Contract Number 14069/99/NL/SB

Space Weather Cost and Risk Assessment

Technical Note for WP620
DRAFT 01

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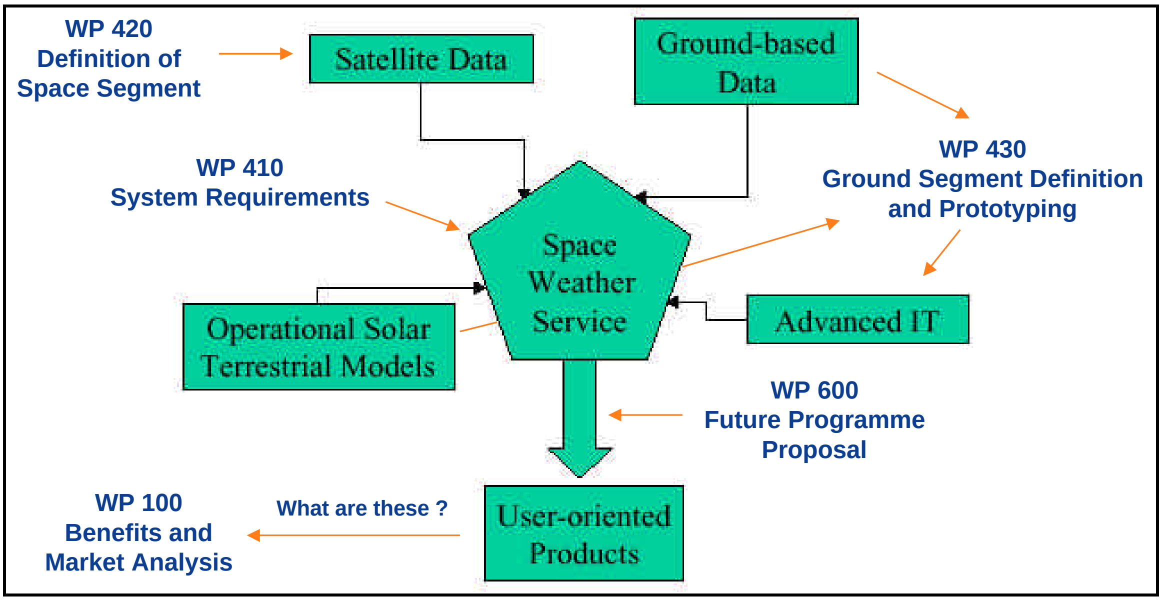
1. INTRODUCTION

The aim of this Work package 620 series is to assess the cost and risk implications for a Space Weather service based on the study requirements.

2. SCOPE

This document considers the costs and risks associated with establishing and running a space weather service as developed during the course of this study. The key elements of a space weather service are illustrated below along with the principal study elements.



The cost input is derived from the following elements of this study :

Work Package	Topic	Cost Data
420 (421)	Payload Definition	Instruments
420 (422, 423, 424)	Space Segment	Hitch-hiking
		Dedicated spacecraft
		Launch
430 (431)	Spacecraft Interface	Spacecraft Ground Segment
430 (432)	Service	Service centre

This analysis will cover the following activities :

- Define standardised methodology for assessing cost and risk
- Define cost estimate for provision of space weather service, as defined in WP610
- Assess non-financial costs, risks and benefits to ESA from the proposed space weather service
- Identify data product trade or purchase strategy, as required by WP420, in return for ESA (or ESA member state) strategic benefits, policy advantages or co-operation areas

- Identify benefits (profits) and benefit loss resulting from both baseline use of these data products and contingency use as a result of failure of one of the ESA space weather service components
- Compare cost and benefits of the proposed ESA space weather service with on-going current and planned ESA and ESA member state activities

3. REFERENCE DOCUMENTS

The following is a set of references used for this section of the study.

(RD/1) System Requirements Definition - ESWP-DER-SR-0001, ESA Space Weather Study (DERA)

(RD/2) Space Segment Options Report , ESA Space Weather Study (Astrium UK)

(RD/3) A Definition of instruments needed for Space Weather measurements - ESWS-RAL-TN-0001, ESA Space Weather Study (RAL)

(RD/4) Ground segment interface with space-based space weather measurements- ESWS-RAL-TN-0004, ESA Space Weather Study (RAL)

(RD/5) Project Implementation Plan - ESWS-RAL-RP-0002, ESA Space Weather Study (RAL)

(RD/6) Meteosat Second Generation, The Satellite Development ESA document, BR-153, Nov 1999

(RD/7) Interface between spacecraft ground segment and space weather service - ESWS-RAL-TN-0002, ESA Space Weather Study (RAL)

(RD/8) Space Weather Service - ESWS-RAL-TN-0003, ESA Space Weather Study (RAL)

4. DEFINITION OF STANDARDISED COST AND RISK METHODOLOGY

4.1 Cost Methodology

The cost methodology behind ESWS costs is simply the arithmetic sum of all the components that contribute to ESWS costs. The five contributions are derived from the following components of the ESWS Implementation Plan (WP610):

- Development group costs
- New Activities
  - Space segment costs (WP420)
  - Ground segment interface with space segment costs (WP431)
  - Ground instrumentation costs (WP421)
- Space Weather Service and Outreach costs (WP432)

Existing Data and Research are also components of the Implementation Plan, however they are not assumed to generate a cost against the ESA Space Weather Programme

Most details of the individual costings are described within each report, however those that are not, (e.g. Ground segment interface with space segment costs) are described in more detail within this report

4.2 Risk Management Methodology

A Space Weather Service will be a long term and expensive venture with, ultimately, many technology areas (users) relying to some extent on regular and reliable access to accurate products. It is therefore imperative that significant risks (i.e. those with a high probability of occurring and/or those that will have a major impact if they do occur) are identified at the outset and monitored throughout. There are many risk management approaches which differ in detail but all involve elements of the following :

- Scoping the system
- Identification of risks
- Prioritisation
- Analysis
- Management planning

The following discussion draws upon the risk management procedure in place at Astrium as a typical example of an approach appropriate to a high technology area.

