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NACON: A Nano-Satellite Constellation for Space Weather Monitoring

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Space Weather has a tremendous effect not only on our day-to-day activities on Earth but also on our space assets. Communications, weather prediction, Internet, TV broadcasting and space mission planning depend heavily on ground and space infrastructure. Thus it becomes more important than ever to establish a space-based network which is capable of providing the necessary data to scientists. The data may be used to predict and analyse all types of weather phenomena, either in our atmosphere or near our planet (earth magneto-tail/ field) or in our solar system (Sun). Such a comprehensive, operational space weather network will heavily depend on the necessary science and data requirements, and of most importance in this study is to design a practical, affordable, autonomous and versatile space solution composed of multiple spacecraft. The number and configuration of these satellites is key into bringing the relevant space weather data to the end user. The paper details a new approach into defining a modular architecture composed of three-level (low, medium and high) solutions pending on the end user requirements. The goal is to design a pragmatic, innovative, versatile, low cost and complete end-to-end system for space weather monitoring with a 10-year lifetime.

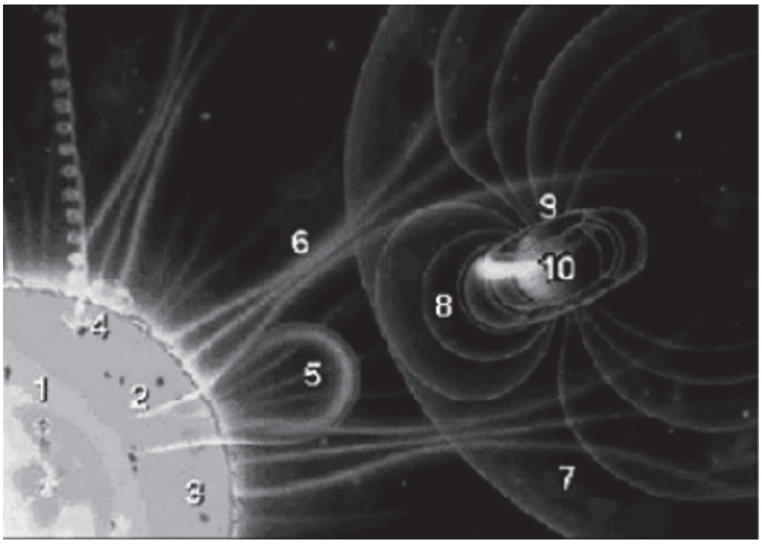
Keywords:

1. Introduction

The study of space weather is largely concerned with the origin and interactions of electromagnetic and corpuscular radiation emanating from space. It also includes its effects on the Earth, its atmosphere, ionosphere and magnetosphere, and on humankind's technological systems operating therein. A primary source of such radiation is the Sun, and so a key aspect of space weather research is the understanding of the Sun-Earth interconnection (Fig. 1), and its dynamics over timescales ranging from minutes (e.g. electromagnetic and relativisitic corpuscular radiation from the Sun and from solar flares), to days (e.g. disruptions of solar wind caused by coronal mass ejections and high speed streams), to years (e.g. variations in solar energy-flux output, sun-spot number, magnetic configuration and flare-probability over the course of the ~11 year "solar cycle")

In addition to the radiation of solar origin, there is a continuous stream of galactic-cosmic-rays (GCRs) originating from deep space sources bombarding the Earth. These comprise mainly protons (~85%), alphas (~14%) and heavy-ions (~1%) with energies ranging from ~1 MeV/nucleon to several GeV/nucleon and beyond. Thus, although they are affected to some extent by traversal of the heliospheric and terrestrial magnetic fields, they are generally very penetrating and highly ionising. They can cause effects both directly, as primary radiation, and indirectly, as the result of the production of secondary particles when interacting with matter – e.g. in the Earth's atmosphere or in the structures of spacecraft. The flux of GCRs is low (~2-4 particles cm^{-2} s^{-1} outside of the magnetosphere depending upon the phase of the solar cycle), and thus they are do not pose a major total ionising dose (TID) hazard, but they are a very significant space environments and effects (SEE) hazard, and in particular, particles with a high linear-energy transfer (LET) can be particularly effective at inducing the more severe, destructive SEEs such as single-event latch-up (SEL).

