ALCATEL
SPACE

Perspectives for a European Space Weather Programme
System Scenarios
Development Plan
Programmatics

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FOREWORD

This document results from the last tasks performed within the ALCATEL Space / LPCE consortium . It is the outcome of a Team Work all along the 18 months of the ESA Space Weather programme study .

All suggested ideas and formulated recommendations have been elaborated by the whole team, thanks to the contribution and motivation of each individual person from the different companies and laboratories involved in this consortium .

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1. INTRODUCTION

This technical note aims at defining the Perspectives for a European Space Weather Programme . It concentrates first on the System scenarios that the ALCATEL-LPCE consortium has derived from the work performed under the ESA study of the European Space Weather Programme . It then provide a synthetic view of the actions and orientations that are be recommended for developping such a programme taking into account the current status of European infrastructures and assets .

The main goal of the overall study is to identify the necessary steps and developments, as well as the European infrastructures, for setting up an operational Space Weather Programme that is able, in a short term, to offer a Forecasting Service to the European users . The operational aspect has then a great impact on the driving criteria for selecting the proper Space & Ground components as it constrains the data availability in terms of minimum time delay and the continuity of observation .

In that frame, and as first task, it has been necessary to select the Ground and Space instrumentation to be operated, in order to provide the monitoring and measurement data necessary to run a Forecasting Service of the Space Weather conditions with all components from Forecast to Nowcast and to Post-analysis .However, this task had to differentiate between three approaches whose specificities were mainly driven by the amount of development and fundings that could be made available to initiate a Space Weather Programme .

Therefore, the first part of this task has been dedicated to the definition of the characteristics of each scenario, in order to derive the selection criteria among the available instruments and observatories

Once the criteria have been identified, the second part of the task addressed the set up of the Space and Ground segment components for each of the defined scenarios, looking for the complementarity bteween Ground and Space based measurements.

Then, the last part of the task dealt with the comparison of the scenarios among themselves against the level of fulfillment with respect to the expected features for a Space Weather Forecasting service . It separates the technical achievements from the programmatics, economical and political aspects .

The second task is reviewing the necessary steps towards the build up of a European Space Weather Programme. It provides a synthesis of the outcomes for each segment identified as required to constitutes an operational forecasting service . It is a preliminary development plan that underlines the main orientations to take and the main corner stones for the operability of such an ambitious project .

2. FRAMEWORK OF THE SYSTEM SCENARIOS DEFINITION

2.1 ESA REQUIREMENTS FOR DIFFERENTIATING THE SCENARIOS

The Statement of Work addresses the following differentiation between three main approaches, dealing essentially with the Space segment:

- Approach 1 / Full Scale : shall contain a full scale space segment including new development and new platforms
- Approach 2 / Medium Scale : shall be based on the equipment of all european spacecraft with hitchhiker standard plasma/field/radiation environment monitors
- Approach 3 / Low Scale : shall focus on the use of existing assets without any supplementary hardware compared to the existing or anticipated space programmes of ESA member states

However, it appeared in the course of the study that the Ground measurements were deeply involved for feeding the Space Weather models and current forecasts. While it is clear that imaging the sun from ground based instruments means a multiplicity of sites and costly calibrations, it is also true that some other measurements currently performed from ground are sometimes difficult to provide from Space based platforms and may be less expensive. This is valid especially for some ionospheric parameters .

Two constraints were then clearly identified :

- It is not possible to separate the selection of any Space segment from the complementary Ground measurements
- The elaboration of the three scenarios would be more intelligible in terms of a global Space Weather programme performance than the sole Space segment capabilities .

2.2 ALCATEL CONSORTIUM RATIONALE

In order to make this differentiation between three "cost-based" approaches , the ALCATEL-LPCE consortium has re-considered the scenarios .
On one hand, it appeared that the last two approaches proposed in the SOW would allow neither substantial development nor the continuity of a Space Weather forecasting service . It could give access only to a partial capacity.On the other hand, the Full Scale approach required so many new components and infrastructures that no realistic funding could be envisaged in a short term to afford such a huge system at once .

Therefore, the Consortium decided to propose reduced approaches that could match much lower fundings and still answer essential User's requirements . The Full Scale approach remains, but it corresponds to the ideal situation, more or less like a reference case .These intermediate scenarios had to be completely defined and are as described in the following paragraphs together with the characterisation of each System scenario.

The new list of Scenarios has been re-settled as follows :

3 scenarios that contain a new Space segment component, but with different levels of investment from one to another	• Full Scale scenario • Medium Scale Scenario • Low Scale Scenario
2 scenarios with no new spacecraft component, which means very few investment in any Space item	• Hitch-hiker Scenario • Passive Scenario

3. DEFINITION OF SYSTEM SCENARIOS FOR A EUROPEAN SPACE WEATHER PROGRAMME

The following paragraphs detail the definition of each scenario in terms of objectives. They also address what characterize each scenario in terms of global performance and functionality in order to select the components of the various segments.

3.1 FULL SCALE SCENARIO

3.1.1 Definition and assumptions

It shall contain the Space and Ground segments necessary to address as exhaustively as possible the user's requirements as per the result of the correlation between the Top-Down and Bottom-Up approach followed within tasks 2100 and 1000's respectively . Therefore, it shall address all the parameters identified in Table 3.1 .
It shall also be the Ideal programme to constitute an autonomous and fully operationnal service .

3.1.2 Selection criteria

Actually, all instruments necessary to fulfill the acquisition of the needed parameters have been defined in WP 2200 & 2300 as well as WP 3120 for the Ground . Only some options remained and have been addressed through appropriate Space Segment definition trade-offs (WP 2400) .

Generally speaking, this scenario shall ensure :

- Real-time data availability and continuity of observation .
- Appropriate Space & Ground observatories for ensuring maximum Space & Time sampling.
- A dedicated ground data network to ensure the system integrity .

3.2 MEDIUM SCALE SCENARIO

3.2.1 Definition and assumptions

As a reduced and intermediate scenario, its specificity lies in the objective of reduced development and operationnal cost , while still allowing for an improved monitoring of the Sun events and their impacts compared to today's one.
In that sense, it shall provide adequate components and measurements in order to develop Space Weather services , eventhough at a lower rate than for the previous scenario and with possible bias on the operationnal aspects .
In that respect , the Ground segment shall, as far as possible, provide eventual compensation to the reductions on the Space segment.

3.2.2 Selection criteria

Resulting from the above objectives, the criteria to select among possible configurations have been set as follows :

- Maintain a real-time monitoring of the Sun and Solar Wind .
- Improve (compared to present situation) the current monitoring of the solar events effects in order to track the modifications & evolutions within the magnetosphere at a level compatible with Models developments .
- Reduce the Space Segment development cost (combined platforms as appropriate).
- Reduce the ground data collection network .

	Observed quantity		Measurement	I -M
Sun	Flux EUV/UV for aeronomy		Satellite spectrophotometry	I
	Flux UV, EUV et X		Satellite imaging	M
	Solar magnetic field		Ground based and satellite	M, I
	CMEs proxies		magnetograph, Hα and EUV telescopes	M
	CMEs onset times and velocity		Coronograph (ground based and satellite) EUV and X-ray telescopes, radio imaging	M, I
	Shocks		Hα and EUV telescopes, radio	M
	Energetic particles interacting in the atmosphere		Radio, X, gamma diagnostics	M
Interplanetary medium	Solar wind density and velocity		In situ, at the Lagrange point L1	M, I
	Interplanetary Magnetic Field			M, I
	Irregularities in the electronic density		Thomson diffusion in white light (satellite)	M
	Suprathermal electron beams and shock waves		Radio emission (satellite)	M
	InterPlanetary Scintillation		Radio emission (ground based)	M
	Cosmic rays		Neutron and muon monitors (ground based and satellites)	M
Magnetosphere	Spectrum of magnetospheric particles 1 eV = E = 500 M		Satellite observations	I
	Electromagnetic ULF/VLF waves			I
	Energetic Neutral Atoms			M
Ionosphere	Spectrums of auroral precipitations : 0.1 eV = E = 500 k		Satellite observations	I
	Image of auroral ovals		Satellite observations	M
	Convection electric field		in situ (satellite) High latitude radars (EISCAT, SuperDarn, ...) Deduced from the magnetic activity	M
	Electron density	variation with altitude	Incoherent scatter radars	I
		TEC, foF2 and hmF2	GPS, Ionosondes	M
Thermosphere	Neutral wind		Optical interferometry (ground based and satellite) Incoherent scatter radars	I
	Neutral density		Spectrometry (satellite) Accelerometry (satellite)	I
	Neutral temperature		Optical interferometry (ground based and satellite) Incoherent scatter radars	I
	Meteoroids and Space debris		Large debris: radar, optical telescopes (ground) Small particle: in situ	M
	Main Earth magnetic field		Magnetic observatories and dedicated satellites	I
	Magnetic activity at the Earth surface		Magnetic observatories and network of variometers	M

Table 1 : Summary of available observations. The last column indicates if observations are used for model improvement (I) or for monitoring (M)

3.3 LOW SCALE SCENARIO

3.3.1 Definition and assumptions

In order to aim at a "quickly operationnal" and very low cost system, one shall foresee serious cuts in the Space segment . However, this scenario shall remain within a perpetuation of Space Weather services that results in the selection on the essential observations from Space . This justifies the difference with the next two "low profile" approaches.

The ground segment shall then be enhanced as far as possible in order to compensate for reduced Space-based capacity .

3.3.2 Selection criteria

As some instruments can only be used in Space, the following criteria have been applied :

- Minimum and cost-effective Sun and Solar wind monitoring from space, but may not remain in real-time
- Minimized data network (re-use of existing ones)
- Very minimum set of parameters for solar events effects tracking within the magnetosphere, ensuring at least nowcasting .

3.4 HITCH-HIKERS SCENARIO

This scenario is defined by the ESA statement istself , as it shall only contain hitch-hikers payload, the list of which is already in the WP 2200 document . The purpose of the task is only to find appropriate hosting platforms .

The objective of this scenario is to understand what can be achieved with such a minimal Space Segment approach.

It is clear that the ground segment to be proposed in that case shall be as exhaustive as possible in order to compensate as much as achievable for the deletion of main Space-based measurements.

3.5 PASSIVE SCENARIO

Finally, this case considers a "no new item" option . It shall provide statements about what one shall expect if nothing is foreseen as new projects to answer at least some measurements needed for Space Weather service development . It is a kind of "Current Status" to be used as reference .
The only developments that could be foreseen concern the Ground data distribution and processing as well as the forecast services . The latter were not quantified in the study and should however be developped in agreement with the Space Segment capabilities which, in that case, would not be warranted for future use .