It should be noted that later discussions of specific risks are conducted at a very high level. No attempt has been made to apply the risk management process described below beyond a superficial assumption about the situation in which a Space Weather Service will operate and a brainstorming exercise to identify the key risk areas.

Once it becomes clear exactly how a Space Weather Service will be set up and operated, it will be necessary to define an appropriate risk management approach and implement it fully.

4.2.1 Scoping the Situation, the Objective and the Process

The Situation, Objective and Process can be analysed to properly define the circumstances, facts and opinions prior to attempting to define, rank analyse or manage any project risks. The purpose of this activity is to understand fully the environment in which you are working so that appropriate risks can be identified and quantified. Specifically for a Space Weather Service the environment or situation is one of data gathering from a variety of sources, space and ground based, data processing using a variety of models and data dissemination to many different users, all of whom will be expecting reliable access to quality data.

A SWOT analysis can be a useful technique to define the current situation. In risk management it may be useful to consider the four elements of the SWOT matrix as:

Strengths	**Opportunities**
Weaknesses	**Threats**

Figure 1 SWOT Matrix

In defining an objective it is necessary to clearly identify and record the objective to be reached. Another way of considering the objective is to consider 'What you will have that you did not have before'.

The process element is the opportunity for the team to define the recognised steps necessary to achieve the objective. It is also the point in the process that the risk management approach can be tailored to suit a specific projects needs.

4.2.2 Identification of Risks (Brainstorming)

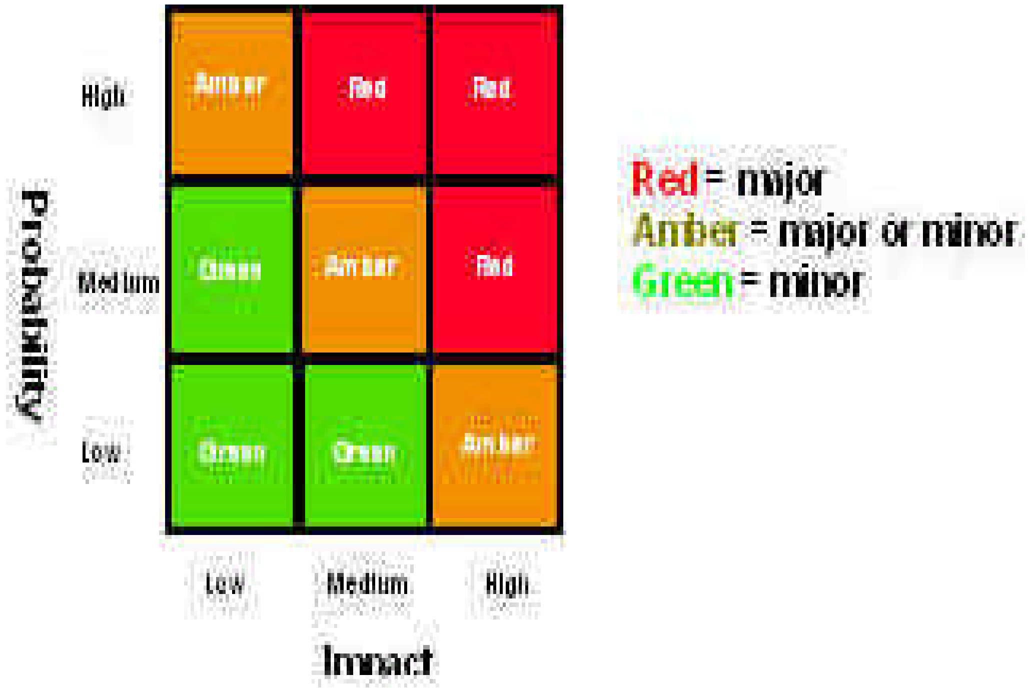
This a three-stage process :

1. Open unbounded brainstorming of the issues and factors.
2. Identification of common weak points that collate in the brainstorm.
3. Identification of specific risk elements associated with each weak point.

Developing this information through brainstorming is useful as it will inevitably involve several people with a collective wide range of experience, thus ensuring that most issues are addressed. It is important not to slide into analysis or 'discussion' of the risks identified beyond common understanding and interpretation of the meaning or wording.
Specific risks can be generated by using the phrase "A risk of / that…"

4.2.3 Ranking & prioritisation of risks. (Scatter Diagram)

Risk ranking is based on a simple three by three box model shown in Figure 2.



The vertical axis (**P**) expresses the **P**robability that a given risk will occur.
The horizontal axis (**G**) expresses the **G**ravity or 'Impact' if it does happen.

Figure 2 Risk ranking

Before ranking any risks it is vital that the team defines the dimensions of risk and agrees the scale of these two axes. It is also important to define the cut off points on this ranking (see Figure 3). All risks above the cut off will be subject to full analysis and mitigation. Risks below will be recorded and monitored.

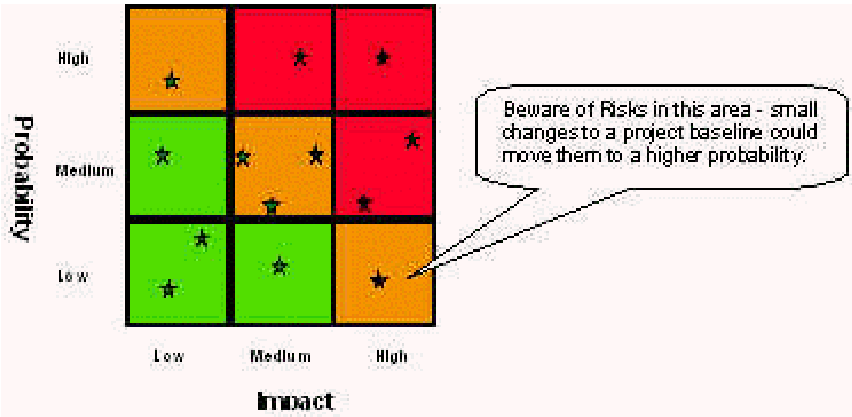


Figure 3 Risk ranking - Cut-off points

4.2.4 Analysis of risks and mitigation planning.

Using the prioritisation each risk is then the subject of a more in-depth analysis. This analysis consists of :

