with shorter warnings.
UR2	1	Now-casts of hazardous radiation levels at altitudes and on routes used by commercial airlines, that may be dangerous to aircrew or affect avionics systems.	Near real-time (<30 minutes)	Airlines and air safety organisations	MIR1, MIR15	Now-casts need to be sufficiently close to real-time to enable mitigation procedures to significantly reduce dose during extreme radiation events. Intercontinental flights last several hours and so real-time data must be available in a shorter time to be of any use.
UR3	1	Post-event information on radiation levels at altitudes and on routes used by commercial airlines to allow calculation of crew (and passenger) radiation exposure and investigation of equipment anomalies.	<1 week (2-3 months if no severe events occur)	Airlines and air safety organisations	MIR2 MIR15	MIR2 specifies that only information on extreme radiation levels is required. However, to compute crew exposure, information at all levels is required. MIR2 specifies 2-3 months timeliness. This seems appropriate for routine crew dose calculations. However, in the event of a severe solar energetic particle event it is likely that more rapid information will be required.

UR4	1	Spatially resolved forecasts of large geomagnetically induced currents, to allow mitigation measures to be taken to protect distributed conductor networks e.g. power grids	>1 hour (1-2 days preferred)	Electric power transmission organisations (also pipeline operators and railways and telephone companies)	MIR3	1-2 days warning is preferred since it allows rescheduling of generator and circuit downtime. However, useful mitigation can be taken based on warnings at shorter notice.
UR5	1	Spatially resolved now-cast information on large geomagnetically induced currents.	< 5 minutes	Electric power transmission organisations (also pipeline operators and railways and telephone companies)	MIR3	Market requirements, summarised in MIR3 and described in more detail in the text of the Market Analysis Report, showed a strong desire for real-time magnetic field data from users. Whilst power transmission companies can monitor induced currents in their systems directly, real-time geomagnetic data is needed to establish the cause of anomalous currents.
UR6	2	Spatially resolved post-event information on geomagnetically induced currents of all sizes.	< 1 month	Electric power transmission organisations (also railways and telephone companies)	MIR3	Whilst no explicit market interview requirement was specified in MIR3 for post-knowledge of geomagnetically induced currents, it is assumed to be implicit. Such information has been used in the past to diagnose the cause of failures in relays and transformers and has enabled sensitive equipment to be identified. This need is likely to continue.

UR7	1	Forecasts of perturbations in the geomagnetic field	>1 day (2-4 weeks preferred)	Geological prospectors and military	MIR4	The 2-4 weeks specified in MIR4 is an aspiration that will be very hard to meet to a reasonable degree of accuracy. This amount of warning would act as input to planning of surveys but it is anticipated that, even with shorter warnings fruitless surveying could be avoided. This is backed up by a supplementary comment under MIR4 stating that certain users requested flare data 1-3 days in advance. Detection of submarines by magnetic anomaly detection uses similar technology and warnings would enable periods of detector blindness to be anticipated. Whilst MIR4 includes offshore drilling as a potential beneficiary, it is not clear that this is true.
UR8	2	Now-cast of perturbations in the geomagnetic field	<5 minutes	Geological prospectors and military	-	This could enable ambiguity between instrument problems and space weather effects to be identified in real time.
UR9	1	Post-event knowledge of perturbations in the geomagnetic field	<1 day	Geological prospectors and drilling industry	MIR5	It is estimated that correction of magnetically oriented drilling requires a time-scale of about 1 day to prevent drilling errors becoming unacceptable.
UR10	1	Forecasts of ionospheric disturbances leading to loss of range, degradation and outage of radio communications e.g. fadeout, polar cap absorption and scintillation	> 1 day	RF systems (civil and military)	MIR6, MIR9, MIR13	RF systems include radar and comms to and from spacecraft. Timeliness requirements depend strongly on the user. 1 day is taken as a typical time for alternative communications to be arranged.

UR11	2	Now-casts of ionospheric reflection properties for HF frequency selection	< 5 minutes	RF systems (civil and military)	MIR6, MIR9	MIR6 requires only forecasts but, for HF frequency selection, now-casts should be the main requirement. Frequency selection may require the complete density profile, not just f_0F2. These data also give real-time information on over-the-horizon radar range and blind-spots.
UR12	1	Now-casts of ionospheric total electron content	< 5 minutes	GNSS location systems and radar systems (civil and military)	MIR7, MIR9	Real-time data are needed for correction of GNSS positions. Users may not be affected if they have access to 2-frequency GNSS systems. Trans-ionospheric radar systems are affected however. Radio tracking of satellites and radio-location of emergency beacons are similarly affected.
UR13	1	Post-event information on environments affecting operational satellite systems, e.g. radiation and charging environment	< 1 day	Satellite operators (civil and military) and insurance and financial services	MIR8, MIR10, MIR11, MIR12, MIR15	MIR8 requires post-knowledge. MIR 10, 11 and 12 do not explicitly state whether forecasts, now-casts or post-knowledge is required. Post-knowledge is considered most valuable since it is used for diagnosis of anomalies. MIR12 refers to transfer orbits but is combined here since operational orbits cover LEO, MEO and GEO, and hence transfer orbit altitudes. Timeliness of less than 1 day is required if immediate action is to be taken. Final diagnosis is often satisfied by a longer time scale for data availability.
UR14	1	Forecasts of hazardous environments affecting operational satellite systems.	>1-2 days	Satellite operators (civil and military)	MIR10, MIR11, MIR12	As stated above, MIR 10, 11 and 12 do not explicitly state whether forecasts, now-casts or post-knowledge is required. However, forecasts are considered useful since they enable some preventative measures to be taken and recovery procedures prepared.

UR15	1	Now-casts of hazardous environments affecting operational satellite systems	< 5 minutes	Satellite operators (civil and military)	MIR10, MIR11, MIR12, MIR15	As stated above, MIR 10, 11 and 12 do not explicitly state whether forecasts, now-casts or post-knowledge is required. However, now-casts are considered useful since disturbed environments are often long-lasting and it is often not too late to enable some preventative measures to be taken and recovery procedures prepared,
UR16	1	Now-casts of atmospheric drag affecting LEO spacecraft	< 5 minutes	Satellite operators (civil and military)	MIR13	MIR13 is assumed to be a LEO requirement only. Drag information is needed for orbit, re-entry and attitude perturbation calculations. The military require atmospheric drag information for tracking objects in LEO.
UR17	2	Forecasts of auroral intensity, duration and location	>12 hours	Tourism	MIR16	Whilst 1 day was specified in MIR16, it is expected that notification during the preceding daylight hours should be useful.
UR18	1	Forecasts of all hazardous environments affecting humans in space	> 1 day	Space Agencies	-	A 1 day warning would allow early return of crew from LEO in the event of an extreme forecasted event.
UR19	1	Now-casting of all hazardous environments affecting humans in space	< 30 minutes	Space Agencies	-	Real-time data could enable crew to move to a less exposed part of the space station in the case of intense radiation or meteoroids.
UR20	1	Post-event knowledge of radiation environments affecting humans in space	<2-3 months	Space Agencies	-	As with aircrew, routine information on radiation is needed for crew dose assessments.
UR21	2	Forecasts of severe SPE/SEPE affecting spacecraft launch operations	>1 day	Launch Providers	-	Warnings of severe events more than 1 day ahead would allow a planned launch delay.
UR22	2	Post-knowledge of SPE/SEPE affecting spacecraft launch operations	<1 day	Launch Providers	-	In the event of an imperfect launch, the solar proton environment would form part of the diagnostic process.

UR23	1	Continuous data availability during and after extreme events		General	MIR17	Space weather monitors must not become inoperative during severe space weather events. This implies a system requirement for more robust space weather monitoring systems.
UR24	1	Continued data availability in the event of premature failure or end-of-life of key space weather systems		General	MIR18	MIR18 reflected concern amongst users in the limited life-span and lack of redundancy of SOHO and ACE.
UR25	1	Efficient distribution of data to users and continuous availability		General	-	This is an essential requirement if a Space Weather System is to be trusted.