A third major environment concerns charged particles trapped in the terrestrial magnetic field – i.e. the magnetosphere. These form the inner and outer Van Allen belts. These belts are rings of trapped particles,



1. Solar Surface
2. Sunspots
3. Prominences
4. Solar Flares
5. Coronal Mass Ejections
6. Solar Wind
7. Magnetosphere
8. Radiation Belts
9. Polar Regions
10. Ionosphere/thermosphere

Fig. 1 The Sun-Earth Connection. (Image courtesy of NASA)

centred on the geomagnetic dipole, and lying in the plane of the geomagnetic equator. The inner belt comprises high-energy (10's-100's MeV) protons and lower energy (10's-100's keV) electrons, whilst the outer belt comprises primarily high-energy electrons (100's of keV~7 MeV). Figure 2 shows the trapped proton environment at 1320 km altitude as recorded by Surrey's CRE payload on-board the KITSAT-1 micro-satellite. Figure 3 shows single event upset (SEU) data for the commercial-off-the-shelf (COTS)-based on-board computer program memory of the S80/T spacecraft launched alongside KITSAT-1 into the same orbit. The correlation between SEUs and protons is clear.

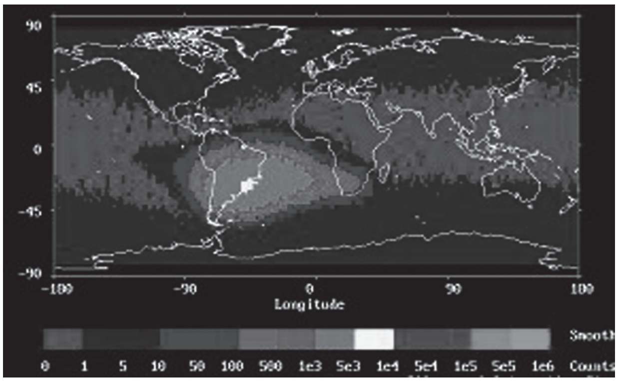


Fig. 2 PoSAT-1 CRE (>30 MeV) Data.

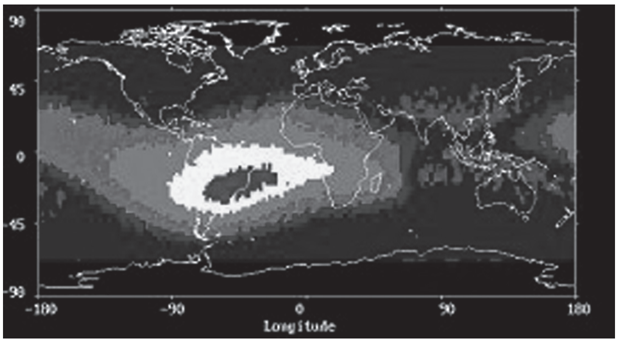


Fig. 3 KITSAT-1 CRE (> 30 MeV) Data-SAA.

The inner belt and outer belt electrons are not ionizing enough to contribute to SEEs, but they are a significant source of TID for spacecraft that remain in the belts (such as those in Mid-Earth orbit (MEO) and GEO, or for those that traverse the belts for instance in Geostationary Transfer Orbit (GTO) or Highly Elliiptical Orbit (HEO). However, if necessary, material shielding can be used to reduce electron dose to low levels. The equivalent to 1 cm thickness of aluminium is enough to stop virtually all the electrons. However, protons are not so easily stopped and thus the trapped protons are a significant source of TID for satellites that traverse the inner belt.