- Identification of the event or activity that will occur if the risk is to happen
- Identification of any risk mitigation actions that would in effect reduce the probability of the risk occurring.
- Identification of the effects seen or felt when the risk becomes reality. Understanding the outcome can define the recovery action plan to be in place prior to the risk event occurring.
- Identification of the 'Trigger' - Definition of the event or flag that indicates in advance that the risk is certain to occur. This is then monitored as part of the risk management approach.
- Analysis of the projects costs and schedule baseline from the following perspectives :
  - With no action.
  - With preventative counter measures only
  - With reactive counter measures only
  - With both preventative and reactive counter measures

The outcome from this analysis can then be reflected back into the project costing or contingency budget, to the baseline plan and the milestone delivery plan as necessary.

4.2.5 Management Plan

The projects management plan is updated to reflect the risk actions defined and then re-evaluated to ensure no new risks or weak points have been introduced. The project management plan then includes a number of sub documents including :

Risk impact summary
Risk mitigation action plan
Risk log or register

In particular, the risk register is a useful summary of the above analysis and for each risk identified, it typically records the following :

- Risk area (e.g. space segment)
- Description of risk (e.g. instrument failure)
- Trigger event (e.g. operator error)
- Consequences if risk occurs (e.g. loss of data supporting a CSMR)
- Probability of risk occurring (e.g. low)
- Gravity of occurrence (impact on system) (e.g. loss of CME forecast)
- Risk mitigation actions (e.g. alternative data source)
- Risk retirement event (e.g. spare instrument in hot standby)
- Financial information
  - Cost if risk occurs
  - Cost of mitigation
  - Cost if risk occurs with mitigation

A Space Weather Service Risk Management procedure would require a regular review of the risk register with the goal of :

- Updating information
- Reviewing mitigation strategies
- Including new risks as they are identified
- Retiring risks

The outline of the complete process is shown in below, which contains principles, which are universally applicable. These principles should be adapted to suit the needs of the specific situation in order to obtain maximum efficiency of the process.

Figure 4 Risk Management Methodology – Complete Process

5. COST ESTIMATE FOR PROVISION OF SPACE WEATHER SERVICE

This section summarises the costs from each of the components that contribute to the Total cost of a future ESA Space Weather Programme. A total cost for each potential option is then defined, which includes all of the cost components.

5.1 Development Group summary

The Development Group costs arise from the assumption that 2 people per year are required with a staff cost rate of 130 KEuro consistent with high expertise. This results in a cost of 260 KEuro/year. The Development Group is actually a competent person charged with developing networks with the relevant people and encouraging new developments

	Cost (MEuro)
Annual cost	0.26
No. years (2004-2015, 12 yrs)	12
Total cost	**3.12**

Table 1 Development Group Costs

5.2 Space segment costs summary

The following tables are a summary of the total cost of all the possible space segment architectures derived from the WP420 report.

Hitch-hiker type	Programme type	Total cost (MEuro)	Total cost without magnetograph (MEuro)
Max hitch-hikers	All missions	530.99	397.00
Max hitch-hikers	Euro + International collaboration	757.67	623.68
Max hitch-hikers	European led only	953.76	762.46
Large instrument dedicated	All missions	368.03	234.04
Large instrument dedicated	Euro + International collaboration	546.43	412.44
Large instrument dedicated	European led only	617.02	425.73

Table 2 Hitch-hiker only preferred orbit solutions

Note that a hitch-hiker only space segment, would also include a magnetograph. The costs without a magnetograph are added should dedicated spacecraft be used in conjunction with hitch-hikers. In these cases, the magnetograph would be discarded in favour of a magnetometer at L1 as it is cheaper and a more direct observation (the magnetograph gives only inferred results).

Implementation type	Programme type	Total cost (MEuro)
Max hitch-hikers	All missions	581.20
Max hitch-hikers	Euro + International collaboration	600.35
Max hitch-hikers	European led only	684.00

Table 3 Dedicated only space segments with maximum hitch-hikers - Overall cost results (Magnetometer at L1)

		Total Costs (MEuro) for each Orbit preference for CSMR with optional orbits		
Implementation type	**Programme type**	**L1**	**SS**	**GEO**
Large instrument dedicated	All missions	705.53	779.67	731.49
Large instrument dedicated	Euro + International collaboration	768.37	798.82	808.40
Large instrument dedicated	European led only	915.07	882.46	959.41
Full dedicated	All missions	1023.4	979.38	1009.07
Full dedicated	Euro + International collaboration	1023.4	1078.22	1264.29
Full dedicated	European led only	1131.54	1161.87	1360.44

Table 4 Dedicated only space segment with large instruments dedicated and Full dedicated overall cost results (Magnetometer at L1)

Implementation type	Programme type	Total cost (MEuro)
Max hitch-hikers	All missions	978.20
Max hitch-hikers	Euro + International collaboration	1224.03
Max hitch-hikers	European led only	1446.46

Table 5 Total Cost of space segment including Hitch-hikers and Dedicated spacecraft for space segment of Maximum hitch-hikers (no Magnetograph)

		Total Cost (MEuro)		
Implementation type	Programme type	L1	SS	GEO
Large instrument dedicated	All missions	939.57	1013.71	965.53
Large instrument dedicated	Euro + International collaboration	1180.82	1211.26	1220.85
Large instrument dedicated	European led only	1340.80	1308.20	1385.14

Table 6 Total Cost of space segment including Hitch-hikers and Dedicated spacecraft for space segment of with large instruments dedicated (no Magnetograph)

		Total Cost (MEuro)		
Implementation type	Programme type	L1	SS	GEO
Full dedicated	All missions	1023.4	979.38	1009.07
Full dedicated	Euro + International collaboration	1023.4	1078.22	1264.29
Full dedicated	European led only	1131.54	1161.87	1360.44

Table 7 Total Cost of space segment of Full Dedicated spacecraft (no Magnetograph)

Table 8 summarises the results to show what the cheapest implementation solution is for each programme type.