4. DESCRIPTION OF SYSTEM SCENARIOS

The first three scenarios are detailed in Tables 4.1 and 4.2 for respectively the Space and Ground segments .

Specific descriptions are provided for the last two options .

4.1 FULL SCALE SCENARIO

4.1.1 Description

The Full Scale scenario Space Segment sections are illustrated in Figures 4.1 to 4.3 . It results from the assessments performed within task 2300 and 2400 . One of the main drivers has been to provide the maximum data flow in real-time , which guided the choice towards the GEO spacecraft for Sun observation according to the High Rate of data resulting from the continuous Sun scanning .The possibility, then, to download all data towards only one ground station appeared as a drastic advantage from the operational point of view .

The main characteristics are as follows :

- Fully instrumented Platforms in various orbits :
  - L1 for Solar Wind monitoring
  - Geostationnary orbit for Sun monitoring
  - GTO-type of orbit for Radiation Belts mapping
  - High Excentric orbit for Polar cap monitoring
  - Sun Synchronous LEO orbits for ionosphere monitoring
  - Highly inclined and equatorial circular LEO for ionosphere/thermosphere monitoring
- Several hitch-hiker payload for complementing the Magnetosphere mapping in terms of particle population
- Centralised Data Collection system : by using the Sun Observation GEO Platforms as data relay of every other spacecraft of the System .
- Maximum number of spacecrafts in order to ensure observation continuity and appropriate inputs for the development of forecasting and analysis models.

It is a self-standing system, in the sense that some telecommunication features are justified by the completeness of the system . For instance, data relay from L1 to earth via GEO is not viewed as an optimum solution , but as the result of the centralisation aspects of the data ; the relay of the data from Ionosphere monitoring spacecrafts can be done through other means, but the availability of a single Data Station vs the use of additional networks eases the operability of the system .

The Ground Segment components group many networks already in use for Solar-Terrestrial Physics studies . One of the major concern is to get them fully operationnal in terms of data availability, data reliability and correlation with other measurements .

Table 2 : Full Scale , Medium Scale and Low Scale Scenarios_ Space Segments Descriptions

	Full Scale	Medium Scale	Low Scale
Solar Observation	(1) 2 Geosynchronous Spacecrafts with full intrumentation (2) L1 Instruments on Upstream Monitor : radio-spectrograph (<40 MHz min; up to 200 MHz if feasible)	(1) L1 Observer with low freq. Radio-spectrograph(<40MHz) (2) H-α imager with reduced TM rate (3) Suppression of SXI	(1) LEO satellite, with limited instruments : • EUV Imager • Coronagraph • EUV Flux • EUV Spectrometer
Solar Wind-heliosphere	(1) Upstream Monitor at L1 with full Instruments and including radio-spectrograph	(1) Upstream Monitor at L1 combined with Solar observation (separated if less costly / more heritage)	1. Upstream Monitor at L1 with full Instruments
Magnetosphere Monitoring (Radiation Belts)	1. Three Equatorial spacecrafts in GTO 2. Hitch-hikers on GEO/MEO s/c	1. Three Equatorial spacecrafts in GTO 2. Hitch-hikers on GEO/MEO s/c	1. One Equatorial spacecraft in GTO 2. Hitch-hikers on GEO/MEO s/c
Ionosphere / Thermosphere	1. High Excentric Spacecraft 2. Two Sun-synchronous LEO 3-15 & 9-21 LT (600km) 3. Two inclined LEO (75°) on the same orbit 4. 1 pair of equatorial LEO on the same orbit	1. Two Sun-synchronous LEO at 600km 3-15 & 9-21 LT 2. Hitch-hikers for radiation belt	

Table 3 : Full Scale , Medium Scale and Low Scale Scenarios_ Ground Observation Segments

	Full Scale	**Medium Scale**	**Low Scale**
Solar observations	Broad frequency radio spectrographe (above 40 MHz) Radio imaging.	Broad frequency radio spectrographe (above 40 MHz) Radio imaging.	Broad frequency radio spectrographe (above 40 MHz) Radio imaging. Magnetograph network. Hα network.
Upstream (including interplanetary)	Broad frequency radio spectrograph. Radio imaging. Neutron and Muon detectors.	Broad frequency radio spectrograph. Radio imaging. Neutron and Muon detectors.	Broad frequency radio spectrograph. Radio imaging. Neutron and Muon detectors.
Magnetospheric monitoring	Covered under I/T monitoring	Covered under I/T monitoring	Covered under I/T monitoring
Ionosphere/thermosphere Monitoring	Magnetometer networks. Positioning networks SuperDARN network. F10.7cm	Magnetometer networks. Positioning networks SuperDARN network F10.7cm Ionosonde Network	Magnetometer networks. Positioning networks SuperDARN network F10.7cm Ionosonde Network

Note. Some instruments and networks are used for research and must be turned into operational facilities, with guaranteed funding.

Figure 1 : Full Scale Scenario : Space Segment and Global Data Circulation system

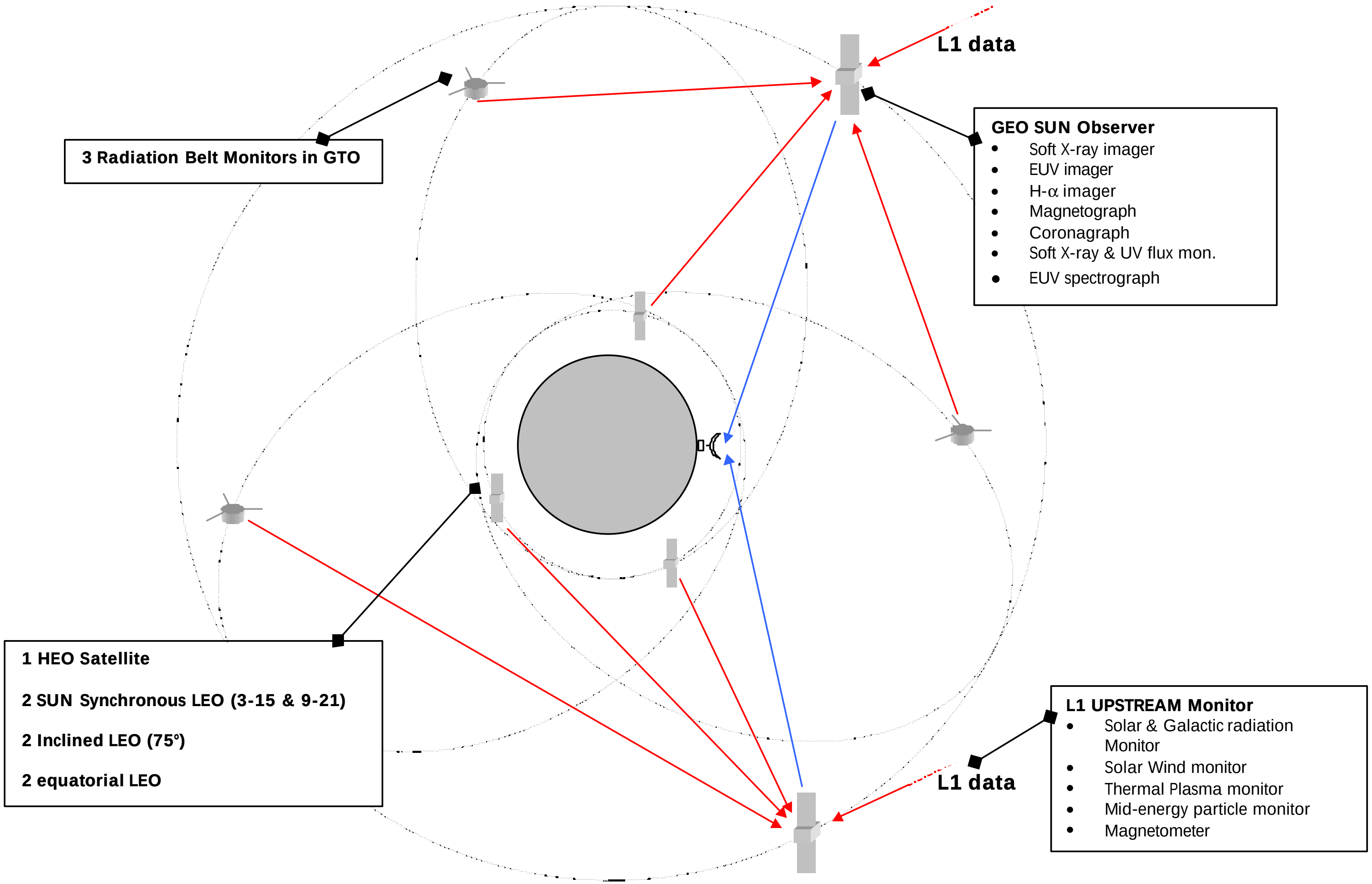
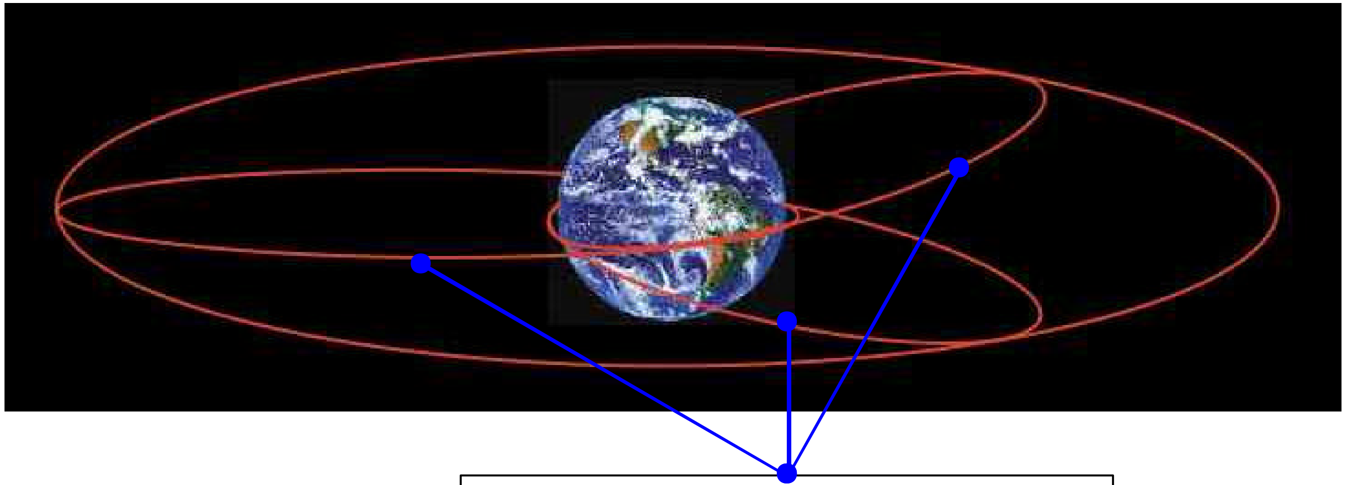