Previous studies came to broadly similar conclusions as to the nature of the User Community, and to the sorts of data and instruments that could provide for these requirements [1-4]. Following closely the areas already identified by ESA through SWENET and Service Development Activities (SDAs). These can be split broadly into five User Groups:

User Group 1: Airlines and Air Safety Organizations, Space Agencies, Launch Agencies and Satellite Operators – prime concerns forecast, now-cast and post-event analysis of radiation levels in the atmosphere and at orbital altitudes, the SEE and spacecraft charging environment, and atmospheric drag.

User Group 2: Electronic Power Transmission Organizations, Pipeline, Railway and Telephone Companies, Geological Prospectors, and the Drilling Industry – prime concerns: forecast, now-cast and post-event analysis of geomagnetic disturbances.

User Group 3: GNSS and RF Communications Industry, Tourism – prime concerns: forecasts and now-casts of ionospheric disturbances, ionosphere total electron content, and auroral activity.

User Group 4: Insurance and Financial Services – prime concerns: forecast, now-cast and post-event analysis of environments effecting operational technological systems including spacecraft, aircraft and service providers – e.g. the power industry.

User Group 5: Space Science Community – prime concerns: accurate, multi-spatial and multi-temporal data on all space weather parameters as inputs to models.

2. Nanosatellite Constellation Architecture

The nanosatellite beacon constellation (NACON) needs to be tailored according to three scenarios, pending on mission/science requirements and technology availability:

- **Low level solution:** the minimum measurements required for input to services geared at mitigating space weather effects on spacecraft operations
- **Medium level solution:** incorporates all elements of the low level solution plus additional measurements of value for modelling aspects of the geospace environment and data of importance for services geared towards mitigating ground-based space weather effects (as opposed to focusing on spacecraft effects alone)
- **High level solution:** incorporates all elements of the low and medium level solution plus other space weather measurements of interest to the scientific community e.g. imaging data

2.1 NACON Low Level Solution - Magnetospheric Monitors

This scenario is particularly aimed at the requirements of User Group 1, and the scientific requirements for Magnetospheric Monitoring identified in [2]. It is very close to operational readiness using current technology based on the FRISBEE platform [5], and instruments already developed by Surrey and Mullard Space Science Laboratory (MSSL). It comprises up to eight 20 kg nano-satellites operating in LEO Sun-synchronous orbits (~600 km, 9-10 am/pm), and 4 nano-satellites operating in GTO (~200 km x 36,000 km), with their apogees separated in local time by 6 hours each giving a “petal” arrangement. This configuration closely matches that proposed in the ESA CDF Space Weather Study for the Inner Magnetosphere Monitor constellation [4].

The scientific payload is restricted to a dc magnetometer and electrostatic charged particle (ion and electron) analyzer (Thermal Plasma Monitor and Mid Energy Plasma Monitor), providing both high time resolution and characterisation of collisionless plasma processes, together with a miniaturised SPE, GCR, and trapped proton environment monitor, CEDEX, to measure total-ionising radiation dose and the higher energy protons and heavy ions associated with single-event-effect activity. The dc magnetic field, sampled at 128 vectors per spin period, provides a good road map of the solar-terrestrial system and local variability. However, measuring and following the collisionless processes, which lie at the heart of the solar terrestrial interaction, requires at least some characterisation of the particle populations. Additionally, collision-free particles also provide tracers of connectivity and intervening phenomena between locations. Thus the scientific payload includes the plasma monitors.

These instruments would share an integrated data processing unit, spacecraft interface, and power supply. Although the magnetometer would be based on a standard fluxgate instrument, the particle detectors are based on a common unit incorporating a miniaturised electrostatic analyser based on Cluster PEACE and Cassini ELS heritage. The detectors are corner mounted with a full 360° field of view in a plane parallel to the spin axis. Thus full 4p steradian coverage by a single sensor is accomplished in half a spin period. The ion sensor and electron sensor are mounted on the corners of the spacecraft. The baseline spin period for this mission is 4 seconds. The penetrating particle environment (i.e. the SEE-environment) is measured by the CEDEX payload, which is a miniaturised version of the CRE and CEDEX instruments flown on previous Surrey spacecraft [5, 6]. This uses a large-area PIN diode-based detector connected to a multi-channel analyser (MCA) to measure the linear-energy transfer (LET) spectrum inside the spacecraft due to protons (>30 MeV) and heavy-ions. The 512 channel MCA covers a LET range of approximately 30 – 10,000 MeV $cm^2 g^{-1}$, and can handle up to 200,000 particle events per second. It also has PIN-diode-based dose-rate meters to measure total ionising dose under representative shielding thicknesses. An accelerometer is used to examine the effect of atmospheric drag. The target payload requirements are summarised in Table 1.