Programme type	Cheapest Implementation type	Orbit location	Total cost (MEuro)
All missions	Large instrument dedicated	L1	939.57
Euro + International collaboration	Full dedicated	L1	1023.4
European led only	Full dedicated	L1	1131.54

Table 8 Summary of cheapest implementation solutions to each programme type

5.3 Ground segment interface with space segment costs summary

The costs for the Ground segment interface with space segment costs (WP431) are only described for two space segment architecture cases in the WP431 report, i.e. hitch-hiking, and Full dedicated with L1 as the preferred orbit option for the majority of instruments. Other space segment architecture options are derived from the dedicated example by using a simplified version of the building blocks. This means that each additional instrument adds 0.34MEuro to the Set up costs, with the assumption that operations costs do not change, and that each additional GEO ground station results in an increase of 0.7MEuro/yr for the operations costs, when converting from L1 to GEO (L1 is three ground stations at 30%, whilst each GEO, for CSMR 1, is two ground stations at a 100% which is double the cost). Other cost differences are ignored as they are very small. Examples is the additional cost of an extra instrument per year, which is only 13KEuro/yr, and the initial set-up cost difference between L1 and GEO, which is only 65KEuro (as L1 has three ground stations and GEO has only 2 for CSMR 1).

The following tables are a summary of the total cost of all the possible space segment architectures derived from the WP431 report.

Hitch-hiker type	Programme type	Total cost (MEuro)	Total cost without magnetograph (MEuro)
Max hitch-hikers	All missions	125.2	116.9
Max hitch-hikers	Euro + International collaboration	166.2	157.9
Max hitch-hikers	European led only	194.2	180.9
Large instrument dedicated	All missions	106.4	98.1
Large instrument dedicated	Euro + International collaboration	142.1	133.8
Large instrument dedicated	European led only	154.1	140.8

Table 9 Hitch-hiker only preferred orbit solutions

Implementation type	Programme type	Total cost (MEuro)
Max hitch-hikers	All missions	142.08
Max hitch-hikers	Euro + International collaboration	142.08
Max hitch-hikers	European led only	161.48

Table 10 Dedicated only space segments with maximum hitch-hikers - Overall cost results (Magnetometer at L1)

		Total Costs (MEuro) for each Orbit preference for CSMR with optional orbits		
Implementation type	**Programme type**	**L1**	**SS**	**GEO**
Large instrument dedicated	All missions	161	161.34	161
Large instrument dedicated	Euro + International collaboration	182.18	171.34	184.98
Large instrument dedicated	European led only	215.58	190.74	223.28
Full dedicated	All missions	216.9	196.06	227.16
Full dedicated	Euro + International collaboration	216.9	221.24	274.38
Full dedicated	European led only	240.3	240.64	297.78

Table 11 Dedicated only space segment with large instruments dedicated and Full dedicated overall cost results (Magnetometer at L1)

Implementation type	Programme type	Total cost (MEuro)
Max hitch-hikers	All missions	258.98
Max hitch-hikers	Euro + International collaboration	299.98
Max hitch-hikers	European led only	342.38

Table 12 Total Cost of ground segment interface with space segment including Hitch-hikers and Dedicated spacecraft for space segment of Maximum hitch-hikers (no Magnetograph)

		Total Cost (MEuro)		
Implementation type	**Programme type**	**L1**	**SS**	**GEO**
Large instrument dedicated	All missions	259.1	259.44	259.1
Large instrument dedicated	Euro + International collaboration	315.98	305.14	318.78
Large instrument dedicated	European led only	356.38	331.54	364.08

Table 13 Total Cost of ground segment interface with space segment including Hitch-hikers and Dedicated spacecraft for space segment of with large instruments dedicated (no Magnetograph)

		Total Cost (MEuro)		
Implementation type	**Programme type**	**L1**	**SS**	**GEO**
Full dedicated	All missions	216.9	196.06	227.16
Full dedicated	Euro + International collaboration	216.9	221.24	274.38
Full dedicated	European led only	240.3	240.64	297.78

Table 14 Total Cost of ground segment interface with space segment of Full Dedicated spacecraft (no Magnetograph)

Table 15 summarises the results to show what the cheapest implementation solution is for each programme type.

Programme type	Cheapest Implementation type	Orbit location	Total cost (MEuro)
All missions	Large instrument dedicated	SS	196.06
Euro + International collaboration	Full dedicated	L1	216.9
European led only	Full dedicated	L1	240.3

Table 15 Summary of cheapest implementation solutions to each programme type

5.4 Ground based instrumentation costs

It is assumed that the ESA Space Weather Programme would only cover costs of two innovative ground-based instruments (see below) and that other requirements would be covered by the Member States through their support of existing and ongoing programmes (solar, geomagnetic and ionospheric observatories plus neutron monitors).

The two innovative instruments would be HF backscatter radar (CSMR 50) and Interplanetary Scintillation (CSMR 45).

5.4.1 HF backscatter costs

There is already a network of 9 stations in the Northern hemisphere. As it probably needs three stations to complete this, a costing model is used, in which the SW programme pays for those three stations and contributes 50% of running costs for the network of 12 stations (with the implication that the US pays the other 50%).

Hence, the costs are assumed to be the following:

- A set-up cost of about 700 KEuro per station, so total is 2.1 MEuro
- An operations cost of about 160 KEuro per station-year, so total (6 station years) is 960 KEuro/year. Note that the operations cost includes routine replacement of key system components.

5.4.2 Interplanetary Scintillation costs

This ultimately requires a network of six stations - three well-spaced in longitude within each of the northern and southern hemispheres. It would be a major step forward from existing systems, so costs are very speculative at this stage. It is assumed that we cost only a single prototype at present, but note that success of the prototype would lead to a more extensive proposal.