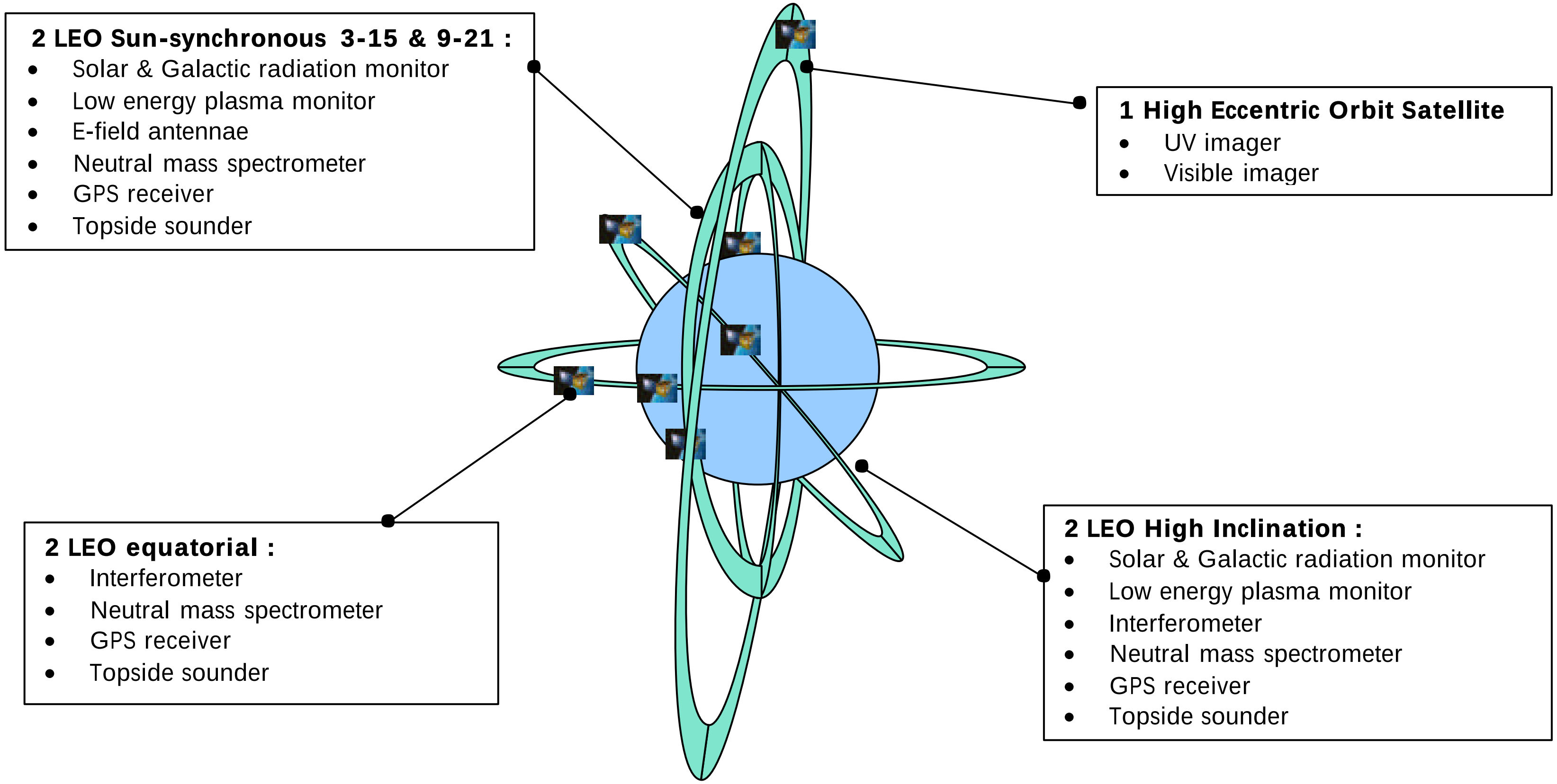
Figure 2 : Full Scale Scenario : Magnetosphere Radiation Belts Monitoring : GTO-TYPE Orbits, 120° apart



Radiation Belt Monitors on 3 GTO-type orbits

- Thermal Plasma monitor
- Mid-energy particle monitor
- Magnetometer
- Waves

Figure 3 : Full Scale Scenario : Ionosphere/Thermosphere HEO and LEO Satellites monitoring Orbits .



2 LEO Sun-synchronous 3-15 & 9-21 :
- Solar & Galactic radiation monitor
- Low energy plasma monitor
- E-field antennae
- Neutral mass spectrometer
- GPS receiver
- Topside sounder

1 High Eccentric Orbit Satellite
- UV imager
- Visible imager

2 LEO equatorial :
- Interferometer
- Neutral mass spectrometer
- GPS receiver
- Topside sounder

2 LEO High Inclination :
- Solar & Galactic radiation monitor
- Low energy plasma monitor
- Interferometer
- Neutral mass spectrometer
- GPS receiver
- Topside sounder

4.1.2 *PROS and CONS*

	PROS	CONS
Technical	• Exhaustive Measurements for Solar events detection & tracking • Real-Time and continuous data flow => optimized monitoring of all segments • Optimized data circulation mission and infrastructure : single ground station • Rapid development of prediction Models for Magnetosphere/Ionosphere • Maximum re-use of existing instruments concepts	• Large but limited mapping of Magnetosphere (i.e. compared to SWARM*) • New H-α and Radio-spectrograph space instruments (but technology exist) • High performance inter-satellite links system
Programmatics Economical & Political	• Full Autonomy for EUROPE • Sun Obs spacecraft in GEO easily derived from telecommunication platforms (compared with L1 wrt data transmission) • Very light operational cost of the Space-Data collection ground segment • Attractive Cooperation possible for the 2 Sun Obs GEO Spacecrafts	• Large number of spacecrafts & Launches • Long deployment phase (eventhough very different launchers are envisaged)

* The SWARM-like constellation has not be selected as it leads to a very high number of satellites , and subsequent launches, that is not thought to bring a very substantial operational advantage compared to the GTO-orbits constellation .

4.1.2.1 Cost Aspects

The preliminary global cost assessment of the overall System can be broken down as below. It does include only partial quotation of ground infrastructure.

	Development & Deployment	Operation
Spacecrafts Platform + Instruments	1110 M€	n.a.
Ground Obs (1)	16 M€	1 M€/y
Ground Data Reception	35 M€	2.5 M€/y
Total	1161 M€	3.5 M€/y

(1) The Ground Observation section does not quote all necessary operational infrastructures. It corresponds to technical upgrade of existing networks. It only give an indicative figure for : 2 radio-heliographs + 2 radio-spectrographs + operations of all . For information , 1 magnetometer station is about 60 k€ and getting Superdarn operational is about 30 k€/year .

4.2 MEDIUM SCALE SCENARIO

4.2.1 Description

One of the main modifications is the grouping of Sun and Solar wind monitoring at L1 .This enables a serious reduction in Space platforms , but generates a problem of very high data rates for real-time data transmission due to the high data rate of Sun imaging instruments . This justifies the reduction of the H-α imager cadence and the suppression of Soft-X ray Imager which is considered as less essential .The latter can be compensated by increasing the range of wavelengths on the EIT telescope. In any case, the ground data reception shall be ensured by a dedicated network, as the DSN currently in use for SOHO and ACE does not provide sufficient continuity, and thus prevent from a true real-time detection of events .

The fact is that the combination of Sun imaging with Solar wind instruments lead to a more complex concept than SOHO and ACE as the measurements constraints are quite contradictory (SUN pointing on one side and wide angle detection cone for the other , that lead to a spinner concept for ACE and 3-axis stabilized for SOHO respectively)

The other highly reduced segment concerns the Ionosphere/Thermosphere , limiting the Space-based observation to the minimum number necessary for providing inputs to the main applications (like Orbitography, navigation and VHF/UHF communications interruptions) as well as the development of prediction models .

Globally, the space segment is much lighter, and this reduces the data communication problem, except, as already stressed out, for the L1 satellite. However, the suppression of relay link will constrain the LEO and GTO spacecrafts to download their data with some delay .

4.2.2 PROS and CONS

	PROS	**CONS**
Technical	• Optimised Measurements for Solar events detection & tracking • Real-Time and continuous Sun and Solar Wind monitoring • Essential coverage of radiation belts for Space applications • Maximum re-use of existing instruments concepts • Classical Data transmission systems (eventhough less performant)	• Large but limited mapping of Magnetosphere (i.e. compared to SWARM) • New H-α space instruments (but technology exist) • Holes in the Ionosphere/Thermosphere monitoring needing a consolidation of the ground segment • Larger development time for prediction Models for Magnetosphere/Ionosphere • Dispersed Ground Data collection system (L1 + GTO) • New data reception network for L1
Programmatics Economical & Political	• Full Autonomy for EUROPE • Single platform/launch for L1 => reduced development and operational costs • Rapid operability (3 Launches)	• Long deployment phase • Complex satellite in L1 (or 2 satellites, but then increased operational cost) • Single L1 platform less versatile than L1 + GEO platform (evolution) •

4.2.3 Cost Aspects

The preliminary global cost assessment of the overall System can be broken down as below. It does include only partial quotation of ground infrastructure.

	Development & Deployment	Operation
Spacecrafts Platform + Instruments	580 M€	n.a.
Ground Obs (1)	16 M€	1 M€/y
Ground Data Reception (2)	26 M€	2 M€/y
Total	622 M€	3 M€/y

(1) The Ground Observation section does not quote all necessary operational infrastructures. It corresponds to technical upgrade of existing networks. It only give an indicative figure for : 2 radio-heliographs + 2 radio-spectrographs + operations of all . For information , 1 magnetometer station is about 60 k€ and getting Superdarn operational is about 30 k€/year .

(2) The Ground data reception addresses only the L1 satellite (combined SUN + Solar wind) operation network. The ground hardware for Sun-synchronous LEO remains to be optimised . It is assumed that the ground data reception for Radiation Belts GTO shall use the ESA Network .

4.3 LOW SCALE SCENARIO

4.3.1 Description

According to the objectives, this scenario shall provide the minimum Space-based observation in the frame of a Space Weather service . The very low cost approach is also associated with a need to rapidly develop an observatory that allow the current services to continue .

The Upstream monitor in L1 appears anyway as a compulsory item for collecting any exploitable Solar Wind data . As no reduction of payload would mean any significant benefit on the project cost without retrieving essential data, the same project as for the Full scenario is maintained .