This page is intentionally blank

Appendix B System Measurement Requirement tables

System Measurement Requirements for UR1

(UR1=Forecasts of hazardous radiation levels at altitudes and on routes used by commercial airlines that may be dangerous to aircrew of that may affect avionics systems)

Users : Airlines and air safety organisations
Timeliness : ~18 hours preferred
User priority : 1

Info type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	**Physical Parameter**	**Spatial Sampling**	**Temporal Sampling**	**SMR no.**
Flux and Spectrum of Solar Protons during Solar Proton Events (3.6.2)	1	Climatic models, e.g. JPL-91 using only solar cycle phase as input	Mature – quantitative (but current models do not reach sufficiently high energies)	N/a	N/a	N/a	N/a	N/a
		Physics based models based on CME and flare detection. The warning is very short – the protons start to arrive a few minutes after the X-rays.	Mature – qualitative (Stereo images could such improve such predictions significantly)	1	Solar EUV / X-ray images	Single point measurement in space	1 hour	SMR1.1
				7	X-ray flux (or radio flux)	Single point measurement in space	1 min	SMR1.2
		Physics based models to predict CMEs and flares based on solar structures are in infancy. They possibly provide several hours warning of CME onset.	Speculative	1	Solar EUV / X-ray images	Single point measurement in space	1 hour	SMR1.3
		Numerical models of solar protons based on time series, e.g. work by Southampton University [20].	Immature (Such models may take other inputs in addition to those listed)	7	X-ray flux incl. spectra	Single point measurement in space	1 hour	SMR1.4

System Measurement Requirement for UR2

(UR2= Now-casts of hazardous radiation levels at altitudes and on routes used by commercial airlines that may be dangerous to aircrew or that may affect avionics systems)

Users : Airlines and air safety organisations
Timeliness : Near real-time (<30 minutes)
User priority : 1

Info type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	**Physical Parameter**	**Spatial Sampling**	**Temporal Sampling**	**SMR no.**
Flux and spectrum of Solar Energetic Particles. (R3.6.1)	1	Real-time measurements in space plus mapping to aircraft location using a rigidity cut-off model[1] plus a radiation transport model[2]	Mature - quantitative	31 & R3.6.3	>100MeV Ions. Energy spectra required	Single-point measurement in interplanetary space preferably external to magnetosphere (GEO orbit would suffice however)	30 minutes	SMR 2.1
				19	Magneto-spheric magnetic field	Multi-point measurements in magnetosphere	30 minutes	SMR2.2
		Real-time measurements at fixed ground locations plus mapping to aircraft location using interpolation in rigidity and scaling laws to convert to aircraft altitude (as created by particle transport codes)	Mature – quantitative	10 & R3.6.3	Neutron flux	Ground measurements. Global coverage, satisfied by a range of rigidities from the equator to the polar cap and a range of longitudes.	30 minutes	SMR 2.3

		Real time measurements on aircraft	Mature – quantitative	11 & R3.6.3	Neutron flux	Aircraft based measurements	5 minutes	SMR 2.4

1. A rigidity model like the Størmer model [21] may be used. Shea and Smart [22] is an alternative. A magnetic field model is required.
2. A radiation transport model like Geant [23] is required.

System Measurement Requirements for UR3

(UR3=Post-event information on radiation levels at altitudes and on routes used by commercial airlines to allow calculation of crew (and passenger) radiation exposure)

Users : Airlines and air safety organisations
Timeliness : <1 week
User priority : 1

Info type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	Physical Parameter	Spatial Sampling	Temporal Sampling	SMR no.
Flux and spectrum of Galactic Cosmic Rays and Solar Protons (R3.6.1)	1	Historical measurements in space plus mapping to aircraft location using a rigidity cut-off model[1] plus a radiation transport model[2]	Mature - quantitative	31 & R3.6.4	>10MeV Ions. Energy spectra required.	Single-point measurement in interplanetary space preferably external to magnetosphere (GEO orbit would suffice however)	1 hour	SMR3.1
				19	Magneto-spheric magnetic field	Multi-point measurements in magnetosphere	1 hour	SMR3.2
		Historical measurements on the ground using interpolation between rigidities plus scaling laws to convert to aircraft altitude.	Mature - quantitative	10 & R3.6.4	Neutron flux	Ground measurements. Global coverage, over a range of rigidities from the equator to the polar cap, and a range of longitudes.	1 hour	SMR3.3

		Historical measurements on aircraft	Mature - quantitative	11 & R3.6.4	Neutron flux	Aircraft based measurements	5 minutes	SMR3.4
		Application of GCR climatic models, e.g. CREME [24] which uses solar cycle phase as input or CARI [25], in the event that no large SEPEs were observed.	Mature – quantitative	R3.6.4	N/a	N/a	N/a	N/a
		Modelling of SEPE flux, e.g. the method proposed by Lantos [26] but perhaps including a greater number of measurements.	Immature	10 & R3.6.4	Neutron flux	Ground measurements. Global coverage, over a range of rigidities from the equator to the polar cap, and a range of longitudes.	1 hour	SMR3.5

1. A rigidity model like the Størmer model [21] may be used. Shea and Smart [22] is an alternative. A magnetic field model is required.
2. A radiation transport model like Geant [23] is required.

System Measurement Requirements for UR4

(UR4=Spatially resolved forecasts of large, geomagnetically induced currents, to allow mitigation measures to be taken to protect distributed conductor networks, e.g. power grids)

Users : Electric power transmission organisations (also pipeline operators and railways and telephone companies)
Timeliness : >1 hour (1-2 days preferred)
User priority : 1

Info type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	Physical Parameter	Spatial Sampling	Temporal Sampling	SMR no.
Local info on GICs (R3.7.1)	1	Physical modelling or empirical association between local magnetic field variation and GICs based on prediction of dB/dt (see below)	Immature	N/a	N/a	N/a	N/a	N/a
Local info on rate of change of magnetic field (dB/dt) (R3.7.1)	1	Short-term forecasts through forecasts of Kp from upstream solar wind data, e.g Costello model [27]	Mature – quantitative	12 & R3.7.2	Vsw	Single point measurement at L1	15 minutes	SMR4.1
		Longer term numerical models for Kp forecasting	Immature	14 & R3.7.2	Kp	Global index	3 hours	SMR4.2
		Probabilistic models of geoeffective solar wind structures, e.g. Cargill method [28] – presently only Dst	Immature	18 & R3.7.2	IMF (B-field)	Single point measurement in interplanetary space, e.g. at L1 point	1 minute	SMR4.3
				12 & R3.7.2	Vsw	Single point measurement in IMF, e.g. at L1 point	1 minute	SMR4.4

		Physics based models based on CME detection are of use but are not yet fully effective. They possibly provide 2-3 days warning of some events. Stereo images could improve them significantly.	Mature - qualitative	2	Coronagraph images	Single point measurement in space	1 hour	SMR4.5
				7	X-ray flux (or radio flux)	Single point measurement in space	1 minute	SMR4.6
				21	Interplanetary radio scintillation	Multiple measurements from multiple points on the ground	1 hour	SMR4.7
				3	Stereo visible or UV images of Sun-Earth space	2 points well separated from Earth e.g. L4 and L5	1 hour	SMR4.8
				40	Interplanetary radio bursts	Single point measurement in space	1 hour	SMR4.9
		Physics based models based on solar features. They possibly provide several hours warning of CME onset.	Speculative	1	Solar EUV / X-ray images	Single point	1 hour	SMR4.10

System Measurement Requirements for UR5

(UR5=Spatially resolved now-cast information on large geomagnetically induced currents)

Users : Electric power transmission organisations (also railways and telephone companies)
Timeliness : < 5 minutes
User priority : 1

Info type	**Info priority**	**Model processes required to generate information**	**Availability/maturity of model or process**	**Measurement requirements**				
				Note / Ref	**Physical Parameter**	**Spatial Sampling**	**Temporal Sampling**	**SMR no.**
Local information on rate of change of magnetic field (R3.7.3)	1	Interpolation from local real-time magnetic field measurements	Mature - quantitative	20 & R3.7.1	B-field (hence dB/dt)	Measured on the ground at a range of latitudes and longitudes. Particularly dense measurements in auroral zone.	10-second resolution	SMR5.1
		Physics-based, modelling of local field variation from real-time global magnetic indices. Relation to Kp is currently most useful.	Immature	14	Kp*	Global index	5 minutes	SMR5.2
				15	Dst*	Global index	5 minutes	SMR5.3
				4	Auroral oval, size, location and intensity	Single point measurement	1 hour	SMR5.4
				16	AE index (alternatively AKR)	Global index	1 minute	SMR5.5
Local information on GICs (R3.7.3)	2	Physical modelling or empirical association between local magnetic field variation and GICs	Immature	20 & R3.7.3	B-field (hence dB/dt)	Measured on the ground at a range of latitudes and longitudes. Particularly dense measurements in auroral zone.	10-second resolution	SMR5.6

System Measurement Requirements for UR6

(UR6=Spatially resolved post-event information on geomagnetically induced currents of all sizes)

Users	:	Electric power transmission organisations (also railways and telephone companies)
Timeliness	:	<1 month
User priority	:	2

Info type	**Info priority**	**Model processes required to generate information**	**Availability/maturity of model or process**	**Measurement requirements**				
				Note / Ref	**Physical Parameter**	**Spatial Sampling**	**Temporal Sampling**	**SMR no.**
Local information on GICs (R3.7.3)	1	Physical modelling or empirical association between local magnetic field variation and GICs	Immature	20 & R3.7.3	B-field (hence dB/dt)	Measured on the ground at a range of latitudes and longitudes. Particularly dense measurements in auroral zone.	10-second resolution	SMR6.1
Local information on Rate of change of magnetic field (dB/dt) (R3.7.3)	1	Interpolation from past local magnetic field measurements. Implemented for some systems.	Mature - quantitative	20 & R3.7.3	B-field (hence dB/dt)	Measured on the ground at a range of latitudes and longitudes. Particularly dense measurements in auroral zone.	10-second resolution	SMR6.2
		Physics-based modelling of local field variation from global magnetic indices. Relation to Kp is currently most useful	Immature	14	Kp	Global index	3 hours	SMR6.3
				15	Dst	Global index	1 hour	SMR6.4
				4	Auroral oval, size, location and intensity	Single point measurement	1 hour	SMR6.5
				16	AE index (alternatively AKR)	Global index	1 minute	SMR6.6