Hence, the costs are assumed to be the following:

- A set-up cost of 1 MEuro
- An operations cost of 2 SY/year, i.e. 260 KEuro/year in total.

5.4.3 Cost results summary

The following table is a summary of the total cost of setting up and operating Ground based instrumentation, which is described in the WP421 report.

	H-F Backscatter Cost (MEuro)	Interplanetary Scintillation Cost (MEuro)	Total (MEuro)
Initial cost	2.1	1	3.1
annual cost	0.96	0.26	1.22
no. years (2004-2015, 12 yrs)	12	12	
Total cost	13.62	4.12	**17.74**

Table 16 Ground based instrumentation costs

5.5 Space Weather Service and Outreach costs summary

The following table is a summary of the total cost of setting up and operating the Space weather Service, and are derived from the WP431 report.

	Cost (MEuro)
Initial/Set-up costs	0.798
annual costs	0.375
No. years (2004-2015, 12 yrs)	12
Total costs	**5.298**

Table 17 Space Weather Service and Outreach costs

5.6 Total Space Weather Service costs

The total space weather costs are listed in the following tables for each space segment option:

Hitch-hiker type	Programme type	Total cost	Total cost without magnetograph
Max hitch-hikers	All missions	682.34	540.06
Max hitch-hikers	Euro + International collaboration	950.03	807.74
Max hitch-hikers	European led only	1174.11	969.52
Large instrument dedicated	All missions	500.59	358.30
Large instrument dedicated	Euro + International collaboration	714.69	572.40
Large instrument dedicated	European led only	797.28	592.69

Table 18 Total Cost of Space Weather Programme for the Hitch-hiker only space segment

Implementation type	Programme type	Total cost
Max hitch-hikers	All missions	1263.34
Max hitch-hikers	Euro + International collaboration	1550.17
Max hitch-hikers	European led only	1815.00

Table 19 Total Cost of Space Weather Programme including Hitch-hikers and Dedicated spacecraft for space segment of Maximum hitch-hikers (no Magnetograph)

Implementation type	Programme type	L1	SS	GEO
Large instrument dedicated	All missions	1224.83	1299.31	1250.79
Large instrument dedicated	Euro + International collaboration	1522.96	1542.56	1565.78
Large instrument dedicated	European led only	1723.34	1665.89	1775.38

Table 20 Total Cost of Space Weather Programme including Hitch-hikers and Dedicated spacecraft for space segment of with large instruments dedicated (no Magnetograph)

Implementation type	Programme type	L1	SS	GEO
Full dedicated	All missions	1266.46	1201.60	1262.39
Full dedicated	Euro + International collaboration	1266.46	1325.62	1564.83
Full dedicated	European led only	1398.00	1428.67	1684.38

Table 21 Total Cost of Space Weather Programme of Full Dedicated spacecraft (no Magnetograph)

Table 22 summarises the results to show what the cheapest implementation solution is for each programme type.

Programme type	Cheapest Implementation type	Orbit location	Total cost (MEuro)
All missions	Full dedicated	SS	1201.60
Euro + International collaboration	Full dedicated	L1	1266.46
European led only	Full dedicated	L1	1398.00

Table 22 Summary of cheapest implementation solutions to each programme type

To review the elements contributing to the cost of the space weather programme it is useful to see how the cost is broken down. An example cost breakdown is shown in Table 23 and Figure 5 for a Full dedicated space segment with L1 as the preferred orbit option for a Space Weather programme including European missions and International collaboration

Total Cost Breakdown	Total cost (MEuro)
Space Segment	1023.4
Ground Interface to Space Segment	216.9
Ground instrumentation	17.74
Space Weather Service	5.2979
Development Group	3.12

Table 23 Example Total Cost Breakdown for Full dedicated space segment with L1 as the preferred orbit option for a Space Weather programme including European missions and International collaboration

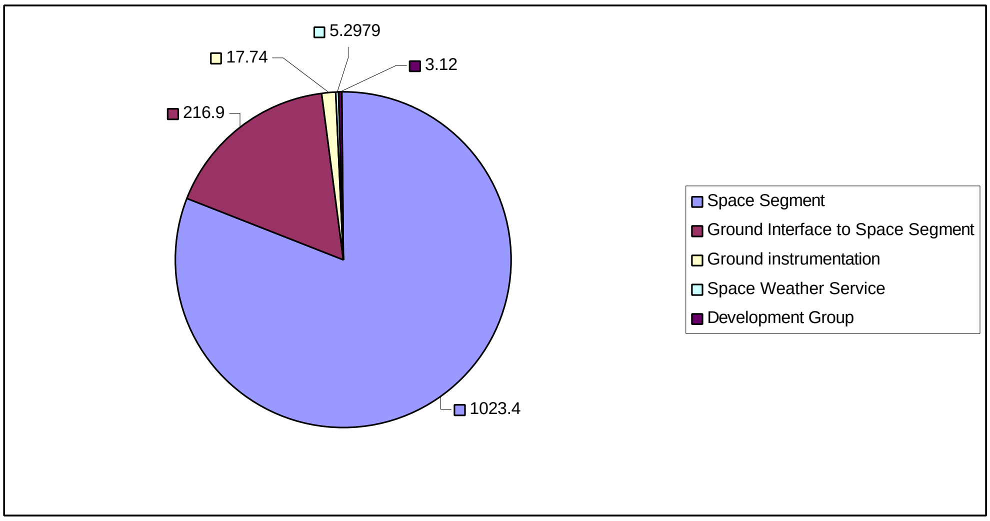


Figure 5 Pie chart with Total Cost Breakdown for Full dedicated space segment with L1 as the preferred orbit option for a Space Weather programme including European missions and International collaboration

We can see clearly that the space segment is by far the main cost driver in a future space weather programme accounting for 82% of the overall costs. Another significant driver is the ground interface to the space segment which accounts for 17%, whilst the other three cost elements are much lower with just 1%. We can thus conclude that a future space weather programme is extremely sensitive to the space segment, which also drives the ground segment interface.