We propose a first deployment in 2010, followed by similar deployments in 2013, and 2016 (Table 2). Over this period, we conservatively envisage that advances in microelectronics and MNT technologies should mean that the mass and power requirements of the spacecraft bus and payload instruments will reduce to a third of that shown, with the spacecraft reducing to ~ 7 kg, the payload to ~2 kg and the payload power requirements to ~ 6 W.

TABLE 1: *NACON Low Level Target payload requirements for 2010.*

Instrument	Mass kg	Power W	Data Rate kbps
Magnetometer (head/boom/electronics)	1.0	2.0	0.75
Thermal Plasma Monitor – TPM	0.7	4.0	30
Mid Energy Plasma Monitor - MEPM	2	4.0	30
Electronics	0.6	5.0	-
SEE Environment Monitor - CEDEX	1.0	2.0	1
Accelerometer	0.5	1.0	1
Total	5.8	18.0	62.75

TABLE 2: *NACON Low Spacecraft Constellation.*

Configuration / Launch Date(s)	Orbit Types	# Spacecraft Launched	Spacecraft Mass (kg)	Perigee → Apogee (km)	Inclination (deg)
Low Level 2010, 2013 & 2016	Sun-Sync (10 am)	8	20 → 10	~ 600 (circular)	~ 98
	GTO	4	20 → 10	200 → 36000 km	~ 7

2.2 Medium Level Solution - Ionospheric Monitors

This scenario is particularly aimed at the requirements of User Group 2 and 3. In addition to the satellites of Scenario 1, a further set of nanosatellites (up to 8) will be launched into a second LEO (~600km) Sun-synchronous orbit in a plane that is orthogonal to the first, and a third set of nanosatellites (again upto 8) will be launched into a low-altitude (600 km) equatorial orbit (LEO). These satellites will primarily be dedicated to monitoring the ionosphere and auroral regions. They will do this by monitoring GPS (or Galileo) signals as they are occulted by the Earth, thus providing a probe into the ionosphere and thermosphere.

The Topside sounders and E-field antennas will similarly probe the electron content and activity in the ionosphere. The neutral mass spectrometer will be used to sample the atmospheric environment of the spacecraft directly, and the imagers will be used on the near-polar orbiting spacecraft to monitor auroral activity. Deployment will begin in 2013, with a further replacement deployment in 2016. All spacecraft will carry a basic sub-set of instruments, as shown in Table 3.

In addition, each spacecraft will carry *one* of the following instruments shown in Table 4.

Thus the full payload masses will range from 6.7 kg to 12.0 kg. We envisage that the 2016 deployment will see a further reduction in mass and power consumption due to the application of MNT technologies; the payload mass reduced to 4-8 kg (Table 5). We shall also consider the merits of putting some of the spacecraft into elliptical orbits (apogee ~ 15,000 km) in a similar scenario to that used on the Swedish Viking Mission in order to probe higher regions.

2.3 NACON High Level Solution - Solar and Upstream Measurements

This scenario is particularly aimed at User Group 5. We propose to place 5 groups of up to 8 nanosatellites into equatorial highly elliptical orbits (HEO), and a sixth group nanosatellite will be placed into a polar HEO. One nanosatellite will be launched out to the L1 halo orbit and the Geotail will be monitored by 35 solar kite (2 kg) “pico-satellites”. Needless to say the high solution includes the low and medium solutions and this scenario will be examined closer as it has the most technical and science challenges and return. All the nanosatellites will carry a common core of payloads, primarily aimed at plasma monitoring, shown in Table 6.