System Measurement Requirements for UR7

(UR7=Forecasts of perturbations in the geomagnetic field)

Users	:	Geological prospectors and military
Timeliness	:	>1 day (2-4 weeks preferred)
User priority	:	1

Info type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	**Physical Parameter**	**Spatial Sampling**	**Temporal Sampling**	**SMR no.**
Warnings of storm and substorm events, represented by Kp or Dst Activity indices.	1	Physical models based on solar rotation. These are crude but have desired timeliness (~27 days)	Mature – indicative	14	Kp	Global index	3 hours	SMR7.1
				15	Dst	Global index	1 hour	SMR7.2
				12	Vsw	Single point	1 hour	SMR7.3
		Physical models based on detection of CMEs and flares, with lead time of days. Already in use but may be improved with stereo imaging.	Mature – qualitative	2	Coronagraph images	Single point measurement in space	1 hour	SMR7.4
				7	X-ray flux (or radio flux)	Single point measurement in space	1 hour	SMR7.5
				21	Interplanetary radio scintillation	Multiple measurements from multiple points on the ground	1 hour	SMR7.6
				3	Stereo visible or UV images of Sun-Earth space	2 points well separated from the Earth e.g. L4 and L5	1 hour	SMR7.7

				40	Interplanetary radio bursts	Single point measurement in space	1 hour	SMR7.8
		Physical models based on prediction of flares and CMEs from solar features	Immature	1	Solar EUV / X-ray images	Single point measurement in space	1 hour	SMR7.9
		Physics based on forecasts of Kp with lead of up to 1 hour through forecasts from L1 solar wind data, e.g Costello model [27]	Mature – qualitative	12 & R3.1.2	Vsw	Single point measurement at L1	15 minutes	SMR7.10
		Numerical models for Kp forcasting	Immature	14 & R3.1.2	Kp	Global index	3 hours	SMR7.11
		Probabilistic models of geoeffective solar wind structures, e.g. Cargill method [28] – presently only Dst.	Immature	18 & R3.1.2	IMF (B-field)	Single point measurement in interplanetary space, e.g. at L1 point	1 minute	SMR7.12
				12 & R3.1.2	Vsw	Single point measurement in IMF, e.g.at L1 point	1 minute	SMR7.13

System Measurement Requirements for UR8

(UR8=Now-casting of perturbations in the geomagnetic field)

Users : Geological prospectors and military
Timeliness : 5 minutes
User priority : 2

Info type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	**Physical Parameter**	**Spatial Sampling**	**Temporal Sampling**	**SMR no.**
Real-time geomagnetic field measurements	1	Interpolation models using ground-based magnetic field measurements.	Mature - quantitative	20 & R3.7.1	B-field	Measured on the ground at a range of latitudes and longitudes.	Every 10-seconds for prospecting.	SMR8.1
		Modelling of local field variation from global magnetic indices. Relation to Kp is currently most useful.	Immature	14	Kp*	Global index	5 minutes	SMR8.2
				15	Dst*	Global index	5 minutes	SMR8.3
				16	AE index (alternatively AKR)	Global index	1 minute	SMR8.4

System Measurement Requirements for UR9

(UR9=Post-event knowledge of perturbations in the geomagnetic field)

Users : Geological prospectors and drilling industry
Timeliness : <1 day
User priority : 1

Info type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	**Physical Parameter**	**Spatial Sampling**	**Temporal Sampling**	**SMR no.**
Post event geomagnetic field measurements	1	Interpolation models using ground-based magnetic field measurements.	Mature - quantitative	20 & R3.7.1	B-field	Measured on the ground at a range of latitudes and longitudes.	Every 10-seconds for prospecting. Every 1 hour average for drilling.	SMR9.1
		Modelling of local field variation from global magnetic indices. Relation to Kp is currently most useful.	Immature	14	Kp	Global index	3 hours	SMR9.2
				15	Dst	Global index	1 hour	SMR9.3
				16	AE index (alternatively AKR)	Global index	1 minute	SMR9.4

System Measurement Requirements for UR10

(UR10=Forecasts of ionospheric disturbances leading to loss of range, degradation and outage of radio communications e.g. fadeout, polar cap absorption and scintillation)

Users : RF systems (civil and military)
Timeliness : >1 day
User priority : 1

Info Type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	**Physical Parameter**	**Spatial Sampling**	**Temporal Sampling**	**SMR no.**
Forecasts of ionospheric density profile including f_0F2, leading to loss of range and fading (R3.5.1)	1	Climatic models	Mature - quantitative	17 & R3.5.2	SSN	Single index	1 day	SMR10.1
				9 & R3.5.1	F10.7	Single point measurement on the ground	1 day	SMR10.2
				8 & R3.5.1	EUV flux	Single point measurement	1 day	SMR10.3
				14 & R3.5.2	Kp	Global index	3 hours	SMR10.4
		Numerical models, e.g. TSAR, STIF service	Immature	22 & R3.5.2	f_0F2 from ionosonde	Local or multipoint measurements from the ground	1 hour	SMR10.5
Forecasts of scintillation (R3.5.1)	1	Forecasts based on Kp prediction from solar wind, e.g. via Costello model [27] and input to NwRA model [29]	Mature – quantitative	12	Vsw	Single point measurement in interplanetary space, e.g. L1	15 minutes	SMR10.6
		Forecasts based on SSN and numerical prediction of Kp, eg. input to NwRA model [29]	Immature	17 & R3.5.2	SSN	Single index	1 day	SMR10.7

				14 & R3.5.2	Kp	Global index	3 hours	SMN10.8
		Physics based models using solar radio waves and X-rays as input (mainly equatorial scintillation)	Immature	9	F10.7	Single point measurement on the ground	1 hour	SMR10.9
				7	X-ray flux (or radio flux)	Single point measurement in space	1 hour	SMR10.10
Forecasts of polar cap absorption events via forecasts of solar proton events	1	Physics based models based on CME and flare detection. (Already of some use but are not yet fully effective.) Stereo images could improve them significantly.	Mature – qualitative	2	Solar coronagraph images	Single point measurement in space	1 hour	SMR10.11
				3	Stereo visible or UV images of Sun-Earth space	2 points well separated from the Earth e.g. L4 and L5	1 hour	SMR10.12
				7	X-ray flux (or radio flux)	Single point measurement in space	5 mins	SMR10.13
				40	Interplanetary radio bursts	Single point measurement in space	1 hour	SMR10.14
		Physics based models to predict CMEs and flares based on solar structures are in infancy.	Speculative	1	Solar EUV / X-ray images	Single point measurement in space	1 hour	SMR10.15
		Numerical models of solar protons based on time series, e.g. work by Southampton University [20]. Not yet available. May take a variety of inputs in addition to these.	Immature	7	X-ray flux and spectrum.	Single point measurement in space.	1 hour	SMR10.16
Forecasts of short-wave fade-out via EUV emissions from flares	1	Physics based models based on flare detection.	Mature - qualitative	7	X-ray flux (or radio flux)	Single point measurement in space	5 mins	SMR10.17

				9	F10.7cm	Single point measurement on the ground	5 mins	SMR10.18
		Physics based models to predict flares based on solar structures are in infancy.	Speculative	1	Solar EUV / X-ray images	Single point measurement in space	1 hour	SMR10.19
Forecasts of decreased signal to noise ratio arising from solar radio emissions	1	Physics based models based on flare detection.	Mature - quantitative	7	X-ray flux (or radio flux)	Single point measurement in space	5 mins	SMR10.20
				9	F10.7cm	Single point measurement on the ground	5 mins	SMR10.21
		Physics based models to predict flares based on solar structures are in infancy.	Speculative	1	Solar EUV / X-ray images	Single point measurement in space	1 hour	SMR10.22
Forecasts of ionospheric storms, i.e. geomagnetic storms producing changes in f_0F2 and fading effects, e.g. from travelling ionospheric disturbances	1	Physical models based on solar rotation. These are crude but have desired timeliness (~27 days)	Mature – indicative	14	Kp	Global index	3 hours	SMR10.23
				15	Dst	Global index	1 hour	SMR10.24
				12	Vsw	Single point	1 hour	SMR10.25
		Physical models based on detection of CMEs and flares, with lead time of days. Already in use but may be improved with stereo imaging.	Mature – qualitative	2	Solar coronagraph images	Single point measurement in space	1 hour	SMR10.26
				7	X-ray flux (or radio flux)	Single point measurement in space	1 hour	SMR10.27
				21	Interplanetary radio scintillation	Multiple measurements from multiple points on the ground	1 hour	SMR10.28
				3	Stereo visible or UV images of Sun-Earth space	2 points well separated from the Earth e.g. L4 and L5	1 hour	SMR10.29