The most important cut in development cost relies then on a LEO-based Sun observation . This reduces dramatically the payload capability to its minimum set, but it allows a very cost effective space based platform of the Minisat class to be lauched very easily . However, the data transmission becomes problematic with large delays in downloads, unless a specific ground data collection segment is built to allow for frequent downloads .

The rest of the Space segment is reduced to a single satellite in GTO as RBM, aiming at a minimum of tracking capability for the effects resulting from solar events inside the magnetosphere .It shall provide only sparsed data, and spread in time , but it will at least provide in-situ measurements of the Radiation belts modification within or after a storm . Actually, this scenario would greatly benefit from an international cooperation (like with LWS) in order to share the orbits and/or the payloads .

This Space segment is illustrated in figure 4. The Ground-based measurements take then a more important role, as it shall be developped largely in terms of H-α imagers (with appropriate spreading around the world) as well as magnetographs .A global overview of the needed scope of development has been addressed and appear in Tables 4 & 5 . It provides both some qualitative assessment of the existing capability and the prioritorization of the future actions to take .

4.3.2 PROS and CONS

	PROS	**CONS**
Technical	• Minimised bu essential Sun and Solar Wind monitoring for optimum development cost . • Re-use of existing instruments concepts • Light platforms development/launches	• Limited observation (Sun, Magnetosph. , Ionosphere) => limitations on Forecasting models & SW products developments • Larger development time for prediction Models for Magnetosphere/Ionosphere • Dispersed Ground Data collection system • Limited Data transmission system capability => not real-time
Programmatics Economical & Political	• Ensures minimum Autonomy for EUROPE : on essential observations . • Lowest Space-based development costs for a continuity of SW forecast services. • Rapid operability (3 Launches) • compatibility with Solar-B for Sun Obs. => cooperation (instr; grnd stations) .	• Dependance on international coop. for essential H-α observations • Limited potential for development of Users Services =>risk of slow down of interest .

4.3.3 Cost Aspects

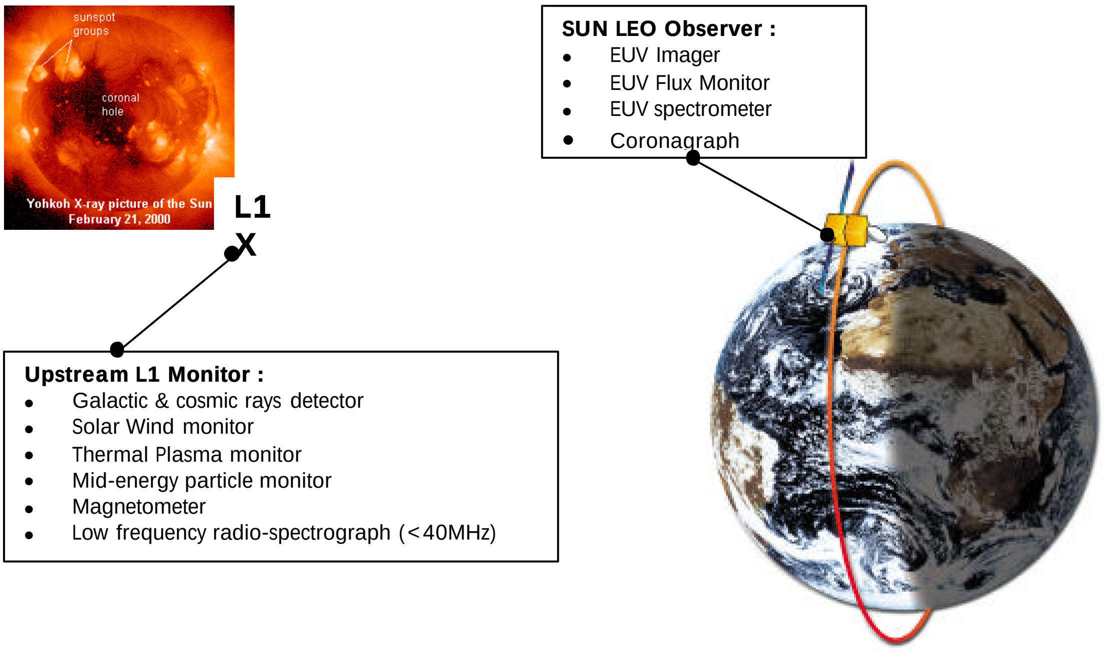
The preliminary global cost assessment of the overall System can be broken down as below. It does include only partial quotation of ground infrastructure.

	Development & Deployment	**Operation**
Spacecrafts Platform + Instruments	255 M€	n.a.
Ground Obs (1)	18.5 M€	1.2 M€/y
Ground Data Reception(2)	4 M€ per station	1.0 M€/y
Total	277.5 M€	2.2 M€/y

(1) The Ground Observation section does not quote all necessary operational infrastructures. It corresponds to technical upgrade of existing networks. It only give an indicative figure for : 2 radio-heliographs + 2 radio-spectrographs + 2 H-α telescopes + operations of all . For information , 1 magnetometer station is about 60 k€ and getting Superdarn operational is about 30 k€/year .

(2) The ground network for data reception of the Sun LEO remains to be optimised . Only hardware for one ground station is quoted here .The operation cost is extrapolated from other figures .

Figure 4 : Low Scale Scenario : essential Sun & Solar Wind Observer



SUN LEO Observer :

- EUV Imager
- EUV Flux Monitor
- EUV spectrometer
- Coronagraph

Upstream L1 Monitor :

- Galactic & cosmic rays detector
- Solar Wind monitor
- Thermal Plasma monitor
- Mid-energy particle monitor
- Magnetometer
- Low frequency radio-spectrograph (<40MHz)

Table 4 : Recommended Ground Segment Developments (1/2)

Region	Instrument	Current status	Deduced Parameters	Use for SW	Remarks	Recommendation
Sun	Full disc magnetograph	Networks under construction.	Mean field Solar rotation and oscillations Vector magnetograms	To detect onset of solar events	Networks include GONG+ USAF-ISOON, SOLIS	Accessibility uncertain. Use existing networks if available. Augment/implement network to provide 24hr coverage Priority to space
Sun	Full disk Ha network	Network under construction	Velocity profiles of solar chromospheric structures Moreton waves	To detect onset of flares and CMEs	Networks include USAF-ISOON, BBSO (coordinator)	Accessibility uncertain. Use existing networks if available. Augment/implement network to provide 24hr coverage Priority to space
Sun	Coronagraph	Research	Plasma density	Proxy for CME propagation	No established network. Seeing limitations.	No ground network recommended.
Sun and Interplanetary	Broad frequency radio spectrograph (> 10MHz)	Research	Velocities of shocks, electron beams and energetic particles. Proxy for moreton waves.	Detection of SEP events. Shock propagation.	No established network.	Network needs to be set up with minimum of 3 sites for 24hr coverage.
Sun and thermosphere	10.7 cms flux monitor	Network exists	10.7 cms flux	Proxy for solar activity. Required for thermospheric models	US network Data fully accessibility	To be maintained for continuity of geophysical records
Sun and interplanetary	Radio imaging below 1 GHz	Research	Intensity and polarization maps	CME onset and development SEP events. Proxy of Moreton waves and shocks	No established network. Cannot be done from space.	Network needs to be set up with minimum of 3 sites for 24hr coverage.
Interplanetary	Interplanetary scintillations	Research	Starlight intensity fluctuations	Presence and motion of shocks out to several AU	No established network. Dual site measurements show CME structure and propagation	Promising technic. Needs more investigation to establish SW capability.

Table 5 : Recommended Ground Segment Developments (2/2)

Interplanetary	Neutron and muon detectors	Operational networks	Cosmic ray flux variations. Anisotropies.	Radiation dose. Detection of interplanetary shocks and CMEs propagation	International neutron networks exist, operational 24 hrs/day. Present muon networks has big gap over Europe. Cannot be done from space. Real time data freely accessible.	Use existing neutron network. Muon detector required in European region.
Magnetosphere and ionosphere	Magnetometer network	World wide networks exist. Operational	Absolute values of B. Ionospheric currents	Geomagnetic indices. Storm and substorm detection	24 hr coverage Data freely accessible. Gaps over Russia and Northern asia	Use existing networks Fill gaps in local time.
Ionosphere	SuperDARN coherent radars	Research	Velocity maps. Boundary location, Convection electric field	Electric field and convection maps.	18 hr MLT coverage in northern hemisphere, 12 hrs in south. Data is freely available, convection maps available in real time.	Establish 24hr coverage, and operational capability.
Ionosphere	Ionosondes	Research	Ionospheric density profile below F region.	Maximum useable frequency for HF communications TEC, scintillations.	Over 50 stations in Europe, only 6 automated and provide. Pressure to close down.	Intercalibrate instruments. On-line data access required. COST are assessing for SW. Recommend use for absolute Ne measurements
Ionosphere	Positional receivers	Operational for GPS	TEC, position, neutral density corrections	Prediction of HF communications Scintillations	GPS data is freely available	Higher spatial resolution required (COST are assessing for SW). Intercalibration required. Future data must be freely available for SW.
Ionosphere	Incoherent scatter radar	Research	Ionospheric Density, temperature, velocity	Calibration tool	Useful for model development	Support continued operation.
Thermosphere	Optical interferometers	Research	Neutral density and temperature	Potential use for atmospheric drag	Limited to clear skies.	Potential use for model development
Ionosphere	Riometers	Research	Radio wave absorption	Scintillations. Electron precipitation	Long term future at risk. 23 sites providing limited spatial coverage	Potential use for model development

4.4 HITCH-HIKERS SCENARIO

4.4.1 Description

This scenario cannot be described the same way as the previous ones as most of the hitch-hiker payloads address only the monitoring of energetic particles fluxes. This appears in WP 2200 & 2300 document .

Therefore, the proposed space-based measurements covers the Magnetospheric needs of boarding as many of these small equipments on GEO, LEO and more rarely accessible MEO orbits platforms . It thus covers the need for ponctual measurements at these different altitudes but without any intermediate sampling. This means a mesh of measurement points that is too wide and dependant on non-owned satellites operations .

Nevertheless, it may be of interest to consider the following list of possible hosting satellites with their associated hitch-hikers :

- GALILEO
- All European GEO Telecom
- Skybridge
- MSG and METOP
- LEO of National agencies (i.e. minisat or microsat platforms; ...)
- All ESA close-to-earth orbiting satellites

The only other type of hitch-hiker that can be added is of the GOES SXI class for monitoring the Sun from GEO orbits. However, this corresponds to a high mass increase as well as some operational constraints for the hosting satellite which prevents from any Commercial Telecommunication satellite to accept it. This is the reason why the US operate it only on-board NOAA satellites as the latter uses it directly for its Space Weather forecasting service .

