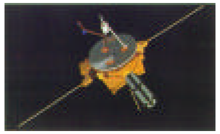
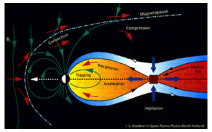
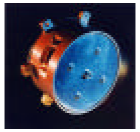

Rationale and Requirements for a European Space Weather **Service** (part 2)

D.J.Rodgers (QinetiQ)

ESA Space Weather Workshop
December 2001

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User and Measurement Requirements

- The studies considered:
  - 'Full scale' space segments - requiring development of new instruments and spacecraft platforms
  - 'Hitchhiker' space segments - i.e. space weather payloads (standard plasma, field or radiation environment monitors) on planned European spacecraft.
  - 'Existing only' space segments - i.e. only existing and planned space assets developed under the space programmes of ESA member states.
- The full set of requirements required the 'full scale' system but the studies retained the links between users requirements and measurements to allow trade-offs to be made in smaller systems.

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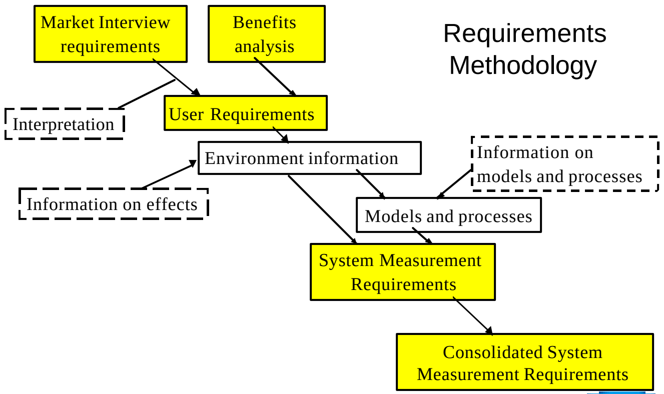
Requirements Methodology



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No. User requirement

Airlines and air safety organisations

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.

(risk assessments, crew roster changes, putting staff on alert)

2 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.

(avoiding action)

3 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.

(fulfilment of statutory requirements - important to come from an authoritative source)

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Electric power transmission organisations (also pipeline operators and railways and telephone companies)

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

(putting staff on alert, planning generating capacity, suspension of maintenance)

5 Spatially resolved now-cast information on large geomagnetically induced currents.

(implement mitigation procedures, diagnose anomalous currents)

6 Spatially resolved post-event information on geomagnetically induced currents of all sizes.

(diagnose failures)

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Geological prospectors and military

7 Forecasts of perturbations in the geomagnetic field

(rescheduling of surveys, warnings of outages in submarine MAD systems)

8 Now-cast of perturbations in the geomagnetic field

(instrument anomaly diagnoses, suspension of surveys, identification of MAD outages)

Geological prospectors and drilling industry

9 Post-event knowledge of perturbations in the geomagnetic field

(correction of survey results, correction of drill orientation)

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RF systems (civil and military)

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

(planned re-routing of communications)

11 Now-casts of ionospheric reflection properties for HF frequency selection

(optimisation of RF transmission)

GNSS location systems and radar systems (civil and military)

12 Now-casts of ionospheric total electron content

(correction of GNSS positions)

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Satellite operators (civil and military) and insurance and financial services

13 Post-event information on environments affecting operational satellite systems, e.g. radiation and charging environment

(anomaly diagnosis)

14 Forecasts of hazardous environments affecting operational satellite systems.

(putting staff on alert, having recovery procedures available)

15 Now-casts of hazardous environments affecting operational satellite systems

(real-time response to anomalies,)

16 Now-casts of atmospheric drag affecting LEO spacecraft

(re-entry calculation, orbit perturbation calculation, BMD tracking)

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Tourism

17 Forecasts of auroral Intensity, duration and location

(information for tourists)

Space Agencies

18 Forecasts of all hazardous environments affecting humans in space

(planning of EVA, early return from orbit)