				40	Interplanetary radio bursts	Single point measurement in space	1 hour	SMR10.30
		Physical models based on prediction of flares and CMEs from solar features	Speculative	1	Solar EUV / X-ray images	Single point measurement in space	1 hour	SMR10.31
		Physics based forecasts of Kp with lead of up to 1 hour through forecasts from L1 solar wind data, e.g Costello model [27]	Mature – quantitative	12	Vsw	Single point measurement at L1	15 minutes	SMR10.32
		Numerical models for Kp forecasting	Immature	14	Kp	Global index	3 hours	SMR10.33
		Probabilistic models of geoeffective solar wind structures, e.g. Cargill method [28] – presently only Dst.	Immature	18	IMF (B-field)	Single point measurement in interplanetary space, e.g. at L1 point	1 minute	SMR10.34
				12	Vsw	Single point measurement in IMF, e.g.at L1 point	1 minute	SMR10.35

System Measurement Requirements for UR11

(UR11=Now-casts of ionospheric reflection properties for HF frequency selection)

Users : Radio systems (civil and military)
Timeliness : < 5 minutes
User priority : 2

Info Type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	**Physical Parameter**	**Spatial Sampling**	**Temporal Sampling**	**SMR no.**
Nowcast ionospheric density profile, including MUF and f_0F2 (and E1 and F1) (R3.5.1)	1	Global or regional models e.g. ITU-BR [30], ITU-R [31], using interpolation between local measurements	Mature – quantitative	22 & R3.5.3	f_0F2 from ionosonde (also E1 and F1)	Local or multipoint	5 minutes	SMR11.1
		Nowcast models of ionospheric density profile (including MUF and f_0F2) by scaling static models with dynamic TEC data, e.g. PRISM [32], the PIM model [33] updated by JPL GIM	Mature – quantitative	23	TEC, derived from GNSS propagation delay	Many measurements across the globe	5 minutes	SMR11.2

System Measurement Requirements for UR12

(UR12=Nowcasts of ionospheric total electron content)

Users : GNSS location systems and radar systems (civil and military)
Timelness : < 5 minutes
User priority : 1

Info Type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	**Physical Parameter**	**Spatial Sampling**	**Temporal Sampling**	**SMR no.**
Nowcast of TEC (R3.5.1)	1	Global or local model supplied with data through GNSS and interpolating from local measurements, e.g. JPL GPS GIM and local North America TEC maps, IPS regional maps.	Mature – quantitative	23 & R3.5.3	TEC, derived from GNSS propagation delay	Local, or global with 100km separation	5 minutes	SMR12.1

System Measurement Requirements for UR13

(UR13=Post-event information on environments affecting operational satellite systems, e.g. radiation and charging environment)

Users	:	Satellite operators (civil and military) and insurance and financial services
Timeliness	:	< 1 day
User priority	:	1

Info Type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	**Physical Parameter**	**Spatial Sampling**	**Temporal Sampling**	**SMR no.**
Local information on plasma populations that control surface charging (R3.1.1)	1	Association of charging environments with Kp	Mature - indicative	14 & R3.1.2	Kp	Global index	3 hours	SMR13.1
		Interpolation modelling of electron and ion flux by using magnetic field models to map along field lines. (Note that mapping according to L-shell is not appropriate.)	Mature – qualitative (B-field models are mature but not sufficiently dynamic for all applications)	28 & R3.1.1	10-100keV electrons. Good spectral information	L=3 to 9, GEO	1 minute	SMR13.2
				27 & R3.1.1	1-10keV electrons. Good spectral information	L=3 to 9, GEO	1 minute	SMR13.3
				26 & R3.1.1	Cold ions. Total density only.	L=7 and below	1 minute	SMR13.4
				19	Magnetospheric magnetic field	Multi-point measurements in magnetosphere	1 minute	SMR13.5
		Modelling of plasma environment where good plasma measurements are not available, e.g. via Salammbo [34] or MSFM. The MSFM requires the inputs listed.	Mature – qualitative	24 & R3.1.2	Cross-tail electric field	Tail or PEO	3 hours	SMR13.6
				6 & R3.1.2	Auroral equatorward boundary	Ground, local midnight	3 hours	SMR13.7

				25 & R3.1.2	Ionospheric ion drift velocity	PEO	Seconds	SMR13.8
				14 & R3.1.2	Kp*	Global index	15 minutes	SMR13.9
				16 & R3.1.2	AE index (alternatively AKR)	Global index	1 minute	SMR13.10
				15 & R3.1.2	Dst*	Global index	15 minutes	SMR13.11
				12 & R3.1.2	Vsw	Interplanetary space	15 minutes	SMR13.12
				13 & R3.1.2	Nsw	Interplanetary space	15 minutes	SMR13.13
				18 & R3.1.2	IMF (B-field)	Interplanetary space	15 minutes	SMR13.14
Local post-event information electron environment associated with internal charging	1	Models based on extrapolation/interpolation of suitable radiation-belt measurements. Requires magnetic field model for along field-line and L-shell mapping.	Mature - quantitative	32 & R3.1.1	Relativistic electrons (>0.3MeV). Some spectral information	GEO, GTO	1 hour	SMR13.15
				19	Magnetospheric magnetic field	Multi-point measurements in magnetosphere	1 minute	SMR13.16
Local post-event information on micro-meteoroids and debris.	1	Climatological models of debris, e.g. IDES. Requires continuous updating.	Mature - quantitative	34 & R3.2.1	Debris size and velocity distribution	LEO	6 months	SMR13.17
		Climatological model of random meteoroids. Can be mapped to LEO using gravitational modelling	Mature - quantitative	35 & R3.2.1	Meteoroid size and velocity distribution	Above atmosphere	6 months	SMR13.18
		Models of meteoroid streams	Mature - qualitative	35 & R3.2.1	Meteoroid size and velocity distribution	Above atmosphere	1 day	SMR13.19
Local post-event information on the radiation environment associated with SEE	1	Mapping of galactic and solar cosmic ray fluxes from interplanetary space to all orbits based on magnetic field rigidity.	Mature – quantitative	10 & R3.2.1	Secondary neutrons	Ground, range of rigidities	1 day	SMR13.20

				31 & R3.2.1	>100MeV Ions	Single point measurement in space	1 day	SMR13.21
				29 & R3.2.1	>10MeV ions (SEPE)	Outer magneto-sphere or interplanetary space	1 hour	SMR13.22
				19	Magnetospheric magnetic field	Throughout magnetosphere	1 hour	SMR13.23
		Mapping of trapped proton fluxes from suitable measurements using magnetic field models to map along field-lines and in L-shell	Mature - quantitative	30 & R3.2.1	>10MeV protons (trapped)	Throughout inner radiation belt.	1 day	SMR13.24
Local post-event information on the radiation environment associated with total dose effects and NIEL	1	Mapping of trapped fluxes from suitable measurements using magnetic field models to map along field-lines and in L-shell	Mature – quantitative	30 & R3.2.1	>10MeV protons (trapped)	Throughout inner radiation belt.	1 day	SMR13.25
				32 & R3.2.1	Relativistic electrons (>0.3MeV). Some spectral information	GEO, GTO	1 hour	SMR13.26
		Mapping of GCR and solar cosmic ray fluxes from interplanetary space to all orbits based on magnetic field rigidity.	Mature - quantitative	10 & R3.2.1	Secondary GCR neutrons	Ground, range or rigidities	1 day	SMR13.27
				31 & R3.2.1	>100MeV Ions (GCR)	Single point measurement in space	1 day	SMR13.28
				29 & R3.2.1	>10MeV ions (SPE/SEPE)	Single point measurement in interplanetary space / outer magneto-sphere	1 day	SMR13.29

System Measurement Requirements for UR14

(UR14=Forecasts of hazardous environments affecting operational satellite systems)

Users : Satellite operators (civil and military)
Timeliness : >1-2 days
User priority : 1

Info Type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	**Physical Parameter**	**Spatial Sampling**	**Temporal Sampling**	**SMR no.**
Forecasts of plasma environments likely to cause surface charging (R3.1.1)	1	Physical models of sub-storm activity based on CME and coronal hole detection	Mature - qualitative	2 & R3.1.2	Solar coronagraph images	Single point measurement	1 hour	SMR14.1
				21	Interplanetary radio scintillation	Multiple measurements from multiple points on the ground	1 hour	SMR14.2
				3 & R3.1.2	Stereo visible or UV images of Sun-Earth space	2 points well separated from the Earth e.g.L4 and L5	1 hour	SMR14.3
				7 & R3.1.2	X-ray flux (or radio flux)	Single point measurement	5 mins	SMR14.4
				1 & R3.1.2	Solar EUV / X-ray images	Single point measurement in space	1 hour	SMR14.5
				40	Interplanetary radio bursts	Single point measurement in space	1 hour	SMR14.6