6. RISK DEFINITION

Several major risk areas have been identified that are associated with development and operation of an ESA Space Weather Service. All three space segments are considered, i.e. current and planned missions, hitch-hikers and dedicated spacecraft. However, risk mitigation (in terms of space segment failures) for current and planned missions only, is severely restricted and is limited to just using another current and planned mission if one exists. This is because the use of hitch-hikers or dedicated spacecraft is not considered

Risk mitigation associated with Current and Planned mission failure as part of either Hitch-hiker or dedicated segments, is a different case to current and planned missions only, as new replacements can also be used. Therefore possible low-cost Hitch-Hiker/dedicated backup replacements should be identified.

6.1 Programmatic

Programmatic risks are caused by delay in spacecraft/instrument delivery. This can be mitigated by ensuring some overlap between successive spacecraft/instruments. This also has a positive knock-on effect with the space segment, as it guards against launch or early/late on-orbit failures.

6.2 Collaborative

Collaborative risks result from NASA or other non-European National Agency internal funding problems in collaborative programmes (e.g. SDO) for Current and Planned missions. This can be mitigated by identify possible low-cost hitch-hikers or dedicated backup solutions before a problem occurs.

Another risk is the potential failure of a Non-European space segment component in a data product trade as part of an ESA space weather service. This would be mitigated by defining a clear responsibility as to which organisation ensures that a replacement is ready, quickly.

6.3 Space Segment

These are failures that affect CSMR met by the space segment architecture. A major programmatic mitigation which affects the space segment is the intention for there to be some overlap of 6-12 months between successive spacecraft/instruments. This would help against launch or early/late on-orbit failures and could prevent a gap occurring in a particular CSMR, or a group of CSMR’s.

6.3.1 Launcher failure

This is failure of the launch vehicle carrying the host or dedicated satellite. For dedicated spacecraft, this can be mitigated by immediate use of a flight spare, which would have been intended as the follow-on spacecraft and therefore kept in storage. If a flight spare is not developed then it should be possible to upgrade the existing engineering/structure model.

For hitch-hiking the problem is more difficult, as we would need to use a flight spare on backup hosts that had been previously identified. This cannot be done immediately as we would need to select a host and then follow the standard process of integration etc, which could be some time. This could lead to a gap in CSMR data, depending if the gap from failure to launch of backup hitch-hiker was longer than the overlap of successive instruments.

Insurance is worth taking out as a cost mitigation

6.3.2 Launcher Programme Delay

A severe delay in the launch date caused by problems with the launcher could affect the programmatics of a space weather programme. For dedicated spacecraft this could be mitigated by maintaining compatibility with more than one launch vehicle

For Hitch-hiking, the launch is driven by the host spacecraft, which we have no control over. The only solution here would be to identify a backup host and use a flight spare, as the main instrument has probably already been integrated to the host.

6.3.3 Spacecraft failure

This is failure of the host or dedicated satellite whilst in space. The intention would be for there to be some overlap of 6-12 months between successive spacecraft/instruments, so there might not be a gap in a particular CSMR, or a group of CSMR's.

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For dedicated spacecraft, this can be mitigated by immediate use of a flight spare, which would have been intended as the follow-on spacecraft and therefore kept in storage. If a flight spare is not developed then it should be possible to upgrade the existing engineering/structure model.

For hitch-hiking the problem is more difficult, as we would need to use a flight spare on backup hosts that had been previously identified. This cannot be done immediately as we would need to select a host and then follow the standard process of integration etc, which could be some time. This could lead to a gap in CSMR data, depending if the gap from failure to launch of backup hitch-hiker was longer than the overlap of successive instruments.

Again, Insurance is worth taking out as a cost mitigation

6.3.4 Instrument degradation/failure

This is degradation or failure of the instrument whilst in space. As with mitigation of spacecraft failure, the intention would be for there to be some overlap of 6-12 months between successive instruments, to guard against a gap in a particular CSMR, or a group of CSMR's.

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For dedicated spacecraft, this can be mitigated by designing with redundancy as far as possible, however if this fails, immediate use of a flight spare should be aimed at, which would be on the follow-on spacecraft and therefore kept in storage. However, this may be an expensive solution if only one instrument failed on a multi-payload dedicated spacecraft. A low-cost alternative might be to find a host spacecraft, if a spare instrument is available. This may take a while, though and has implications regarding AIT.

For hitch-hiking we would need to use a flight spare on backup hosts that had been previously identified. This cannot be done immediately as we would need to select a host and then follow the standard process of integration etc, which could be some time. This could lead to a gap in CSMR data, depending if the gap from failure to launch of backup hitch-hiker was longer than the overlap of successive instruments.

Again, Insurance is worth taking out as a cost mitigation

6.3.5 Spacecraft degradation (e.g. AOCS, antenna)

This risk is caused by degradation of one or more spacecraft systems.

Dedicated spacecraft should employ redundancy wherever possible, and be designed with large margins. If the degradation exceeds a critical value, immediate use of a flight spare should be aimed at, which would be on the follow-on spacecraft and therefore kept in storage.

Hitch-hikers should employ a similar strategy if degradation exceeds a critical value. This would mean identification of a suitable backup host to integrate with a flight spare

6.3.6 Systematic failure

Systematic failure could be common to both dedicated spacecraft and hitch-hikers, and would have a costly, long term affect on a space weather programme as follow-on designs would be flawed. The only way to mitigate this problem would be to identify backup design solutions and make sure it didn't happen again.

6.4 Ground based instruments

This is primarily limited to instrument failure. Ways to mitigate this are to build in redundancy wherever possible, and if this fails maintain spares in storage, for use as replacements.

6.5 Ground Segment

6.5.1 Antenna tracking failure due to weather, motor, other (e.g. electronic)

Antenna failures can be mitigated by building in redundancy wherever possible, and if this fails, a backup ground station that has been previously identified should be temporarily used

6.5.2 Station computer failure

This is the failure of the station computer at the ground station. Station computer failures should be mitigated by building in redundant systems.