Moreover, the X-ray observation does not appear as optimum to us, and an EUV imager would have been more essential . European satellites that could be envisaged for such additional payloads are Meteosat Second Generation and/or METOP .

The Ground Segment component shall then be at minimum similar to the Low scenario one with its specifically recommended developments as in Table 4.3 . Eventhough it is believed that some funding of this ground development would probably be more efficiently invested in essential space-based platforms like a small L1 monitor when aiming at Space Weather service development .

4.4.2 PROS and CONS

The main remark is that this scenario does not allow to develop any Space Weather forecasting service as the essential Sun and Solar wind monitoring are not present beyond a certain time range due to SOHO and ACE end-of-life (see also chapetr 4.5)

The ponctual measurements provided within the Magnetosphere would be too sparsed and uncorrelated to elaborate a reliable investigation of solar events effects and propagation .

Even a significant Ground segment development would not ensure the appropriate assessment of the parameters needed for an operationnal forecasting . It shall only allow for continuation of scientific studies of the Sun activity and geomagnetic storms consequences on very local segments with limited in-situ measurements .

	PROS	CONS
Technical	• In-situ check points of storms impacts at very low cost • Small and technologically mastered equipments	• Essential observations for Space Weather Forecasting absent (ex : no EUV; no solar wind data) • Space Measurements serves post-analysis only
Programmatics Economical & Political	• No significant investment	• No Autonomy : dependance on international cooperation for essential observations • Very limited potential for development of Users Services : too sparsed in-situ validation; dependant on other operators' good will . • Strong slow-down of Space Weather services activities • Re-orientation of user's community towards sole US products and/or worst case sizing

4.4.3 Cost Aspects

No cost is provided here as it would correspond, apart of the Groud Segment, to the manufacturing of very few equipments . It is then in the order of 100 to 200 k€ per hosting platform, assuming also that raw data collection and packaging would be handled via the hosting platforms Ground Segment .

Developments in Ground data distribution and processing would certainly accompany these hitch-hikers . However, the lack of essential measurements (Solar data; Solar wind) to elaborate a minimum Sun activity forecasting and nowcasting would prevent from labelling it as a Space Weather Forecasting service .

4.5 PASSIVE SCENARIO

4.5.1 Description

It simply corresponds to the use of Satellites and Ground observatories already in place .

Concentrating on the sole Space Weather oriented infrastructures, one can then summarize as follows :

	Space	Ground
Solar Observation	(3) SOHO : ***lifetime 2006*** (4) SXI on GOES : ***USA*** (5) Solar-B in LEO : ***JAPAN/USA***	(1) Magnetographs (incomplete and not 24Hrs) (2) H-a network (incomplete and not 24 hrs) (3) Coronagraphs (not adapted) (4) Radio-spectro & Imaging (not complete)
Solar Wind-Heliosphere	(2) ACE : ***lifetime 2005***	n.a.
Magnetosphere Monitoring (RBM)	Very few Hitch-hikers : GOES & POES; GE-americom (USA); LANL's ones' (USA) ; COMRAD on Stentor in GEO (Fr); … -> data not accessible for many of them	(1) Magnetometer networks
Ionosphere / Thermosphere		(1) Ionospheric sounders (2) SUPERDARN network (incomplete) (3) Intermagnet network (4) GPS Networks (partial) (5) F 10.7 cm measurements

4.5.2 PROS and CONS

The main remark is that this scenario, similarly to the previous one, leads obviously to a very high risk for the development of any Space Weather forecasting service after the lifetime of existing facilities .This is justified by no (neither official nor planned) follow-on projects for SOHO and ACE , especially in Europe .Any user and Service developper in Europe would then have to rely upon data availability from other countries .

NASA has a TRIANA project almost ready for L1, but not at all dedicated to a Space Weather mission (oriented towards Earth monitoring) .The LWS programme is effectively on-going but not at all ensuring that Europe could benefit from it (and some of the observed parameters characteristics are different from the ones identified in our study). Furthermore, no satellite replacement is planned so far, that prevent from any warranty in the continuity of service .The Solar-B satellite from the Japanese Space agency (follow-on of Yohkoh satellite in cooperation with NASA) fulfill only partly the needs for an operational Sun observation . As consequences, the European capability, in terms of Space Weather forecasting and monitoring, would become very hazardous (other data from the other countries does not meet our requirements) and totally dependant on the Data Access scheme these other countries will select .

Finally, the same remarks on Ground segment development as for the Hitch-Hiker scenario applies.

4.5.3 Cost Aspects

No cost is provided here. This scenario corresponds only to the continuity of operation of current satellites like SOHO and ACE and the access to data delivered by SEC-Boulder from NOAA . Same remarks apply, as for Hitch-Hikers scenario, concerning Ground segment development.

5. PROGRAMME PROPOSAL : DEVELOPMENT AND PROGRAMMATICS

5.1 OVERVIEW OF THE CURRENT INTERNATIONAL PROGRAMMES

In order to assess adequately what should be envisaged at a European level, it was deemed necessary to understand the international context within which such a Programme should take place .
A complete review of the existing and planned projects around the world linked with Space Weather science and monitoring has been performed . The result are in Tables 6 to 9 , where a classification has been used to quote and mark the various projects in terms of :

- their relevance to Space Weather monitoring according to our requirements (see WP 2100, 2200 & 2300)
- their relevance to Space Weather science support

The following scale has been set up :

With respect to Space Weather monitoring :

- 1 = small interest , i.e. poor performance and/or inadequate parameter monitored and/or orbit used
- 2 = medium interest, i.e. partially answers our monitoring need
- 3 = high interest, i.e. meets our need in terms of parameter and performance and orbit

With respect to Space Weather science support :

- 1 = small interest , i.e its not its prime objective by far
- 2 = medium interest, i.e. it contributes , but with some lack of information wrt accuracy/space or time sampling
- 3 = high interest, i.e. it shall help to understand basic physics behind SW/help to develop models

Additional information has been brought in order to characterise these projects wrt to their objectives : type of measurements and lifetime .

What results from this review is that :

(1) Very few projects match the need for Space Weather Operational Monitoring except the ones defined as part of the US Living with a Star Programme (in terms of measured parameters and targeted performances).
(2) Some isolated projects are very much contributing to this monitoring but are not part of a consolidated and coherent programme. They address mostly isolated parameters and are thus not sufficient for an exhaustive observation.
(3) Many projects planned for studying Magnetosphere and Ionosphere are actually far from addressing the parameters required by a Space Weather forecasting service .

It is clear, then, that a European Space Weather space segment is required in order to provide any operational service in Europe with the necessary data to ensure proper forecast .

5.2 SPACE AND GROUND OPPORTUNITIES FOR A SPACE WEATHER PROGRAMME

5.2.1 Space Segment Pilot Projects

Among the Spacecrafts identified within the various operational scenarios of chapter 4, ALCATEL Space-LPCE consortium has derived a set of 3 spacecrafts that are deemed essential to any triggering of a Space Weather programme in Europe . The basic driver of all of these projects has been the best compromise between the development + operational cost and the criticality of the resulting measurements and observation for enabling a Space Weather forecasting service to operate . These Space Pilot Projects are identified below with the criteria and arguments that served for their selection .

Pilot Project 1 : Upstream L1 Monitor

Objective :	Solar Wind Monitoring
Satellite :	Spinning satellite in Lagrange point L1
Instrumentation :	Galactic & cosmic rays detector Solar Wind Monitor Thermal Plasma monitor Mid-energy particle monitor Magnetometer Low frequency radio-spectrograph (<40 MHz)

Rationale :

- Solar Wind in-situ monitoring is essential for Space Weather
- No continuity of forecasting service without this monitoring after ACE
- No concrete projects existing at time being for this objective (except TRIANA in the US, but not with an operational objective)

Pilot Project 2 : SUN LEO Observation

Objective :	Solar activity and events Monitoring
Satellite :	1 satellite of mini-sat class in LEO dawn-dusk orbit
Instrumentation :	EUV Imager EUV Flux monitor EUV Spectrometer Coronagraph

Rationale :

- Sun observation & monitoring is essential for Space Weather
- No continuity of forecasting service without this monitoring after SOHO
- L1 monitor is more costly and leads to restriction on Ground data reception at equal observation
- GEO observation is a must for enhanced intrumentation but is more costly and requires more developments
- Minisat LEO leads to very low cost and very rapid operability (development within 3 years)
- Easy cooperation/heritage on instrumentation from SDO and Solar-B

Pilot Project 3 : Radiation Belt GTO Monitors

Objective :	Radiation belts precipitation & characteristics Monitoring
Satellite :	3 Satellites of mini-sat or micro-sat class in GTO orbit (600-36000 km) With 120° between lines of apside
Instrumentation :	Thermal Plasma monitor Mid-energy particle monitor Magnetometer Waves Instruments

Rationale :

- Large gaps, currently, in operational in-situ measurements within radiation belts (proper time & space sampling)
- Direct use for Satellite environment monitoring (leading user's family)
- Direct use for Magnetospheric models development and further improvements on prediction
- Low cost design can be reached with combined launch
- Easy cooperation with other agencies (share of orbits)

These three projects were also provided to ESA for selection of their own internal sizing exercise through the CDF organization .

5.2.2 Ground Segment Priorities

The development of the observations from Ground based instruments has already been identified as determinant for ensuring a Space Weather programme to be operated . However, the current organisation of this Ground segment is a concatenation of several scientific, research-oriented and pseudo-operational networks . The recommendations and priorities that can be formulated to develop this segment have been addressed in Tables 4 & 5 .

A dedicated study on the Ground segment development would be highly recommended due to the diversity of the measurements and the complex "cooperation agreements" either currently in place or to be settled for any future operation. Important fundings should also be expected for ensuring the adequate updating of the instrumentation, both in terms of performance & calibration and in terms of operational 24 hours-a-day use .
This would only be possible through coordination of national initiatives within europe and a strong will for cooperation between the different entities involved .