		Numerical self-prediction models of magnetic indices and cross-prediction from solar wind possibly as input to MSFM or similar	Immature	12 & R3.1.2	Vsw	Interplanetary space, preferably L1 or closer	15 minutes	SMR14.7
				18 & R3.1.2	IMF (B-field)	Interplanetary space, preferably L1 or closer	15 minutes	SMR14.8
				16 & R3.1.2	AE index (alternatively AKR)	Global index	1 minute	SMR14.9
				14 & R3.1.2	Kp	Global index	3 hours	SMR14.10
				15 & R3.1.2	Dst	Global index	1 hour	SMR14.11
		Probabilistic models of geoeffective solar wind structures, e.g. Cargill method [28] – presently only Dst.	Immature	18	IMF (B-field)	Single point measurement in interplanetary space, e.g. at L1 point	1 minute	SMR14.12
				12	Vsw	Single point measurement in IMF, e.g.at L1 point	1 minute	SMR14.13
Forecasts of radiation environments likely to cause internal charging (3.1.1)	1	Numerical models of outer belt electron fluence, e.g. neural nets of Moorer analogue-finding method [35].	Immature	32	Relativistic electrons (>0.3MeV). Incl. spectra	GEO, GTO	1 hour	SMR14.14
				14	Kp	Global index	3 hours	SMR14.15
				15	Dst	Global index	1 hour	SMR14.16
				12	Vsw	Interplanetary space, preferably L1	1 hour	SMR14.17

				18	IMF (B-field)	Interplanetary space, preferably L1	1 hour	SMR14.18
		Physical models of outer belt electron fluence	speculative	19	Magnetospheric magnetic field	Multi-point measurements in magnetosphere	1 hour	SMR14.19
				20	Terrestrial magnetic field – B (ULF waves)	Multi-point measurements on ground	10 seconds	SMR14.20
				12	Vsw	Interplanetary space, preferably L1	1 hour	SMR14.21
				13	Nsw	Interplanetary space, preferably L1	1 hour	SMR14.22
				18	IMF (B-field)	Single point measurement in interplanetary space, e.g. at L1 point	1 hour	SMR14.23
				28	10-100keV electrons. Good spectral information	L=3 to 9, GEO	1 hour	SMR14.24
Forecasts of radiation environments likely to cause single event effects (R3.2.1)	1	Physical and numerical models of solar proton events	Immature (except when flare already observed.)	17	SSN	Global index	1 month	SMR14.25
				9	F10.7	Single point measurement on the ground	1 month	SMR14.26
				7	X-ray flux (or radio flux)	Single point measurement in space	5 minutes	SMR14.27
				1	Solar EUV / X-ray images	Single observation in space	1 hour	SMR14.28
		Numerical predictive models of inner belt proton fluxes	Immature	30	>10MeV protons (trapped)	Throughout inner radiation belt.	1 day	SMR14.29

				33	Atmospheric scale height	Global average	1 day	SMR14.30
Forecasts of radiation environments likely to cause total dose effects and NIEL	1	Numerical predictive models of inner belt proton fluxes	Immature	30	>10MeV protons (trapped)	Throughout inner radiation belt.	1 day	SMR14.31
				33	Atmospheric scale height	Global average	1 day	SMR14.32
		Physics based models to predict CMEs and flares based on solar structures. They possibly provide several hours warning of CME onset.	Speculative	1	Solar EUV / X-ray images	Single point measurement in space	1 hour	SMR14.33
		Numerical models of solar protons based on time series, e.g. work by Southampton University [20]. Not yet available. May take a variety of inputs in addition to these.	Immature	7	X-ray flux and spectrum	Single point measurement in space	1 hour	SMR14.34
		Numerical models of outer belt electron fluence	Immature	32	Relativistic electrons (>0.3MeV). Including spectra	GEO, GTO	1 hour	SMR14.35
				14	Kp	Global index	3 hours	SMR14.36
				15	Dst	Global index	1 hour	SMR14.37
		Physical models of outer belt electron fluence	speculative	19	Magnetospheric magnetic field	Multi-point measurements in magnetosphere	1 hour	SMR14.38
				20	Terrestrial magnetic field – B (ULF waves)	Multi-point measurements on ground	10 seconds	SMR14.39
				12	Vsw	Interplanetary space, preferably L1	1 hour	SMR14.40

				13	Nsw	Interplanetary space, preferably L1	1 hour	SMR14.41
				18	IMF (B-field)	Single point measurement in interplanetary space, e.g. at L1 point	1 hour	SMR14.42
				28	10-100keV electrons. Good spectral information	L=3 to 9, GEO	1 hour	SMR14.43
Forecasts of micro-meteoroids and debris. (R3.2.1)	1	Orbit propagation of known large debris	Mature - quantitative	34	Debris size and velocity distribution	LEO	6 months	SMR14.44
		Climatological models of debris, e.g. IDES. Requires continuous updating.	Mature – quantitative	34 & R3.2.1	Debris size and velocity distribution	LEO	6 months	SMR14.45
		Climatological model of random meteoroids. Can be mapped to LEO using gravitational modelling	Mature - quantitative	35 & R3.2.1	Meteoroid size and velocity distribution	Above atmosphere	6 months	SMR14.46
		Models of meteoroid streams	Mature – qualitative	35 & R3.2.1	Meteoroid size and velocity distribution	Above atmosphere	1 day	SMR14.47

System Measurement Requirements for UR15

(UR15=Now-casts of hazardous environments affecting operational satellite systems)

Users : Satellite operators (civil and military)
Timeliness : < 5 minutes
User priority : 1

Info Type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	**Physical Parameter**	**Spatial Sampling**	**Temporal Sampling**	**SMR no.**
Now-cast of the plasma environment associated with surface charging (R3.1.1)	1	Association of charging environments with provisional Kp	Mature - indicative	14 & R3.1.2	Kp*	Global index	5 minutes	SMR15.1
		Modelling of flux by using magnetic field models to map real-time data along field lines. Mapping according to L-shell is not valid.	Mature - quantitative	28 & R3.1.1	10-100keV electrons. Good spectral information	L=3 to 9, GEO	1 minute	SMR15.2
				27 & R3.1.1	1-10keV electrons. Good spectral information	L=3 to 9, GEO	1 minute	SMR15.3
				26 & R3.1.1	Cold ions. Total density only.	L=7 and below	1 minute	SMR15.4
				19	Magneto-spheric magnetic field	Multi-point measurements in magnetosphere	1 minute	SMR15.5
		Nowcast models for where good plasma measurements are not available, e.g. via Salammbo [34] or MSFM	Mature – qualitative	24 & R3.1.2	Cross-tail electric field	Tail or PEO	3 hours	SMR15.6

				6 & R3.1.2	Auroral equatorward boundary	Ground, local midnight	3 hours	SMR15.7
				25	Ionospheric ion drift velocity	Polar orbit	seconds	SMR15.8
				14 & R3.1.2	Kp*	Global index	5 minutes	SMR15.9
				16 & R3.1.2	AE index (alternatively AKR)	Global index	1 minute	SMR15.10
				15 & R3.1.2	Dst*	Global index	5 minutes	SMR15.11
Nowcast of the radiation environment associated with internal charging	1	Nowcast models based on extrapolation/interpolation of suitable real-time measurements. Requires magnetic field model for along field-line and L-shell mapping.	Mature - quantitative	32 & R3.1.1	Relativistic electrons (>0.3MeV). Incl. spectra	GEO, GTO	1 hour	SMR15.12
				19	Magneto-spheric magnetic field	Multi-point measurements in magnetosphere	1 hour	SMR15.13
Nowcast of micrometeoroids and debris.	1	Climatological models of debris, e.g. IDES. Requires continuous updating.	Mature – quantitative	34 & R3.2.1	Debris size and velocity distribution	LEO	6 months	SMR15.14
		Climatological model of random meteoroids. Can be mapped to LEO using gravitational modelling.	Mature – quantitative	35 & R3.2.1	Meteoroid size and velocity distribution	Above atmosphere	6 months	SMR15.15
		Models of meteoroid streams updated for intensity by measurements	Mature - quantitative	35 & R3.2.1	Meteoroid size and velocity distribution	Above atmosphere	1 day	SMR15.16
Nowcast modelling of the radiation environment associated with SEE.	1	Mapping of radiation fluxes from interplanetary space to all orbits based on magnetic field rigidity	Mature – quantitative	10 & R3.2.1	Secondary neutrons (GCR)	Ground, range or rigidities	1 month	SMR15.17

				31 & R3.2.1	>100MeV Ions (GCR)	Single point measurement in interplanetary space (GEO would suffice)	1 month	SMR15.18
				29 & R3.2.1	>10MeV ions (SPE/SEPE)	Single point measurement in interplanetary space (GEO would suffice)	5 minutes	SMR15.19
				19	Magneto-spheric magnetic field	Multi-point measurements in magnetosphere	5 minutes	SMR15.20
		Mapping of trapped fluxes from suitable real-time measurements using magnetic field models to map along field-lines and in L-shell	Mature - quantitative	30 & R3.2.1	>10MeV protons (trapped)	Throughout inner radiation belt.	1 hour	SMR15.21
				19	Magneto-spheric magnetic field	Multi-point measurements in magnetosphere	1 hour	SMR15.22
Now-cast modelling of radiation environment associated with total dose effects and NIEL	1	Mapping of trapped fluxes from suitable real-time measurements using magnetic field models to map along field-lines and in L-shell	Mature – quantitative	30 & R3.2.1	>10MeV protons (trapped)	Throughout inner radiation belt.	1 hour	SMR15.23
				32 & R3.2.1	Relativistic electrons (>0.3MeV). Incl. spectral	GEO, GTO	5 minutes	SMR15.24
				19	Magneto-spheric magnetic field	Multi-point measurements in magnetosphere	5 minutes	SMR15.25
		Mapping of radiation fluxes from interplanetary space to all orbits based on magnetic field rigidity	Mature - quantitative	10 & R3.2.1	>Secondary neutrons (GCR)	Ground, range or rigidities	1 month	SMR15.26