The solar kites, similarly, are used for plasma monitoring, and will carry the magnetometer and one of the plasma instruments or CEDEX. This will keep the payload mass down to 1 kg or less. The nanosatellite(s) at the L1 point will be used for solar monitoring, upstream monitoring and plasma monitoring. They will be non-spinning and will carry the payloads listed in Table 7, in addition to the common core.

Furthermore there is a need to investigate the possibility of including further instrumentation such as a soft X-ray imager, EUV imager, magnetograph, coronograph and high frequency radio spec-

TABLE 3: *NACON Medium Level Target Payload Requirements for 2013*.

Instrument	Mass kg	Power W	Data Rate kbps
Magnetometer (head/boom/electronics)	0.7*	1.3*	0.75
Low Energy Plasma Monitor – LEPM	1.2*	2.6*	30
Electronics	0.4*	3.3*	-
SEE Environment Monitor - CEDEX	0.7*	1.3*	1
GPS Receiver – SSTL**	1	3.3*	0.1
Total	**4.0**	**11.8**	**31.85**

* Assumes 33% mass and power reduction on current state-of-the-art.
** The SAAB GPSOS Instrument may be used instead provided that the mass and power characteristics are within the available budgets

TABLE 4: *Alternate NACON Medium Level Target Payload Requirements (2013)*.

Instrument	Mass kg	Power W	Data Rate kbps
E-Field Antenna	8*	3.1	1.5
Topside Sounder	5*	10	1
Neutral Mass Spectrometer	2.7	7.4	1
UV Imager – SSTL**	5	10	10
Visible Imager –SSTL**	3	10	10

* Assumes a 50% mass reduction on the current state-of-the-art
** The imagers will be carried as a pair by the Sun-Synchronous orbits only and will only be operated over the auroral zones.

TABLE 5: *NACON Medium Spacecraft Constellation*.

Configuration/ Launch Date(s)	Orbit Types	# Spacecraft Launched	Spacecraft Mass (kg)	Perigee → Apogee (km)	Inclination (deg)
Medium Level 2013 & 2016	Sun-Sync (4 pm)	8	27 → 10	~ 600 (circular)	~ 98
	Equatorial	8	27 ® 10	~ 600 (circular)	~ 0

TABLE 6: *NACON High Level Target Payload Requirements for 2016*.

Instrument	Mass kg	Power W	Data Rate kbps
Magnetometer (head/boom/electronics)	0.3*	0.7*	0.75
Thermal Plasma Monitor – TPM	0.3*	1.7*	30
Mid Energy Plasma Monitor - MEPM	0.7*	1.3*	30
Electronics	0.2*	1.7*	-
SEE Environment Monitor – CEDEX	0.4*	0.7*	1
Solar Wind Monitor2.0*	2.2	2	
Total	**3.9**	**8.3**	**61.75**

*Assumes another 50% mass and power reduction in 2016 relative to 2013 status.

TABLE 7: *NACON High Level L-1 Target Payload Requirements*.

Instrument	Mass kg	Power W	Data Rate kbps
Soft X-ray and UV Flux Monitor	1.7*	1.7*	1
EUV Spectrograph	1.7*	1.7*	1
H-a Imager	6.0*	6.7*	120
Radio Spectrograph B (low Frequency)	2	0.8	0.8

*Based on estimated mass and power in 2016.