Table 6 : Overview of World Wide Space Weather related mission (1/4)

Mission	Who	Alive/Dead /Future (A/D/F)	Region (S/H/U/ M/I/T)	Monitoring /Science (MON/S)	Relevant Measurements	Contribution to SW	Imp^ce for SW : Mon^ing(Sci^ce)
Solar Segment							
Yohkoh	ISAS	A (2005)	S	S	Soft X-rays.	Possible Monitoring of Sun. Science mission.	1 (2)
Solar-B[1]	ISAS	F (2005)	S	S	Soft X-rays/EUV. Magnetic fields.	Possible Monitoring of Sun. Solar science.	1 (2)
SOHO	ESA/ NASA	A (2006)	S/H/U	S + MON	Coronagraph. EUV, mag fields. Interior. Solar wind plasma and energetic particles	Monitoring of Sun and solar wind. General solar science	3 (3)
TRACE	NASA	A (2004)	S	S	EUV	Science mission.	1 (2)
GOES-SXI	NOAA	A (c'td)	S	MON	Soft X-rays	Monitoring of Sun	2 (1)
Coronas-F	RUS	A (2005)	S	S	Something	Science mission	1 (2)
HESSI	NASA	F (2000)	S	S	Flare X-rays + γ rays.	Science mission	1 (2)
STEREO	NASA	F (2005)	S/H	S + MON	Coronagraphs + interplanetary plasma + fields	Stereo CME images.	3- (3)
SDO[1]	NASA	F (2007)	S	S + MON	X-ray + EUV. Mag fields. Helioseismology. [Coronagraph]	Some monitoring, but mainly science. [monitoring use depends on coronagraph]	2+ (3)
Solar Orbiter[1]	ESA	F (2011)	S/H	S	Solar imaging and in situ plasma	Science mission.	1 (2)
Picard	CNES	F (2004)	S	MON	Solar constant	Radiative input to Earth	2 (1)

1 Part of ILWS.
2 Not fully defined at this time.
3 Cut-off 2000, unless seen as being of special space weather interest

Table 7 : Overview of World Wide Space Weather related mission (2/4)

Mission	Who	Alive/Dead /Future (A/D/F)	Region (S/H/U/ M/I/T)	Monitoring /Science (MON/S)	Relevant Measurements	Contribution to SW	Imp^{ce} for SW : Mon^{ing}(Sci^{ce})
Upstream Segment							
WIND	NASA	A (2001)	H/U	S + MON	Upstream Plasma and Fields	Monitoring of solar wind. ISTP upstream monitor.	2 (1)
ACE	NASA	A (2005)	H/U	S + MON	Upstream Plasma and Fields	Monitoring of solar wind. Solar wind composition	3 (3)
IMP-8	NASA	A (?)	U/M	MON	Upstream Plasma and Fields	Solar wind monitor + science	1 (1)
SOHO	ESA/ NASA	A (2006)	H/U	S + MON	Solar wind plasma and energetic particles	Solar wind plasma monitoring	2 (2)
Ulysses	ESA/ NASA	A (2004)	H	S	In situ fields and particles	Science mission	1 (1)
Solar Sentinels[1,2]	NASA	F (?)	S/H	S + MON	TBD, but definite in situ	TBD	TBD

1 Part of ILWS.

2 Not fully defined at this time.

3 Cut-off 2000, unless seen as being of special space weather interest

Table 8 : Overview of World Wide Space Weather related mission (3/4)

Mission	**Who**	**Alive/Dead /Future (A/D/F)**	**Region (S/H/U/ M/I/T)**	**Monitoring /Science (MON/S)**	**Relevant Measurements**	**Contribution to SW**	**Imp^{ce} for SW : Mon^{ing}(Sci^{ce})**
Magneto-sphere							
Cluster	ESA	A (2005)	H/M	S	In situ particles and fields	Physics of space weather.	1 (3)
POLAR	NASA	A (?)	M/I	S	In situ particles and fields. Auroral images.	Physics of magnetosphere + aurora	1 (3)
Geotail	ISAS	A (?)	M	S	Tail fields and particles	Physics of magnetotail	1 (3)
Interballs	RUS+	D	M	S	Tail and aurora fields and particles	Physics of magnetosphere	1 (2)
IMAGE	NASA	A (2002)	M/I	S + MON	Images of magsph + ionosphere	Images of magnetosphere energy flow + aurora	2 (3)
TWINS	NASA	F (2003/4)	M	S	Stereo images of magnetosphere	Images of magnetosphere energy flow	2 (3)
RBM[1]	NASA	F (2008)	M	S + MON	In situ particles and fields	Monitoring of radiation belts. Physics of particle accn	3 (3)
LANL n	USDoD	Continuous	M	MON	GEO plasma + EN particles	Monitoring of radiation belts	3 (1)
GOES n	NOAA	Continuous	M/S	MON	Solar particles at GEO	Monitoring of solar energetic particles	3 (1)
DMSP	USDoD	Continuous	M/I	MON	In situ particle precipitation from magnetosphere	Monitoring of auroral energy input.	2 (2)
SAMPEX	NASA	A (?)	M/S/H	S	In situ energetic particles	Physics of radiation belts	2 (2)
CRRES	NASA	D	M	S	In situ energetic particles + fields	Physics of radiation belts	1 (3)
STRV1a+b	DERA	D	M	S + MON	In situ energetic particles	Physics of radiation belts	2 (2)
FAST	NASA	A (?)	M/I	S	In situ fields and particles	Physics of auroral particle acc^{on}	1 (2)
MMS	NASA	F (2008)	M	S	In situ fields and particles	Physics of magnetosphere	1 (3)
Double Star	CHI/ESA	F (2003)	M	S	In situ fields and particles	Physics of magnetosphere	1 (3)
IRIDIUM	Iridium	A (?)	M	MON	Mag fields	Global mag field structure	2 (2)

1 Part of ILWS.
2 Not fully defined at this time.
3 Cut-off 2000, unless seen as being of special space weather interest

Table 9 : Overview of World Wide Space Weather related mission (4/4)

Mission	**Who**	**Alive/Dead /Future (A/D/F)**	**Region (S/H/U/ M/I/T)**	**Monitoring /Science (MON/S)**	**Relevant Measurements**	**Contribution to SW**	**Imp^{ce} for SW : Mon^{ing}(Sci^{ce})**
Ionosph^{ere}/ thermo^{ere}							
TIMED	NASA	F (2002)	I/T	S	Particles, fields, neutral atmos., EUV flux	Physics of ionosphere and thermosphere. Monitor EUV flux.	2 (3)
POES	NOAA	Continuous	I	MON	In situ particles	Energy input to ionosphere	2 (1)
Demeter	CNES	F (2003)	I/M	S	In situ particles and fields	Scientific of Earth environment	1 (2)
∅rsted	DK	A (????)	I/M	S	In situ particles and fields		1 (2)
Munin	SW	D	I/M	S	In situ particles	Plasma environment of IM	1 (2)
Ion mappers[1,2]	NASA	F (2010)	I/T	S + MON	In situ particles and fields	Monitoring of ionosphere.	3 (2)
UARS	NASA	A/D (2002)	I/T/S	S + MON	Ionosphere particles and fields + neutral atmos. Solar UV flux	Physics of IT region. Monitoring solar UV flux	2+ (3)
CHAMP	DLR	A (2004)	T	S	Thermosphere density	Physics of thermosphere	1 (2)

1 Part of ILWS.

2 Not fully defined at this time.

3 Cut-off 2000, unless seen as being of special space weather interest

5.3 EUROPEAN SPACE WEATHER PROGRAMME : A POSSIBLE DEVELOPMENT PLAN

5.3.1 European Opportunities and Constraints

With the objective to set up a preliminary development plan, it appears necessary to draw up a synthetic overview of the current situation in Europe . This means listing the basic contraints and assumptions that shall be considered in order to propose the most appropriate actions to be taken in a short term .

5.3.1.1 User's and Service continuity

- All existing services, in Europe, depends on the US-NOAA SEC-Boulder daily bulletin which relies essentially on SOHO and ACE spacecrafts data . This satellites lifetime is a key limitation .
- All Space agencies need data for environment monitoring and understanding; this is essential for providing the industry and operators for the space environment standard levels
- Specific applications like Power Grid C^{ies} , Satellite drag, Satellite operation, and soon Insurance of space activities need a permanent assessment (operational use of everyday bulletin)

5.3.1.2 Cooperation

- The US Living With a Star Programme provides a great opportunity as it needs cooperation on space projects due to recent budget cuts
- Japan Solar-B project in LEO is in-development and may be used for data collection
- Many Intra-european initiatives have been identified but with a lack of coordination ; many of them use US inputs and cooperation .

5.3.1.3 Organisation & Infrastructure

- No European leading entity could be identified for the overall system
- There is currently a very sparsed interest among European countries
- Consequently, there are very sparsed efforts and initiatives
- Through the ISES network, and managed by the NOAA SEC-Boulder, there is a great effort to organize and promote Space Weather data exchange at International Level (several European ISES centers)
- Other small Ground networks are currently in operation for essential data and one shall benefit for these developping assets .

5.3.1.4 Programmatics & Fundings

- No Space Weather Programme has been announced which limits federation of fundings and official targets, especially in terms of schedule .
- The commercial ROI is limited in a short term but large development is expected, especially from increased sensitivity of the future systems and development of Man in space .
- No real frame at EU level, but Space Weather approach is similar to GMES one's

5.3.1.5 Schedule

- Lifetime of existing space segment : SOHO : 2006; ACE : 2005
- Next Solar Cycle maximum : 2010-2012
- Minimum Time delay for instruments and satellite development
- Minimum Time delay of cooperation & partnerships settlement

5.3.2 Initialisation of a Global Space Weather Programme

We intend, in this section, to address our synthesis of the answers to the question : "What should be done to initialise a European Project" .For sake of clarity, we shall split the answers into the following Segments and Fields :

5.3.2.1 Users & General Programme

The inventory of the User's community for Space Weather services has demonstrated the broad range of impacts resulting from Solar events . Many technological systems and human activities are concerned, but at very different levels of knowledge of the risk. The Satellite Manufacturing & Operation fields, the Power Grid c^{ies}, for instance, are definitely aware of the need to develop the european capacity to monitor Space Weather. All other potential users agree with the need to go further in the understanding of the consequences and of what is at stake, due to the potential high financial impacts. It is urgent to undertake a follow-on of the work performed under this contract in order to support these users in a more precise understanding of what they could expect from a Space Weather Forecasting service and help them to formulate their requirements . One cornerstone of such a study is the definition of worst case situations for each of them .

Table 10 provides a general approach to the current status of "How we understand and manage Space Weather ".
It demonstrates that the perspective of Operational Space Weather Services is definitely within easy reach .
Great efforts have been put, and are still, in : the understanding of the phenomenons (from the Sun events to the physical processes in the magnetosphere and on human being and/or the hardware); the development of prediction models ; the improvement in forecasting Solar events and their consequences .The perpetuation of such progresses would greatly benefit from coordinated efforts within Europe around a leading entity. It would create a real dynamic around the user's community and it would maintain the competences currently available as well .

Either by itself, or through cooperation, Europe has to acquire the possibility to collect all the data necessary to its own needs for detection of solar events and prediction of resulting geomagnetic phenomena .