				31 & R3.2.1	>100MeV Ions (GCR)	Single point measurement in interplanetary space (GEO would suffice)	1 month	SMR15.27
				29 & R3.2.1	>10MeV ions (SPE/SEPE)	Single point measurement in interplanetary space (GEO would suffice)	5 minutes	SMR15.28
				19	Magneto-spheric magnetic field	Multi-point measurements in magnetosphere	5 minutes	SMR15.29

System Measurement Requirements for UR16

(UR16=Now-casts of atmospheric drag for LEO spacecraft)

Users	:	Satellite operators (civil and military) and ICBM monitors
Timeliness	:	< 5minutes
User priority	:	1

Info Type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	**Physical Parameter**	**Spatial Sampling**	**Temporal Sampling**	**SMR no.**
Nowcasts of atmospheric scale height (R3.4.1)	1	Fitting of atmospheric model parameters (e.g. MSIS or CIRA), based on orbital deviations of satellites whose position is well known	Speculative	38	Satellite position	LEO and below	30 minutes	SMR16.1
		Nowcasts using atmospheric models (e.g. MSIS, CIRA or CTIM [34]) plus solar activity parameters	Mature - quantitative	8 & R3.4.1	UV flux (total)	Single point measurement in space	1 day	SMR16.2
				9 & R3.4.1	F10.7	Single point measurement on the ground	1 day	SMR16.3
				17 & R3.4.1	SSN	Index	1 day	SMR16.4
				14	Ap	Global index	1 day	SMR16.5

System Measurement Requirements for UR17

(UR17=Forecasts of auroral intensity and location)

Users : Tourism
Timeliness : > 12 hours
User priority : 2

Info Type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	**Physical Parameter**	**Spatial Sampling**	**Temporal Sampling**	**SMR no.**
Forecasts of auroral intensity and location	1	Statistical correlations of auroral location with geomagnetic activity, e.g. NOAA POES model, through predictions of Kp	Mature - qualitative	14	Kp	Global index	3 hours	SMR17.1
		Physical models of auroral production. (More inputs than listed here may be required).	Speculative	12	Vsw	Interplanetary space, preferably L1 or closer	15 minutes	SMR17.2
				18	IMF (B-field)	Interplanetary space, preferably L1 or closer	15 minutes	SMR17.3
		Extrapolation in time from images (not liable to be very effective when disturbed)	Speculative	4	Auroral imaging	From polar elliptical orbit	1 hour	SMR17.4
				5	Auroral imaging	On the ground	1 hour	SMR17.5

System Measurement Requirements for UR18

(UR18=Forecasts of all hazardous environments affecting humans in space)

Users : Space Agencies
Timeliness : > 1 day
User priority : 1

Info Type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	Physical Parameter	Spatial Sampling	Temporal Sampling	SMR no.
Forecast models of radiation environments likely to cause total dose effects (R3.3.1)	1	Numerical predictive models of inner belt proton fluxes	Immature	30 & R3.3.1	>10MeV protons (trapped)	Throughout inner radiation belt.	1 day	SMR18.1
				33	Atmospheric scale height	Global average	1 day	SMR18.2
		Numerical predictive models of outer belt electron flux	Immature	32	Relativistic electrons (>0.3MeV). Incl. spectra	GEO, GTO	1 hour	SMR18.3
		Physical models of outer belt electron fluence	speculative	19	Magneto-spheric magnetic field	Multi-point measurements in magnetosphere	1 hour	SMR18.4
				20	Terrestrial magnetic field – B (ULF waves)	Multi-point measurements on ground	10 seconds	SMR18.5
				12	Vsw	Interplanetary space, preferably L1	1 hour	SMR18.6

				13	Nsw	Interplanetary space, preferably L1	1 hour	SMR18.7
				18	IMF (B-field)	Single point measurement in interplanetary space, e.g. at L1 point	1 hour	SMR18.8
				28	10-100keV electrons. Good spectral information	L=3 to 9, GEO	1 hour	SMR18.9
		Physics based models based on CME and flare detection. (Already of some use but are not yet fully effective). Stereo images could improve them significantly.	Mature - qualitative	2	Solar coronagraph images	Single point measurement in space	1 hour	SMR18.10
				3	Stereo visible or UV images of Sun-Earth space	2 points well separated from the Earth e.g. L4 and L5	1 hour	SMR18.11
				7	X-ray flux (or radio flux)	Single point measurement in space	5 mins	SMR18.12
		Physics based models to predict CMEs and flares based on solar structures are in infancy. They possibly provide several hours warning of CME onset.	Speculative	1	Solar EUV / X-ray images	Single point measurement in space	1 hour	SMR18.13
		Numerical models of solar particles based on time series, e.g. work by Southampton University [20]. Not yet available. May take a variety of inputs in addition to these.	Immature	7	X-ray flux and spectrum.	Single point measurement in space.	1 hour	SMR18.14
Models providing forecasts of micrometeoroids and debris.	1	Climatological models of debris, e.g. IDES. Requires continuous updating.	Mature – quantitative	34 & R3.2.1	Debris size and velocity distribution	LEO	6 months	SMR18.15

		Climatological model of random meteoroids. Can be mapped to LEO using gravitational modelling	Mature – quantitative	35 & R3.2.1	Meteoroid size and velocity distribution	Above atmosphere	6 months	SMR18.16
		Models of meteoroid streams	Mature - qualitative	35 & R3.2.1	Meteoroid size and velocity distribution	Above atmosphere	1 day	SMR18.17

System Measurement Requirements for UR19

(UR19=Now-casting of all hazardous environments affecting humans in space)

Users : Space agencies
Timeliness : < 30 minutes
User priority : 1

Info Type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	Physical Parameter	Spatial Sampling	Temporal Sampling	SMR no.
Nowcasts of micrometeoroids and debris impact probability.	1	Climatological models of debris, e.g. IDES. Requires continuous updating.	Mature – quantitative	34 & R3.3.1	Debris size and velocity distribution	LEO	6 months	SMR19.1
		Climatological model of random meteoroids. Can be mapped to LEO using gravitational modelling	Mature – quantitative	35 & R3.3.1	Meteoroid size and velocity distribution	Above atmosphere	6 months	SMR19.2
		Models of meteoroid streams updated for intensity by measurements.	Mature - qualitative	35 & R3.3.1	Meteoroid size and velocity distribution	Above atmosphere	1 day	SMR19.3
Nowcast models of the radiation environment associated with total dose effects	1	Real-time on-board measurements	Mature - quantitative	36 & R3.3.1	Dose rate and LET spectrum	On-board	5 minutes	SMR19.4
		Mapping of trapped fluxes from suitable real-time measurements using magnetic field models to map along field-lines and in L-shell	Mature - quantitative	30 & R3.3.1	>10MeV protons (trapped)	Throughout inner radiation belt.	< 30 minutes	SMR19.5
				32	Relativistic electrons (>0.3MeV). Some spectral information	GEO,GTO	< 30 minutes	SMR19.6

				19	Magneto-spheric magnetic field	Multi-point measurements in magnetosphere	< 30 minutes	SMR19.7
		Mapping of real-time GCR and solar proton measurements in interplanetary space to spacecraft according to rigidity.	Mature - quantitative	29 & R3.3.1	> 10 MeV ions	Single point measurement in interplanetary space	< 30 minutes	SMR19.8
				19	Magneto-spheric magnetic field	Multi-point measurements in magnetosphere	< 30 minutes	SMR19.9

System Measurement Requirements for UR20

(UR20=Post-event knowledge of radiation environments affecting humans in space)

Users : Space Agencies
Timeliness : <2-3 months
User priority : 1

Info Type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	**Physical Parameter**	**Spatial Sampling**	**Temporal Sampling**	**SMR no.**
Local post-event info on radiation environments causing total dose effects	1	Personal dosimetry	Mature - quantitative	37 & R3.3.3	Total dose	Worn by astronaut	Mission integrated	SMR20.1
		On-board dose rate monitoring	Mature - quantitative	36 & R3.3.3	Dose rate and LET spectrum	On board	5 minutes	SMR20.2
		Mapping of trapped fluxes from suitable measurements using magnetic field models to map along field-lines and in L-shell	Mature – quantitative	30 & R3.2.1	>10MeV protons (trapped)	Throughout inner radiation belt.	1 hour	SMR20.3
				32 & R3.2.1	Relativistic electrons (>0.3MeV). Some spectral information	GEO, GTO	1 hour	SMR20.4
				19	Magneto-spheric magnetic field	Multi-point measurements in magnetosphere	1 hour	SMR20.5
		Mapping of real-time measurements in interplanetary space to spacecraft according to rigidity	Mature - quantitative	29	> 10 MeV ions	Single point measurement in interplanetary space	1 hour	SMR20.6
				31	> 100 MeV ions	Single point measurement in space	1 hour	SMR20.7

				19	Magneto-spheric magnetic field	Multi-point measurements in magnetosphere	1 hour	SMR20.8

System Measurement Requirements for UR21

(UR21=Forecasts of severe SPE/SEPE affecting launch operations)