19 Now-casting of all hazardous environments affecting humans in space

(suspension of EVA, movement to less exposed locations)

20 Post-event knowledge of radiation environments affecting humans in space

(crew exposure assessment)

Launch Providers

21 Forecasts of severe SEPEs affecting spacecraft launch operations

(launch delay)

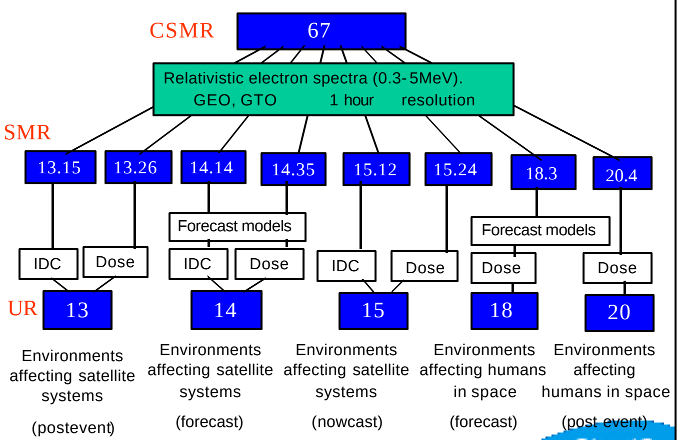
22 Post-knowledge of SEPEs affecting spacecraft launch operations

(launcher anomaly diagnosis)

(UR1=Forecasts 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 : ~18 hours preferred

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



Space Weather Events

- CMEs
- Magnetic Storms
- Solar Flares
- SEPEs
- solar magnetic field changes (precursors to CMEs/flares)
- Substorms
- Interplanetary shocks
- Interplanetary magnetic clouds
- Solar wind fast streams
- Solar wind pressure pulses

Space-based measurements

Solar images
- Solar EUV / X-ray images
- Solar coronagraph images
- Stereo visible or UV images of Sun-Earth space

Solar X-ray and UV fluxes

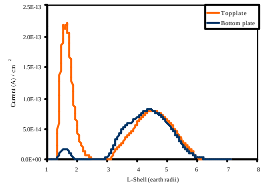
Auroral measurements
- Auroral imaging
- Auroral oval, size, location and intensity

Solar wind properties
- Vsw, Nsw
- IMF

Magnetospheric magnetic field

Plasmaspheric bulk density

Electron and ion fluxes
- 1-10keV electrons spectra
- 10-100keV electrons spectra
- Relativistic electrons (>0.3MeV).
- >10MeV protons (trapped)
- >10MeV ions (SPE/SEPE)
- >100MeV ions (GCR)



Debris and meteoroid properties
- Size and velocity distributions

Dose measurements
- Dose rate and LET spectrum
- Total dose

Interplanetary radio emissions

Ground-based measurements

Auroral measurements
- Auroral imaging
- Auroral equatorward boundary

Solar 10.7 cm radio emission

Secondary neutron fluxes (GCR)

Geomagnetic indices
- Kp, Ap, Dst

Geomagnetic field variations

Interplanetary radio scintillation

Ionospheric measurements
- critical frequencies
- total electron content

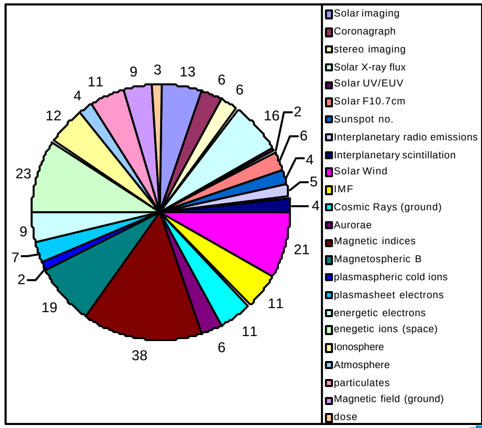
Cross-tail electric field / ionospheric drift

Atmospheric scale height (spacecraft tracking)

Debris and meteoroid properties

Sunspot number

Solar surface magnetic field



Benefits

Benefits arise from the space weather service and the programme that supports it.