trograph. To meet these scientific objectives the spacecraft shall be covering a wide range of local times. Additionally, some combination of equatorial and polar coverage is needed to separate latitudinal and longitudinal variations and to examine the key polar regions. NACON will investigate the terrestrial response to solar wind conditions, and thus must extend to radial distances throughout the outer magnetosphere and upstream/foreshock regions. The proposal is to occupy 4 local time zones (with a duplication in one local time at a different apogee) and one polar orbit. Five to eight spacecraft per orbit ensures a reasonable spread, and provides a reasonable level of redundancy. A certain failure rate has to be expected and is acceptable. Satellite orbits will drift apart, confined to their orbital plane. Thus 3D coverage requires different groups to be launched into orbits with different inclinations and sunward apogees at different seasons. This configuration, sketched in fig. 4 with details in Table 8, rotates in local time with the seasons, but ensures that there is nearly always an upstream monitor and a range of radial distances. Such orbits sample all of the magnetosphere including the solar wind and bow shock, magnetosheath and magnetopause, cusp/auroral regions, dawn and dusk flanks, and near geomagnetic tail.

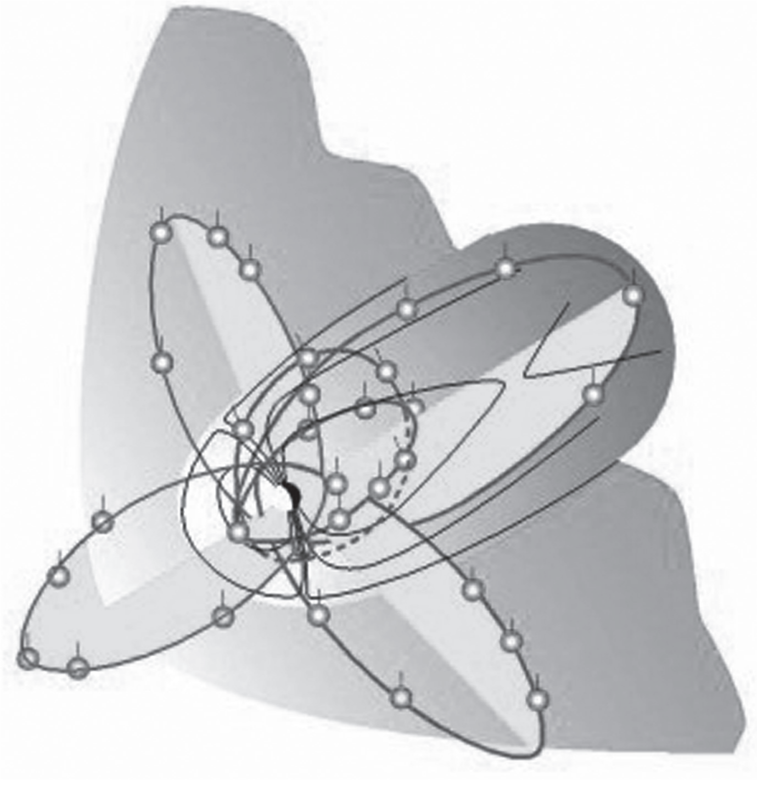


Fig. 4 Sketch of part of the full NACON High Constellation in flight.

TABLE 8: *NACON High Spacecraft Constellation*.

Configuration/ Launch Date(s)	Orbit Types	# Spacecraft Launched	Spacecraft Mass (kg)	Perigee → Apogee (km)	Inclination (deg)
	Equatorial (12:00)	8	10	2.5 $R_E \rightarrow 20\ R_E$	~ 0
	Equatorial (18:00)	8	10	2.5 $R_E \rightarrow 20\ R_E$	~ 0
	Equatorial (06:00)	8	10	2.5 $R_E \rightarrow 20\ R_E$	~ 0
High Level	Equatorial (0:00)	8	10	2.5 $R_E \rightarrow 12\ R_E$	~ 0
~ 2016	Equatorial (0:00)	8	10	2.5 $R_E \rightarrow 30\ R_E$	~ 0
	Polar (0:00)	8	10	2.5 $R_E \rightarrow 15\ R_E$	~ 0
	GEOTAIL Region	35 Solar Kites	2	11 $R_E \rightarrow 23\ R_E$	Ecliptic
	L1 Halo	1	~ 22	Deep Space	Deep Space
# Spacecraft in All Constellations		**112**			