5.3.2.2 Space Component

The Space Component appears as a must for any triggering of Space Weather services .A basic decision for Europe lies in the targeted degree of autonomy. Nevertheless, essential components described above as Pilot Projects are necessary in a short term in order to cover the basic requirements for the continuation of any Forecasting service . Cooperation with other agencies around the world are obviously recommended for sake of development and operational costs savings .One shall only take care of the rules to be applied for data sharing in real-time, as well as data bank access . The following is proposed :

- an Upstream L1 monitor is compulsory for Solar Wind in-situ monitoring ; it is a small satellite, with well proven instrumentation which Europe can afford and that will be of high benefit to Science as well as to direct use for operational Space weather activtities . Aiming at a lauch date of 2007 is realistic and would almost ensure the overlap with current ACE data. An early phase A is then needed to cope with the satellite development schedule. Due to the delay for replacing the satellite in case of failure, a cooperation with the US NOAA programme could also be envisaged for reducing development cost while enabling two S/C's in orbit for better system availability .
- Sun LEO observation is a prime need for monitoring Solar events . Such a small and inexpensive satellite would very quickly offer the core data for the european Space Weather community to pursue its development efforts . A launch date around end of 2006 would then ensure the operational follow-on of SOHO . Early studies on the payload "maximization" would ensure a cost effective solution to be proposed soon to the Space Weather Services community . It could also be operated in conjunction with Solar-B satellite which will also be in LEO .
- the Radiation Belts GTO Monitors are of prime importance for in-situ witnessing of the particle injections .The advantage from international cooperation is abvious due to the three components and the resulting share of the ground data reception . A rapid development shall be envisaged, as the instrumentation is also quite mature . Some studies shall be foreseen soon in order to optimize the performance of the payload versus the platform capacity and possible launch & mission analysis options .

5.3.2.3 Ground Infrastructures & Partnerships

A continuity in some essential Ground components is necessary. These segments have been addressed in 5.2.2 .
It is clear, from our study, that a detailed assessment of the required efforts is necessary . This shall cover at least :

- the upgrade of existing facilities
- the calibration requirements
- the new developments : additional sites for coverage enhancement ; new technoloy equipments
- the adaptation to an operational use
- the data networks developments
- the partnerships to be settled

This evaluation study should start soon in order to be in phase with the Space Segment definition as well as the assessment of the driving parameters for the targeted User's community .

5.3.2.4 Models

Development of the Models, dealing with physical processes as well as those for forecasting, is a key element for any operational Programme . Table 11 & 12 show the recommended actions for each segment .
However, in order to federate and coordinate the efforts, and as identified in WP 5100 about the Proposed New Structures, a specific european Board shall be constituted around the scientific centers and institutions currently developping modelling & prediction softwares. It shall represent a reference authority that defines the adequation of the developments undertaken and is in charge of large scale models integration.
A dedicated review is thus recommended in that respect , aiming at :

- reviewing in technical details, on the basis of the study outcomes, the models developments planned
- determine the short and mid-term objectives : schedule of developments
- provide a road map of the model development philosophy

Then, specific models development shall be initialized .

5.3.2.5 Services

For that segment too, there is a strong need for identification of a European Board that shall enable to coordinate and federate the work and the initiatives across Europe . According to WP 5100, this new structure shall monitor the european leadership for SW Data centers and SW Services .This shall hence consolidate the global offer of services and help rapid and efficient exchange of methods from one application area to another . This entity will then allow for :

- the centralisation of service provision
- federating products development
- federating the user's community
- support the illustration of Worst Cases
- ensure proper Public outreach .

The most important step to take is then to get concrete applications of the Prototyping activity performed within this study and to enhance the capacity for forecasting and nowcasting towards the most promising areas of application .
But the development of Services to the users, aside of strong correlation with the improvement of modelling capacity, shall also be accompanied with serious improvements in data exchange and distribution across Europe . This is already initialised through on-going contracts for Data Grids within ESA and the EU. Space Weather field shall definitely be one of the important targeted applications of these contracts .

Table 10 : Status of Space Weather Forecasting & Anticipation Capabilities

Events	Forecasting the event	Forecasting the time of the event	Quantify the event's importance
Events at SUN			
No event	Y(U)	Y(D)	-
Coronal mass ejections (Halos)	Y(D)	N(D)	N(D)
Proton events	Y(D)	N(D)	Y(U)
Coronal holes	Y(U)	Y(U)	Y(D)
Solar activity/flares/X-ray, EUV radiation	Y(U)	N(D)	N(D)
Interplanetary events at L1			
Interplanetary CMEs and shocks	Y(D)(S)	Y(D)(S)	N(D)(S)
High speed plasma streams	Y(U)(S)	Y(U)(S)	Y(D)(S)
Earth's atmosphere			
Outer radiation belt electrons	Y(M)(L1)	Y(M)(L1)	Y(M)(L1)
Inner belt electrons and protons	Y(M)(L1)	Y(M)(L1)	Y(M)(L1)
Geomagnetic storms and substorms	Y(U)(L1)	Y(U)(L1)	Y(U)(L1)
Aurora	Y(D)(L1)	Y(D)(L1)	Y(D)(L1)
Ionospheric disturbance	Y(U)	Y(D)	Y(D)
Ionospheric scintillation	Y(U)	Y(U)	Y(U)
Thermospheric density increase	Y(U)	Y(U)	Y(U)

Effects on technological systems	Identification	Forecast-ing the event	Forecasting the time of the event	Quantify the event's importance
Satellite anomalies	N(D)	Y(D)	Y(D)	N(D)
Increased drag on satellite	Y	Y(U)	Y(D)	Y(D)
Communication distrurbannce	Y	Y(U)	Y(U)	Y(U)
Geomagnetically induced currents	Y	Y(U)	Y(U)	Y(U)

Legend

- Y= Yes, N=No, M=Mature, U=Useful, D=In Development
- Identification means whether or not we have identified the source of the space weather effect
- S=means that the forecast is basedon solar data.
- L1=means that the forecast is based on data measured at L1.

Table 11 : Recommendation on Future Models Developments (1/2)

Location	Models	Based on	Input	Output	P/E	State of Develop^{nt}	Observations Needed for implement^{on} and development	Remarks	Recom^{ed}Prior of model^{ng} devel^{nt} (FTEs)
Sun + Interplanetary	CMEs	Satellite ground	Speed Start Direct Side N/S **B** at Sun	Speed. Field. Helicity. Proton flux. Arrival time at 1 AU.	P+E	Extensive	Coronagraph EUV, H_{α}. +Stereo coronagraph +Photospheric field Solar wind radio. Cosmic ray muons	Crudely available now. Medium – long term for better models. Physics mediocre.	Medium
Sun + Interplanetary	Recurrent streams	Satellite + ground	**B** at Sun	Speed at 1 AU. Kp, Ap	P+E	Operational	Solar fields. Coronal hole bdy	Fast prototype at SEC (Wang + Sheeley)	Use existing
Sun	Sunspot number	Ground	sunspots	Solar cycle	E	Operational	Sunspot number	Physics not understood.	Low
Sun	Solar activity + interior	Satellite, ground	**B** at Sun. **V** at Sun	Medium term activity	P+E	Research	Photospheric fields and motions	Physics based helioseismology	Medium/High
Sun	EUV irradiance	Satellite, ground	EUV + F10.7	EUV flux	E	Operational	EUV + radio spectra	Need cnts calibrated data	Medium
Sun	Flares/CME start	Satellite, ground	**B** at Sun, topology	Eruption time. Class of flare. Particle signature	P+E	“operational”	Photospheric field. Coronal structure + emission	Difficult!	Low

Table 12 : Recommendation on Future Models Developments (2/2)

Location	Models	Based on	Input	Output	P/E	State of Develop^{nt}	Observations Needed for implement^{on} and development	Remarks	Recom^{ed}Prior of model^{ng} devel^{nt} (FTEs)
Magnetosphere + ionosphere + ground	Indices + tech. systems	Sat at L1, Mag Ntwk	Solar wind	Kp, Dst, AE. GICs.	P+E	Extensive / operational	**B** and **V** in solar wind	Needs development.	Medium
Geospace	Satellite anomalies	Satellite at L1	Solar wind	Risk	E	Operational	**B** and v in solar wind	Needs major development	Medium
Magnetosphere	Radiation environment	Satellite at L1	Solar wind	Flux at GEO (MeV)	P+E	Research	**B** and v in solar wind	Needs work. (Baker/Li)	Use existing
Magnetosphere	Radiation Environment	GEO satellite	Flux at GEO (seed). Indices. SW Neutrals. Waves	Flux at GEO + inner belt	P+E	Research	Particle + wave (VLF: space ULF: ground) data. Indices. SW **B** and v. Field models. Rad measure.	Needs major development	High
Magnetosphere	Global	Physics	Solar wind. F10.7 etc.	**B, V** everywhere. Global currents	P	Research	L1	Needs major development	High
Ionosphere	Electrodynamics	Satellite + ground	Indices IMF Velocities	Convection Conductivities Precipitation	P+E	Pre-Operational	**E** IMF Solar irradiance	Realtime Continuous	Low
Ionosphere	State	Satellite + ground	Indices Nn Precipitation (magn. coupling)	Ne (+ Ni,Te,Ti, Vi)	P+E	Pre-Operational	Ne (topside+in situ) Solar irradiance		Medium
Thermosphere	State (1D and 3D) and dynamics	Satellite + ground	Indices Convection	Nn, Tn, Vn	P+E	Operational		Mostly valid at mid and low latitudes	High

5.3.3 Proposed Programmatics

5.3.3.1 SPACE SEGMENT

The proposed development schedule of the three Pilot Projects satellites is provided in Figure 5 . The key dates are then as follows :

UPSTREAM L1 Monitor

- Instruments KO :	1st quarter 2003
- Satellite KO :	2nd quarter 2003
- Launch Date :	3rd quarter 2007

SUN LEO Monitor

- Instruments KO :	1st quarter 2004
- Satellite KO :	1st quarter 2005
- Launch Date :	3rd quarter 2007

Radiation Belts GTO Monitor

- Instruments KO :	1st quarter 2003
- Satellite KO :	3rd quarter 2003
- Launch Date :	3rd quarter 2007

5.3.3.2 GROUND SEGMENT

The proposed dedicated study for assessment of the Ground Segment road map shall start as soon as possible within the 1st quarter 2002 and is suggested to last 1 year. In parallel, the International Cooperations & Partnerships, necessary due to the need of large number of sites, shall deserve an exhaustive investigation starting early 2002. Finally, the development of new observation sites shall be intiated soon enough to meet the 2006/2007 corner stone.

5.3.3.3 MODELS

The ideal situation would have been to correlate models development and in-situ measurements to support these developments. This is illustrated in figure 6. The proposed dedicated study aiming at a road map shall be initiated early in 2002 in order not to delay any detailed development as per Table 5-x. Moreover, very immediate needs have been expressed from WP 3230 for physical models for which early start in 2002 will condition the autonomy for Europe in the tools for Space Weather forecasting, nowcasting and post-analysis.