ECONOMIC - affecting the price consumers must pay for services and the cost competitiveness of the business in which they work

STRATEGIC - affecting Europe's industrial, military, technological and scientific independence

TECHNOLOGICAL AND SCIENTIFIC - affecting the development of new products and industries as well as pure and applied research

EDUCATIONAL - affecting people's understanding of science, space and how space weather impacts their lives

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Key economic benefits

- **Lower risk of disruption to terrestrial power grids**
- **More efficient use of HF and satellite radio communication systems**
- **Improved accuracy and reliability of global satellite navigation systems**
- **Reduction in risks to aircraft avionic systems**
- **Improved air and marine safety and defence through better use of radar systems**
- **Reduced satellite operations costs, increased satellite reliability and extended lifetime**
- **Greater launch reliability**
- **Improved competitiveness of spacecraft insurers**
- **Reduced radiation exposure of aircrew and astronauts giving reduced cancer risk, longer working life**

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The economic value

- A - The rate of occurrence of the problem
- B - The percentage by which the problem would be alleviated due to the space weather programme
- C -The cost incurred each time the problem occurs.

- Value of the service = $\Sigma(AxBxC)$,

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Key strategic benefits

- **Reduced dependence on non-European resources for forecasting, warning, reporting and analysis of space weather effects and hazards**
- Improved competitive advantages for pan-European organisations and businesses
- Improved effectiveness and independence of European defence forces
- Improved competitiveness of European industry through bringing together of expertise from a wide range of disciplines
- Opportunities for growth of European industries in high-technology fields such as information systems, space platforms, sensors, launch services and ground segment equipment
- **Strengthening of relations with non-European nations through co-operation agreements, industrial partnerships and scientific exchange**

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Key technological and scientific benefits

- **Improvement of physical modelling and use of data-driven models**
- **Stimulation of basic science through improved data availability**
- Opportunity to monitor the effects of technology on the space environment
- Improved resilience of scientific missions
- Opportunity to increase the robustness of technology, to optimise its performance and to understand its limitations
- **Development of new sensors, new platform technology (eg. micro and nano-satellites) and new data handling technology**
- Development of novel technologies that can exploit changes in space weather and, potentially, technologies which modify space weather phenomena

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Key educational benefits

- Improved continuing professional development opportunities for scientists and engineers
- More opportunities to link the content of higher education courses in physics and astrophysics to practical experience from space missions and measurements
- **Improved awareness of basic science and space issues among school students**
- **A stronger presence for European space activities on the World Wide Web giving greater visibility to the world at large**

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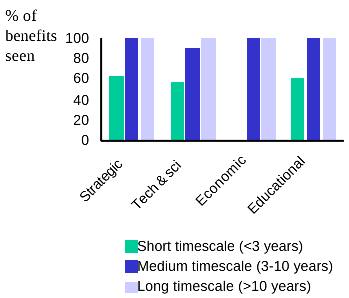
Timescales for benefit realisation

- Short-term benefits prior to operational use of any new assets
  - no economic benefits in this timescale
- Medium-term benefits as soon as new assets become operational
- Long-term benefits depend on further developments in space weather science & technology



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Programme size impacts

Economic and educational	Extent of benefit likely to increase in proportion to programme size; some benefit will be seen even with a small programme
Technological and scientific	Some benefits (about 1 in 3) are dependent on use of hitchhiker spacecraft and/or procurement of dedicated space weather spacecraft; these would not be realised with a small programme
Strategic	Some benefits (approximately 1 in 4) would not be realised with a small programme; others would increase in proportion to programme size

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Summary

A set of User Requirements was established from market surveys and benefits analyses

This led to a large set of required measurements
- a challenging task within available budgets

A European Space Weather Programme could generate significant benefits within a relatively short time and

extensive benefits in the long term

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