2.3.1 Nano Solar Sails for NACON High

One of the key themes in the NACON high constellation is the need to monitor the earth’s magneto-tail. A constellation of 35-40 Solar Kites (SK) are used to artificially precess the apse-line of 11 x 23 Earth radii orbit, thus stationing a fleet of miniature science payloads permanently within the geomagnetic tail and so providing continuous science returns. Using multiple solar kites (~35), the entire geomagnetic tail could be populated by sensors that precess with the annual rotation of the geomagnetic tail, allowing real-time visualisation of the 3D plasma structure of the geomagnetic tail. Although only a low sail characteristic acceleration is required, the effective “V for the mission is 3.5 km/s per year of operation. SK’s have distinct advantages in operating in constellations to provide in-situ science measurements for a variety of missions near Earth, for example tracking Earth’s magnetosphere/geo-tail. This can be done with a much less overall mass penalty which enables a smaller launch mass or the possibility of including larger numbers of SK’s, compared to spacecraft using Solar Electric Propulsion (SEP) or chemical propulsion alternatives. A 1.75 kg (2.275 with 30% margin), 5 x 5 m SK is proposed using COTS technologies with a 3-year lifetime. An integrated sail-boom inflatable structure is proposed providing low specific mass properties to the SK sail structure. The SK can provide a 0.12-mm/s^2 acceleration using an array of ultra miniature science payloads. The detailed design of the mission and Solar Kite has been carried out for ESA, as shown in fig. 5 [6].

3. Nanosatellite Technology

Nanosatellites have significantly matured in the last decade. Recent developments in commercial microelectronics have enabled the development of miniature (<10 kg) spacecraft with significant operational capabilities. From the NACON team, Surrey has been the world pioneer in developing the world’s most sophisticated platform SNAP-1 (< 10 kg), a 3-axis stabilized platform for multiple applications. This spacecraft along with the current state-of the art in this field is discussed in greater detail in [7]. For SNAP-1, a simple standard electrical interface was prescribed for each module, consisting of regulated 5V and raw battery (Vbatt ~7.2V) power connections, with a single bi-directional Controller-Area-Network (CAN) bus for data transfer. All modules, except the on-board computer (OBC) and machine vision system (MVS) contain a standard 8-bit CAN-micro-controller (the Siemens C515), which provides telemetry and telecommand operations, data transfer and a degree of sub-system autonomy. The OBC and MVS systems are based around 32-bit StrongARM SA1100 RISC processors, to which we have added external CAN interfaces operated via the StrongARM’s in-built SPI interface. A standard module box mechanical format was also defined at the beginning of the SNAP programme, thus, every module on SNAP-1 has the same external dimensions, sized approximately to house a standard “Eurocard” printed circuit board (160 mm x 100 mm, with ~13 mm of useable depth). Figure 6 shows the top view of the interior of the SNAP-1 spacecraft. It is constructed from three sets of three electronic module boxes, connected together to form a triangular structure. The small size of the spacecraft is apparent from the scale of the hand in the picture.

3.1 NACON Nanosatellite Solutions

The NACON constellation is designed for three different levels with different spacecraft/payload capabilities pending on the orbit and time of deployment. In parallel, the spacecraft follow a specific trend in which new developments in technology enable spacecraft mass (and power, communications and volume) in a greater extent and payload in a lesser extent to decrease in a 10-year timeframe. However, and this is important, despite the possibility of decreasing the size of the spacecraft, this is traded with a larger payload capacity and capability to enable key science to be gathered from these platforms. This trade of pay-