5.3.3.4 SERVICES

Concrete actions have already been undertaken by ESA to pursue, in 2002, the demonstration of the capabilities in terms of services on the basis of the current studies Prototypes. This is essential to promote the fact that Space Weather forecasting is real .

Nevertheless, it appears as an urgent task to find a way to centralise, within Europe, the definition of new services and the education of users in their formulation of what they expect in terms of : Forecasting; Nowcasting; Post-analysis .

As a preliminary federating action, a kind of User's Club shall be constituted in the first quarter of 2002 . One may take the opportunity of the next ESA Space Weather User's Workshop in December 2002 .

Figure 5 : Suggested Schedule for Satellite Pilot Projects Development

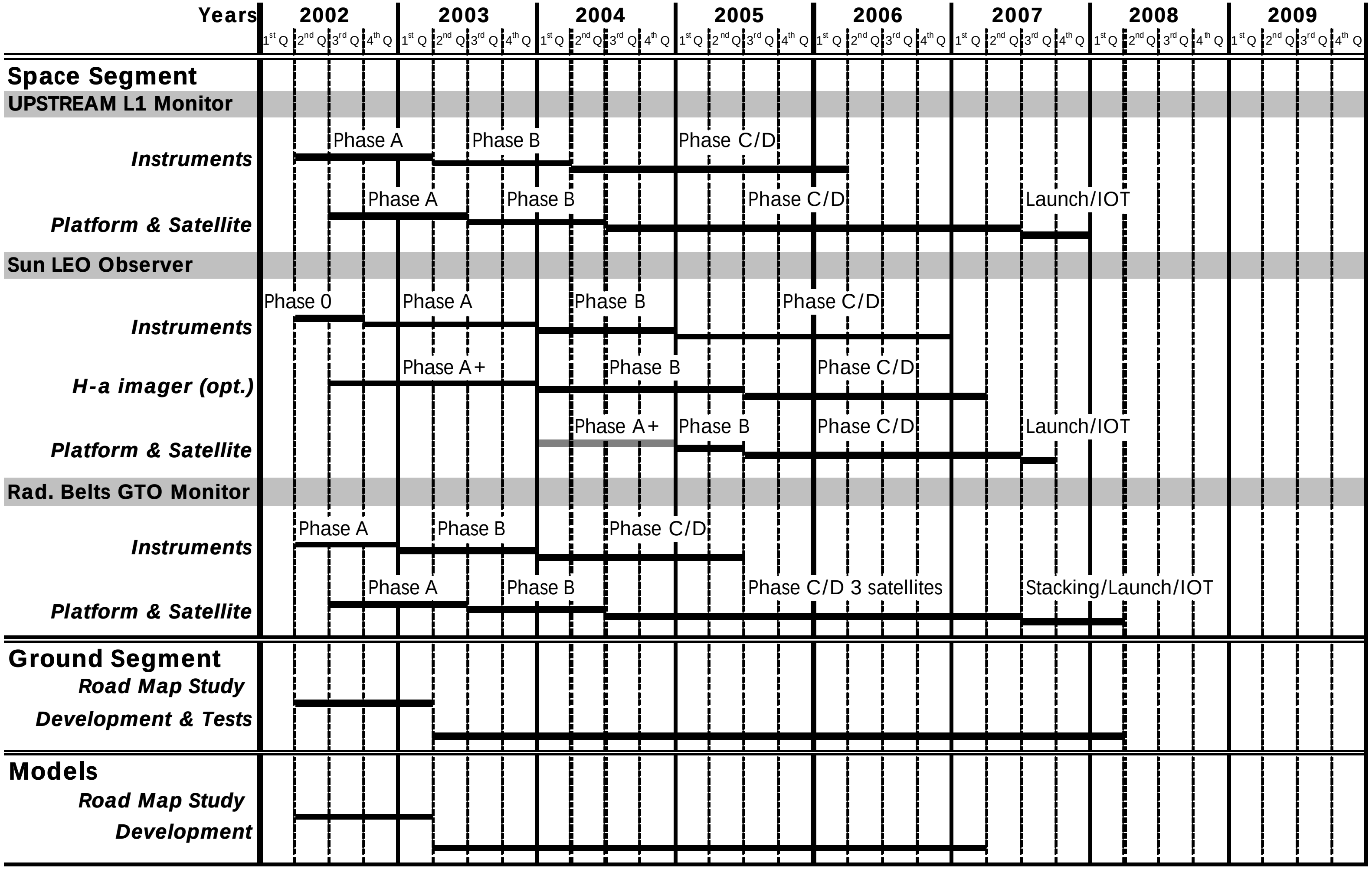
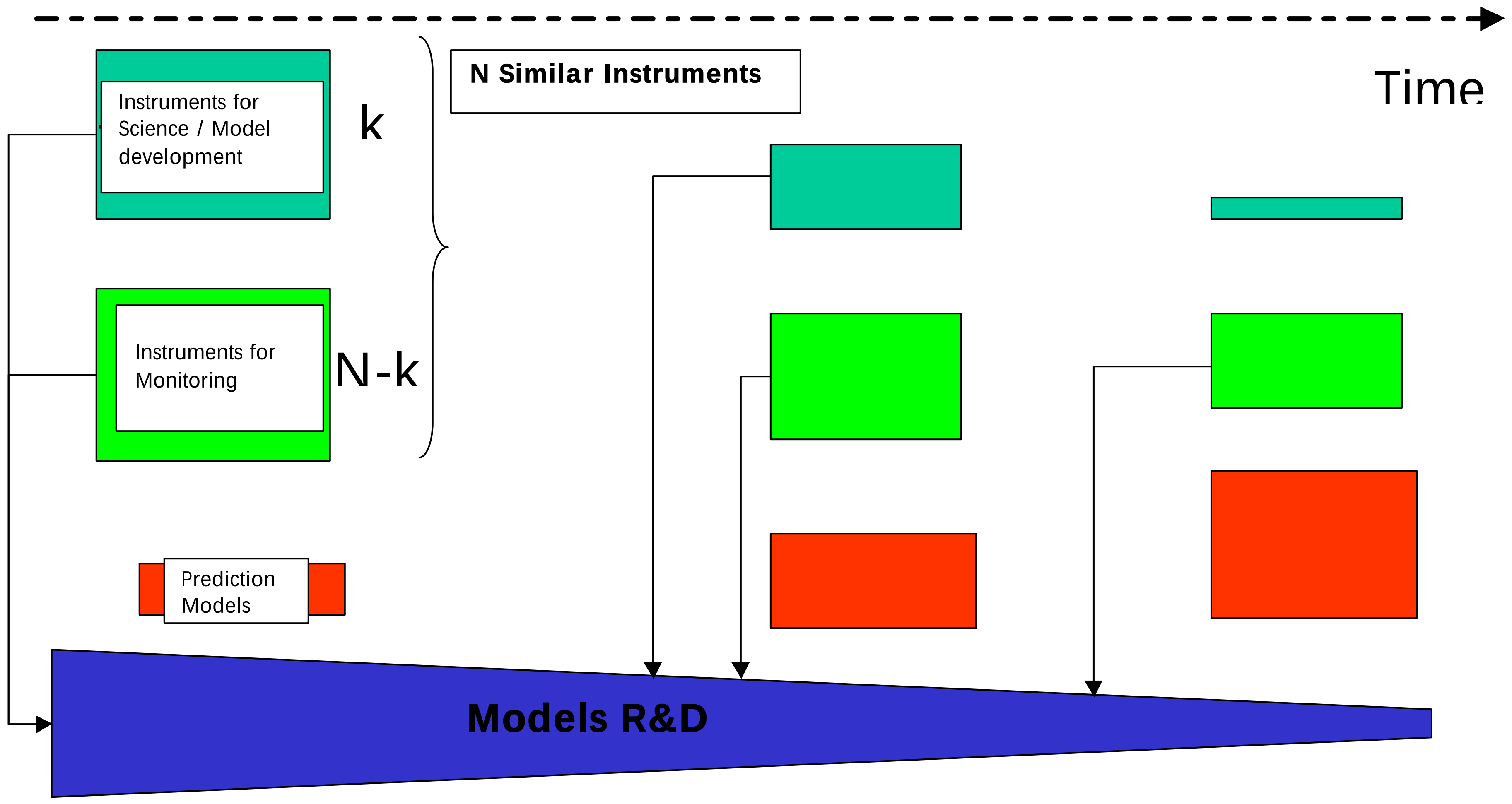


Figure 6 : Philosophy for coupled Measurement/Models developments for a Space Weather Programme



GLOSSARY

ACE	Advanced Composition Explorer
CDF	Concurrent Design Facility
CME	Coronal Mass Ejection
CNES	Centre National d'Etudes Spatiales
DSN	Deep Space Network
ESA	European Space Agency
ESD	Electrostatic Space Discharge
ESTEC	European Space research TEchnological Center (ESA, Noordwijk)
EU	European Union
EUMETSAT	EUropean organization for the exploitation of METeorological SATellites
EUV	Extreme Ulta-Violet
GMES	Global Monitoring for Environment and Security
GEO	Geostationnary Earth Orbit
GIC	Geomagnetically Induced Current
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GTO	Geostationnary Transfer Orbit
HEO	Highly Elliptical Orbit
IMF	Interplenatary Magnetic Field
IPS	Inter-Planetary Scintillation
ISAS	Institute for Space and Astronautical Science (Japan)
ISES	International Space Environment Service network
LEO	Low Earth Orbit
LPCE	Laboratoire de Physique et de Chimie de l'Environnement (CNRS, Orléans)
LPG	Laboratoire de Planétologie de Grenoble,
LPSH	Laboratoire de la Physique du Soleil et de l'Héliosphère
LWS	Living With a Star
MEO	Medium Earth Orbit
MSSL	Mullard Space Science Laboratory
NASA	National Aeronautics and Space Administration (USA)
NOAA	National Oceanic and Atmospheric Administration (USA)
NSWP	National SPACE WEATHER Programme
OPM	Observatoire de Paris Meudon
PCA	Polar Cap Absorption
RASA	Russian Aviation and Space Agency (Russia)
R&D	Research & Development
RBM	Radiation Belts Monitor
S/C	Spacecraft
SDO	Solar Dynamics Observatory
SEC	Space Environment Center (NOAA)
SOW	Statement Of Work
SPE	Solar Proton Event
SRBL	Solar Radio Burst Locator
SW	Space Weather
SXI	Sun X-ray Imager
TEC	Total Electron Content
ULF	Ultra Low frequency
UV	Ultra-Violet
VLF	Very Low Frequency
WEU	Western European Union
WP	Work Package

FIN DE DOCUMENT

END OF DOCUMENT