Users : Launch providers
Timeliness : > 1 day
User priority : 2

Info type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	**Physical Parameter**	**Spatial Sampling**	**Temporal Sampling**	**SMR no.**
Forecasts of SPE/SEPE	1	Physics based models to predict CMEs and flares based on solar structures are in infancy. They possibly provide several hours warning of CME onset.	Speculative	1	Solar EUV / X-ray images	Single point measurement in space	1 hour	SMR21.1
		Numerical models of solar protons based on time series, e.g. work by Southampton University [20]. Not yet available. May take a variety of inputs in addition to these.	Immature	7	X-ray flux and spectrum.	Single point measurement in space.	1 hour	SMR21.2

System Measurement Requirements for UR22

(UR22=Post-knowledge of SPE/SEPE affecting spacecraft launch operations)

Users : Launch providers
Timeliness : < 1 day
User priority : 2

Info Type	Info priority	Model processes required to generate information	Availability/maturity of model or process	Measurement requirements				
				Note / Ref	Physical Parameter	Spatial Sampling	Temporal Sampling	SMR no.
Post event local information on SPE/SEPE	1	Mapping of real-time measurements in interplanetary space to launch location according to rigidity[1].	Mature - quantitative	29	> 10 MeV ions	Single point measurement in interplanetary space	1 hour	SMR22.1
				31	>100MeV ions	Single point measurement in interplanetary space	1 hour	SMR22.2
				19	Magneto-spheric magnetic field	Multi-point measurements in magnetosphere	1 hour	SMR22.3
		Mapping of real-time measurements on the ground to launch location according to rigidity[1].	Mature - quantitative	10 & R3.6.2	Secondary neutron flux	Ground measurements. Global coverage over a range of rigidities from the equator to the polar cap	1 hour	SMR22.4

1. A rigidity model like the StØrmer [21] model may be used. Shea and Smart [22] is an alternative. A magnetic field model is required

This page is intentionally blank

Appendix C Table of Consolidated System Measurement Requirements

CSMR no.	Measurement requirement			Related SMRs	Note
	Physical parameter to be measured	**Spatial sampling requirement**	**Temporal sampling requirement**		
CSMR1	Solar EUV / X-ray images	Single point measurement in space	1 hour	SMR1.1, SMR1.3, SMR4.10, SMR7.9, SMR10.15, SMR10.19, SMR10.22, SMR10.31, SMR14.5, SMR14.28, SMR14.33, SMR18.13, SMR21.1	1
CSMR2	Solar coronagraph images	Single point measurement in space	1 hour	SMR4.5, SMR7.4, SMR10.11, SMR10.26, SMR14.1, SMR18.10	2
CSMR3	Stereo visible or UV images of Sun-Earth space	2 points well separated from Earth e.g. L4 and L5	1 hour	SMR4.8, SMR7.7, SMR10.12, SMR10.29, SMR14.3, SMR18.11	3
CSMR4	Auroral imaging	From polar elliptical orbit	1 hour	SMR17.4	4
CSMR5	Auroral imaging	From the ground	1 hour	SMR17.5	5
CSMR6	Auroral oval, size, location and intensity	Single point measurement	1 hour	SMR5.4, SMR6.5	
CSMR7	Auroral equatorward boundary	Ground, local midnight	3 hours	SMR13.7, SMR15.7	6
CSMR8	X-ray flux	Single point measurement in space	1 min	SMR1.2, SMR1.4, SMR4.6	7
CSMR9	X-ray flux	Single point measurement in space	5 mins	SMR10.13, SMR10.17, SMR10.20, SMR14.4, SMR14.27, SMR18.12	7
CSMR10	X-ray flux	Single point measurement in space	1 hour	SMR7.5, SMR10.10, SMR10.27	7
CSMR11	X-ray flux and spectrum	Single point measurement in space	1 hour	SMR10.16, SMR14.34, SMR18.14, SMR21.2	7
CSMR12	UV flux	Single point measurement in space	1 day	SMR16.2	8
CSMR13	EUV flux	Single point measurement	1 day	SMR10.3	
CSMR14	F10.7	Single point measurement on the ground	5 mins	SMR10.18, SMR10.21	9
CSMR15	F10.7	Single point measurement on ground	1 hour	SMR10.9	9
CSMR16	F10.7	Single point measurement on the ground	1 day	SMR10.2, SMR16.3	9
CSMR17	F10.7	Single point measurement on the ground	1 month	SMR14.26	9

CSMR18	Secondary neutrons (GCR)	Outer magneto-sphere or interplanetary space	1 hour	SMR13.22	10
CSMR19	Secondary neutron flux	Ground measurements. Global coverage over a range of rigidities from the equator to the polar cap and a range of longitudes.	1 hour	SMR2.3, SMR3.3, SMR3.5, SMR22.4	10
CSMR20	Secondary neutrons (GCR)	Ground, range of rigidities	1 day	SMR13.20, SMR13.27	10
CSMR21	Secondary neutrons (GCR)	Ground, range of rigidities	1 month	SMR15.17, SMR15.26	10
CSMR22	Secondary neutron flux	Aircraft based measurements	5 minutes	SMR2.4, SMR3.4	11
CSMR23	Vsw	Single point measurement in IMF, e.g.at L1 point	1 minute	SMR4.4, SMR7.13, SMR10.35, SMR14.13	12
CSMR24	Vsw	Single point measurement at L1	15 minutes	SMR4.1, SMR7.10, SMR10.6, SMR10.32, SMR13.12, SMR14.7, SMR17.2	12
CSMR25	Vsw	Single point measurement in interplanetary space (L1 preferable for some requirements)	1 hour	SMR7.3, SMR10.25, SMR14.17, SMR14.21, SMR14.40, SMR18.6	12
CSMR26	Nsw	Interplanetary space	15 minutes	SMR13.13	13
CSMR27	Nsw	Interplanetary space, preferably L1	1 hour	SMR14.22, SMR14.41, SMR18.7	*13*
CSMR28	Kp	Global index	3 hours	SMR4.2, SMR5.2, SMR6.3, SMR7.1, SMR7.11, SMR9.2, SMR10.4, SMR10.8, SMR10.23, SMR10.33, SMR13.1, SMR13.9, SMR14.10, SMR14.15, SMR14.36, SMR15.1, SMR15.9, SMR17.1	14
CSMR29	Kp*	Global index	5 minutes	SMR8.2	14
CSMR30	Ap	Global index	1 day	SMR16.5	14
CSMR31	Dst	Global index	1 hour	SMR5.3, SMR6.4, SMR7.2, SMR9.3, SMR10.24, SMR13.11, SMR14.11, SMR14.16, SMR14.37, SMR15.11	15
CSMR32	Dst*	Global index	5 minutes	SMR8.3	15
CSMR33	AE index (alternatively AKR)	Global index	1 minute	SMR5.5, SMR6.6, SMR8.4, SMR9.4, SMR13.10, SMR14.9, SMR15.10	16 (39)
CSMR34	SSN	Single index	1 day	SMR10.1, SMR10.7, SMR16.4	17
CSMR35	SSN	Global index	1 month	SMR14.25	17

CSMR36	IMF (B-field)	Single point measurement in interplanetary space, e.g. at L1 point	1 minute	SMR4.3, SMR7.12, SMR10.34, SMR14.12	18
CSMR37	IMF (B-field)	Interplanetary space, preferably L1 or closer	15 minutes	SMR13.14, SMR14.8, SMR17.3	18
CSMR38	IMF (B-field)	Interplanetary space, preferably L1	1 hour	SMR14.18, SMR14.23, SMR14.42, SMR18.8	18
CSMR39	Magnetospheric B-field	Multi-point measurements in magnetosphere	1 minute	SMR13.5, SMR13.16, SMR15.5	19
CSMR40	Magnetospheric B-field	Multi-point measurements in magnetosphere	5 minutes	SMR15.20, SMR15.25, SMR15.29	19
CSMR41	Magneto-spheric B-field	Multi-point measurements in magnetosphere	< 30 minutes	SMR19.7, SMR19.9	19
CSMR42	Magnetospheric B-field	Multi-point measurements in magnetosphere	30 minutes	SMR2.2	19
CSMR43	Magnetospheric B-field	Multi-point measurements in magnetosphere	1 hour	SMR3.2, SMR13.23, SMR14.19, SMR14.38, SMR15.13, SMR15.22, SMR18.4, SMR20.5, SMR20.8, SMR22.3	19
CSMR44	Terrestrial B-field (hence dB/dt)	Measured on the ground at a range of latitudes and longitudes. Particularly dense measurements in auroral zone.	10-second resolution (1 hour average for drilling)	SMR 5.1, SMR5.6, SMR6.1, SMR6.2, SMR8.1, SMR9.1, SMR14.20, SMR14.39, SMR18.5	20
CSMR45	Interplanetary radio scintillation	Multiple measurements from multiple points on the ground	1 hour	SMR4.7, SMR7.6, SMR10.28, SMR14.2	21
CSMR46	f_0F2 from ionosonde (also E1 and F1)	Local or multipoint measurements	5 minutes	SMR11.1	22
CSMR47	f_0F2 from ionosonde	Local or multipoint measurements from the ground	1 hour	SMR10.5	22
CSMR48	TEC, derived from GNSS propagation delay	Many measurements across the globe	5 minutes	SMR11.2	23
CSMR49	TEC, derived from GNSS propagation delay	Local, or global with 100km separation	5 minutes	SMR12.1	23
CSMR50	Cross-tail electric field	Tail or PEO	3 hours	SMR13.6, SMR15.6	24
CSMR51	Ionospheric ion drift velocity	PEO	Seconds	SMR13.8, SMR15.8	25
CSMR52	Cold ions. Total density only.	L=7 and below	1 minute	SMR13.4, SMR15.4	26