6.5.3 Internet Connection failure

An internet connection failure would result in data failing to reach the space weather service database. Multiple access points would mitigate this problem.

6.5.4 Security breach

Security breach by hackers is always a possibility. Therefore security measures such as Firewalls, password protection etc should be used to guard against this.

6.5.5 Third party provider risks

Third Party providers could be interpreted as organisations not involved with the space weather service, who supply critical components that contribute to the operation of a space weather service. A good example would be a utility such as Electricity suppliers. If there were to be a power cut, anything requiring electricity would shut down. Therefore a Standby Generator should be used to mitigate this problem.

6.6 Level 2 and below

Level 2 and below is the term generally applied to data after it has passed through the ground station and onto a processing centre. The main risk here would be faults with the software and algorithms that are used, and the associated upgrades that are required from time to time. This could be mitigated by application of rigorous control procedures.

6.7 Archiving

Archiving of data requires a medium to store the data. Superceding of recording media (e.g. CD's) could be a risk in future, so it must be ensured that a read-write capability is maintained.

6.8 Funding

Although the funding situation at the start of a space weather service may look sound, there is always the possibility that reduction in Public funding (e.g. ESA/Eumetsat) could occur. Essentially there would be no way to solve this problem and still satisfy the same number of CSMR. Prioritising the CSMR would go some way to mitigating the problem. However, this could provoke political pressure from industries requiring non-prioritised CSMR.

6.9 Service Operator Credibility (e.g. ESA/Eumetsat)

Service operator credibility could be badly affected by failures to spot/predict a major solar event such as a flare/CME or a False positive/false negative predictions. This can be mitigated by the following measures:

- Improvement of science modelling, so that predictions are more accurate.
- Encouraging development of services
- Applying reasonable thresholds, which could be raised with increasing service confidence (This may be applied to a system with red/orange/green warnings)
- Don't oversell the service

Another risk for ESA that could affect its credibility would be the failure of an ESA-led space weather mission as part of a data product trade contributing to the NOAA space weather service. Clear definition for responsibility of replacements is necessary so that the problem is mitigated.

6.10 Lack of Users

Once the service is up and running, it is possible that there is a failure to attract interest from markets that were expected to be service users or the general public. This can be avoided or at least alleviated by development of a good outreach programme.

6.11 Programme Cost Estimate

Miscalculation or more importantly, underestimation of total cost of space weather programme in the early stages of the development of the space weather service, could lead to a possible exceedance of the allocated budget at a critical time. This may lead to a radical re-evaluation of the architecture of the space or ground segments, which might result in prioritisation of the CSMR. To prevent this happening, more detailed and focussed studies should be carried out.

6.12 Programme Cost

It is possible that more detailed analysis of the Cost of a Space Weather programme may prove too high for the allocated budget. There are two potential ways to combat this. The first would be to simply prioritise the CSMR so that we are within the allocated budget. The second would be to seek joint ESA/National European Agency science/ space weather collaboration/missions to reduce costs. Solar-Terrestrial missions will always be on ESA's future agenda in some form or other, so it could be advantageous to try and combine future missions to carry out pure science and space weather operations.

6.13 Risk Summary

Major Risk Area	Risk description	Risk mitigation (Current and Planned missions belonging to H-H or dedicated segments)	Risk mitigation (Hitch-hikers)	Risk mitigation (dedicated)
Programmatic	Delay in spacecraft/instrument delivery	Use another mission Identify possible low-cost H-H/dedicated backup replacements	Plan to put follow-on spacecraft/instrument in place before expiry	Plan to put follow-on spacecraft/instrument in place before expiry
Collaborative	NASA/other internal funding problems to collaborative programmes (e.g. SDO) – Current and Planned missions	Identify possible low-cost H-H or dedicated backup solutions	N/A	N/A
	NASA/other current and planned (or new) mission failure in a data product trade	Clear definition of who supplies immediate replacement	Clear definition of who supplies immediate replacement	Clear definition of who supplies immediate replacement
Space	Launcher failure	Use another mission Identify possible low-cost H-H/dedicated backup replacements	Previously identify backup hosts and use a Flight spare (follow-on instrument in storage) Insurance	Flight spare (follow-on s/c in storage) or upgrade engineering/structure model Insurance
	Launcher programme delay	Use another mission Identify possible low-cost H-H/dedicated backup replacements	Identify a backup host if possible maybe with flight spare	Maintain compatibility with more than 1 launch vehicle

Major Risk Area	Risk description	Risk mitigation (Current and Planned missions belonging to H-H or dedicated segments)	Risk mitigation (Hitch-hikers)	Risk mitigation (dedicated)
	Spacecraft failure	Use another mission Identify possible low-cost H-H/dedicated backup replacements	Identify a backup with flight spare	Flight spare (follow-on s/c in storage) or upgrade engineering/structure model Build in redundancy wherever possible Insurance
	Instrument degradation/failure	Use another mission Identify possible low-cost H-H/dedicated backup replacements	Identify a backup with flight spare	Identify a backup with flight spare Build in redundancy wherever possible
	Spacecraft degradation	Use another mission Identify possible low-cost H-H/dedicated backup replacements	Identify a backup with flight spare, if degradation critical	Build in redundancy wherever possible Design with large margins
	Systematic failure	N/A	Identify backup design solution	Identify backup design solution
Ground-based instruments	Instrument degradation/failure	Build in redundancy wherever possible Maintain spares in storage		
Ground segment	Antenna tracking failure due to weather, motor, other (e.g. electronic)	Redundant systems Backup ground station		
	Station computer failure	Redundant systems		
	Internet Connection failure	Multiple access points		
	Security breach	Firewalls etc		
	Third party provider risks	Standby Generator		
Level 2 and below	Software and Algorithms – faults and upgrades	Rigorous control procedures		