CSMR53	1-10keV electrons. Good spectral information	L=3 to 9, GEO	1 minute	SMR13.3, SMR15.3	27
CSMR54	10-100keV electrons. Good spectral information	L=3 to 9, GEO	1 minute	SMR13.2, SMR15.2	28
CSMR55	10-100keV electrons. Good spectral information	L=3 to 9, GEO	1 hour	SMR14.24, SMR14.43, SMR18.9	28
CSMR56	>10MeV ions (SPE/SEPE)	Single point measurement in interplanetary space	<30 minutes	SMR19.8	29
CSMR57	>10MeV ions (SPE/SEPE)	Single point measurement in interplanetary space (GEO would suffice)	1 hour	SMR15.19, SMR15.28, SMR20.6, SMR22.1	29
CSMR58	>10MeV ions (SPE/SEPE)	Single point measurement in interplanetary space / outer magneto-sphere	1 day	SMR13.29	29
CSMR59	>10MeV protons (trapped)	Throughout inner radiation belt	<30 minutes	SMR19.5	30
CSMR60	>10MeV protons (trapped)	Throughout inner radiation belt	1 hour	SMR15.21, SMR15.23, SMR20.3	30
CSMR61	>10MeV protons (trapped)	Throughout inner radiation belt	1 day	SMR13.24, SMR13.25, SMR14.29, SMR14.31, SMR18.1	30
CSMR62	>100MeV ions. Energy spectra required	Single-point measurement in interplanetary space preferably external to magnetosphere (GEO orbit would suffice however)	1 hour	SMR2.1, SMR3.1, SMR22.2	31
CSMR63	>100MeV ions (GCR)	Single point measurement in space	1 hour	SMR20.7	31
CSMR64	>100MeV ions (GCR)	Single point measurement in space	1 day	SMR13.21, SMR13.28	31
CSMR65	>100MeV ions (GCR)	Single point measurement in interplanetary space (GEO would suffice)	1 month	SMR15.18, SMR15.27	31
CSMR66	Relativistic electrons (>0.3MeV). Including spectra	GEO, GTO	<30 minutes	SMR19.6	32

CSMR67	Relativistic electrons (>0.3MeV). Including spectra	GEO, GTO	1 hour	SMR13.15, SMR13.26, SMR14.14, SMR14.35, SMR15.12, SMR15.24, SMR18.3, SMR20.4	32
CSMR68	Atmospheric scale height	Global average	1 day	SMR14.30, SMR14.32, SMR18.2	33
CSMR69	Debris size and velocity distribution	LEO	6 months	SMR13.17, SMR14.44, SMR14.45, SMR15.14, SMR18.15, SMR19.1	34
CSMR70	Meteoroid size and velocity distribution	Above atmosphere	6 months	SMR13.18, SMR14.46, SMR15.15, SMR18.16, SMR19.2	35
CSMR71	Meteoroid size and velocity distribution	Above atmosphere	1 day	SMR13.19, SMR14.47, SMR15.16, SMR18.17, SMR19.3	35
CSMR72	Dose rate and LET spectrum	Onboard spacecraft	5 minutes	SMR19.4, SMR20.2	36
CSMR73	Total dose	Sensor worn by astronaut	Mission integrated	SMR20.1	37
CSMR74	Satellite position	LEO and below	30 minutes	SMR16.1	38
CSMR75	Interplanetary radio bursts	Single point measurement in space	1 hour	SMR4.9, SMR7.8, SMR10.14, SMR10.30, SMR14.6	40

Appendix D Table of CSMRs associated with each main user group

User group identifier	Related URs	Related CSMRs
A	1, 2, 3	1, 8, 19, 22, 42, 43, 62
B	4, 5, 6	1, 2, 3, 6, 8, 23, 24, 28, 31, 33, 36, 44, 45, 75
C	7, 8, 9	1, 2, 3, 10, 23, 24, 25, 28, 29, 31, 32, 33, 36, 44, 45, 75
D	9	28, 31, 33, 44
E	7, 8, 16	1, 2, 3, 10, 12, 16, 23, 24, 25, 28, 30, 31, 32, 33, 34, 36, 44, 45, 74, 75
F	10, 11	1, 2, 3, 9, 10, 11, 13, 14, 15, 16, 23, 24, 25, 28, 31, 34, 36, 45, 46, 47, 48, 75
G	12	49
H	13, 14, 15, 16	1, 2, 3, 7, 9, 11, 12, 16, 17, 18, 20, 21, 23, 24, 25, 26, 27, 28, 30, 31, 33, 34, 35, 36, 37, 38, 39, 40, 43, 44, 45, 50, 51, 52, 53, 54, 55, 57, 58, 60, 61, 64, 65, 67, 68, 69, 70, 71, 74, 75
I	13	7, 18, 20, 24, 26, 28, 31, 33, 37, 39, 43, 50, 51, 52, 53, 54, 58, 61, 64, 67, 69, 70, 71
J	17	4, 5, 24, 28, 37
K	18, 19, 20	1, 2, 3, 9, 11, 25, 27, 38, 41, 43, 44, 55, 56, 57, 59, 60, 61, 63, 66, 67, 68, 69, 70, 71, 72, 73
L	21, 22	1, 11, 19, 43, 57, 62

Appendix E Table of CSMRs relating to various combinations of user group

User group combinations	Related CSMRs
A (only)	22, 42
B (only)	6
C (only)	29
F (only)	13, 14, 15, 46, 47, 48
G (only)	49
H (only)	17, 21, 35, 40, 65
J (only)	4, 5
K (only)	41, 56, 59, 63, 66, 72, 73
A+B	8
A+L	19, 62
C+E	32
E+H	12, 30, 74
H+I	7, 18, 20, 26, 39, 50, 51, 52, 53, 54, 58, 64
H+K	27, 38, 55, 60, 68
C+E+F	10
E+F+H	16, 34
F+H+K	9
H+I+J	37
H+I+K	61, 67, 69, 70, 71
H+K+L	57
F+H+K+L	11
A+H+I+K+L	43
B+C+E+F+H	23, 36, 45, 75
C+E+F+H+K	25
B+C+D+E+H+I	33
B+C+D+E+H+K	44
B+C+E+F+H+K	2, 3
B+C+D+E+F+H+I	31
B+C+E+F+H+I+J	24
A+B+C+E+F+H+K+L	1
B+C+D+E+F+H+I+J	28

Internal distribution list

M.Hapgood	RAL	1
M.Snelling	Astrium	2
E.Taylor	Astrium	3
H.Koskinen	FMI	4
D.Heynderickx	BIRA	5
D.Boscher	ONERA/DESP	6
D.J.Rodgers	DERA	7
L.M.Murphy	DERA	8
C.S.Dyer	DERA	9
R.Crowther	DERA	10
P.Latham	DERA	11
Project file 7/68/1/3	DERA	12
Information Centre	DERA	13-15

Report documentation page

1. Originator's report number:	DERA/KIS/SPACE/CR010157/1.0
2. Originator's Name and Location:	L.M.Murphy Room 1004, A8 Building, DERA Farnborough, Ively Road, Farnborough, Hants GU14 OLX, United Kingdom.
3. Contract number and period covered:	ESTEC contract no. 14069/99/NL/SB April 2000 - October 2001
4. Sponsor's Name and Location:	European Space Agency (ESA), ESTEC, Noordwijk, The Netherlands
5. Report Classification and Caveats in use: Unclassified	6. Date written: April 2001 — Pagination: x + 86 — References: 35
7a. Report Title:	European Space Weather Programme. System Requirements Definition.
7b. Translation / Conference details (if translation give foreign title / if part of conference then give conference particulars): Not applicable	
7c. Title classification:	Unlimited
8. Authors:	Lesley M.Murphy, David J.Rodgers
9. Descriptors / Key words:	Space Weather, European Space Weather Programme, System Requirements, User Requirements

10a. Abstract. (An abstract should aim to give an informative and concise summary of the report in up to 300 words).

This document first presents a set of User Requirements for a possible future European Space Weather System (ESWS). It then presents a set of System Measurement Requirements (SMRs) derived from, and traceable to, each individual User Requirement. Since many User Requirements result in the same (or very similar) System Measurement Requirements, a final consolidation process is carried out to remove duplicate requirements. The end result, ie. the consolidated set of System Measurement Requirements, is recommended as the starting point for detailed definition of ESWS design concepts.

10b. Abstract classification: Unlimited	FORM MEETS DRIC 1000 ISSUE 5

This page is intentionally blank