Major Risk Area	Risk description	Risk mitigation (Current and Planned missions belonging to H-H or dedicated segments)	Risk mitigation (Hitch-hikers)	Risk mitigation (dedicated)
Archiving	Superceding of recording media (e.g. CD's)	Maintain read-write capability		
Funding	Reduction in Public funding (e.g. EUMETSAT)	Prioritisation		
Service Operator Credibility (e.g. ESA/Eumetsat)	Failure to predict a major solar event such as a flare/CME	Improve science modelling Don't oversell the service		
	False positive or false negative	Improve science modelling Encourage development of services Apply reasonable thresholds (red/orange/green) Don't oversell the service		
	Failure of ESA space segment component that is part of a Non-European Space Weather service in a data product trade	Clear definition of who supplies immediate replacement		
Lack of Users	Failure to attract interest from markets expected to be service users	Good outreach programme		
Programme Cost Estimate	Miscalculation of total cost of space weather programme	More detailed/focussed study		
Programme Cost	Cost of Space Weather programme too high	Seek joint science/ space weather collaboration/missions Prioritisation		

Table 24 Risks and Risk Mitigation

7. IDENTIFICATION OF DATA PRODUCT TRADE IN RETURN FOR ESA STRATEGIC BENEFITS, POLICY ADVANTAGES OR CO-OPERATION AREAS

The possibility of trading data products with non-European National agencies with no European involvement is interesting as it can ultimately lead to significant cost reductions in a future space weather programme. Three different collaborative space segment options were studied under WP420, each assuming a different level of collaboration. The potential for data product trade is discussed for the following three collaborative space segment options:

7.1 All missions

The space segment report from WP420, suggests that there may not be much opportunity to trade in terms of current and planned missions, due to the lack of future ESA space weather related missions. However, if the space segment were extended to include hitch-hikers and/or dedicated spacecraft, it would open up the possibility to trade data. This may be an extremely attractive option in terms of saving costs. Example U.S. only missions that could be available in this way could be GOES-NEXT or TRIANA, in exchange for access to data from hitch-hikers or dedicated spacecraft that are components to a future ESA space weather service. In fact, a data trade in this way would result in ESA giving away more that it receives and it might be possible to convince other Non-European National Agencies to lead/pay for some of the hitch-hikers or dedicated spacecraft previously costed as part of the ESA space weather budget. There is certainly potential here to drive down the cost burden for ESA to shoulder, whilst still meeting all or nearly all of the CSMR.

7.2 Missions with European and International Collaboration

This option already includes an element of collaboration with international agencies, however, every current and planned mission included as part of the space segment, already has European involvement at some stage. The issue is whether some of the missions with minimal European involvement can be used in an ESA Space Weather service without trade. If involvement is minimal and use is refused, then some level of trade could be arranged with these organisations, such that use of future ESA Hitch-hikers and Dedicated missions is permitted. This, however may be a problem were a space segment comprising of only current and planned missions used.

7.3 European missions only

This option is at the other extremes of collaboration, in that it aims to be completely autonomous. This means that data trade is not an option, and there is no way of using another data from another organisation’s missions/ground segment. This is why the option is the most expensive.

8. IDENTIFICATION OF BENEFITS (PROFITS) AND BENEFIT LOSSES RESULTING FROM BASELINE USE OF THESE DATA PRODUCTS AND CONTINGENCY USE AS A RESULT OF FAILURE OF ESWS COMPONENT FAILURE

In the event of a data trade between ESA and one or more Non-European National Agencies, the main benefit to ESA would be the significant cost savings (compare cost of All missions to other space segments) if considering hitch-hikers or dedicated spacecraft. However, ESA would now have no real control over missions contributing to the space weather service that are have no European involvement. An important question could be asked here – What happens if one of these missions that ESA relies on fails and who would replace it? This would have to be addressed so that there is a clear responsibility to ensure that a replacement is ready, quickly. This may not be a problem for GOES-NEXT, which has flight spares anyway, but could be an issue for a mission such as TRIANA, which does not.

An added risk for ESA in a data product trade, that could affect its credibility would be the failure of an ESA-led space weather mission as part of the NOAA space weather service. However, the discussion of replacements and responsibility is similar to that applied to the reverse situation described earlier in this section.

9. COMPARISON OF COST AND BENEFITS OF THE PROPOSED ESWS WITH ON-GOING CURRENT AND PLANNED ESA AND ESA MEMBER STATE ACTIVITIES

A useful method to compare ESWS with current and planned ESA activities is to analyse the costs of the major ESA programmes that cover Space Science, Earth Observation and Operational Meteorology. The latter is interesting as is envisaged that a future ESA space weather service would operate in a similar manner to Eumetsat's MSG programme, i.e. Earth Weather monitoring. The cost envelope of major programmes within the Space Science, Earth Observation and Operational Meteorology directorates are as follows:

Directorate	Programme	Cost Envelope (MEuro)	Approximate useful period of operations (years)	Cost per year of operations (MEuro)
Space Science	Cornerstone mission	650	5	130
	Flexi-mission	180	3	60
Earth Observation	Earth Explorer Core mission	350	3	120
	Earth Explorer Opportunity mission	90-120	3	30-40
Operational Meteorology	Meteosat Second Generation (MSG)	1510 (FY 1992) ~1965 (FY 2000)	12	165
	ENVISAT	2000	5	400
TBD	Space Weather	1300	12	110

Table 25 Comparison of costs of various ESA programmes

A direct comparison of these cost envelopes is one way of comparing the costs of different ESA programmes, and gives an idea of the total amount of money required. This illustrates that the cost of an ESA Space weather service would be more expensive that any other programme apart from ENVISAT. However an ESA Space weather service operates over a long time period, and the cost of the programme finances many years of returned data. In this sense, perhaps a better way to compare these programmes is to analyse the cost per year for each year that the programme collects useful data for (see last column of Table 25). This would exclude periods of hibernation for Cornerstone missions such as Rosetta. By looking at the costs in this way, we can see that a rolling ESA space weather programme costs less per year than a single Cornerstone mission, a single EECM, the MSG programme or ENVISAT.

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