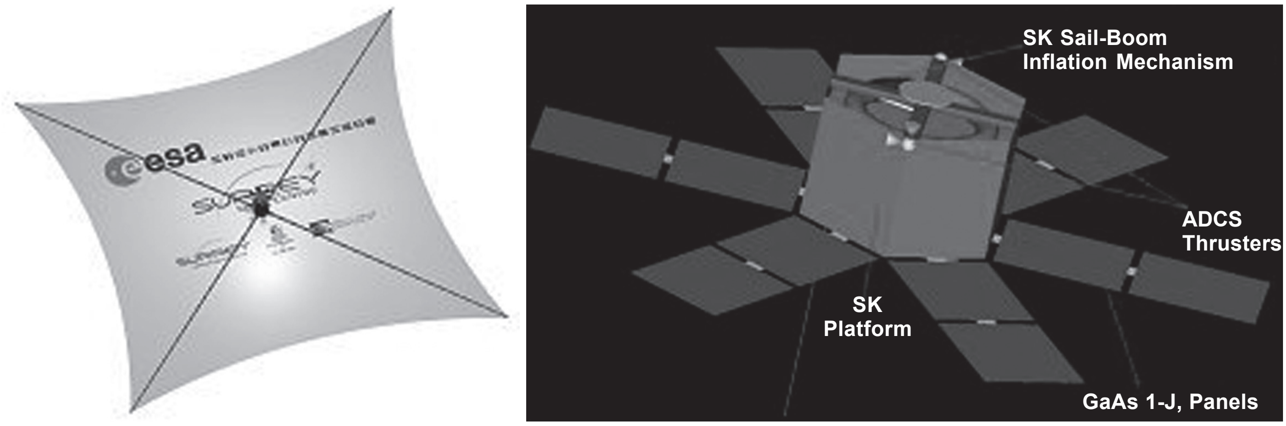


Fig. 5 Solar Kite design under ESA contract.

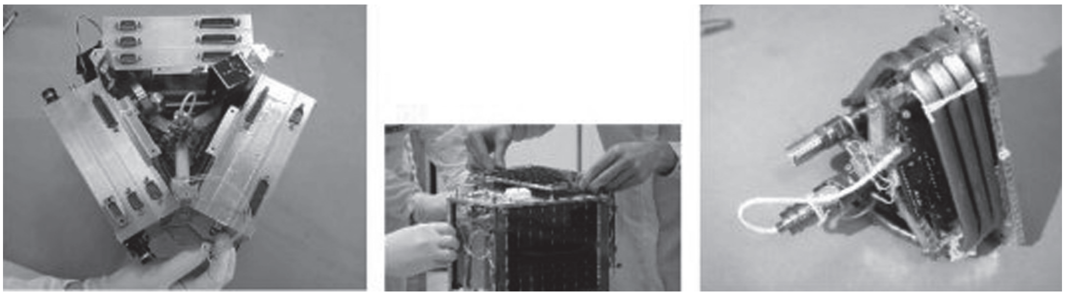


Fig. 6 SNAP-1 Nanosatellite: (a) Centre stack (b) Solar panels body mounted (c) Propulsion module.

load capability/capacity and total spacecraft mass is to be further analyzed, especially for parts of the mission with challenging science and engineering issues such as L1 HALO orbits and HEO. There are three main nanosatellite solutions in the 10-12 year lifetime of the constellation: 20 kg nanosatellite, 15 kg nanosatellite introduced after 5-6 years and then a 10 kg baseline nanosatellite spacecraft available by 2015, assuming the 10 kg spacecraft (2015) to have about the same functional capability and performance as the 20 kg spacecraft (2005).

3.2 Nanosatellite Mass Trends

Figure 7 provides a rough qualitative illustration of the expected (total) mass evolution of typical micro/nanosatellites for the purpose of space weather monitoring over the next decade. It shows that even the high-level solution payload, which may require a 30 kg satellite mass at present, would be able to fit into a 10 kg nanosatellite by about 2016. For clarification it should be mentioned that the trend shown refers to a *model* payload with a given functional objective. From past experiences we have learned that the reduction in mass usually attracts a number of additional instruments or also a further sophistication of the existing payload. Therefore, the trend shown in fig. 7 may not reflect the actual mass trends of micro-/nano-satellites launched. Although there will be a similar miniaturization in the subsystems of the spacecraft platform this trend may be a little less pronounced. In actual practice, also this trend will be weakened again due to the increased and more sophisticated payload support requirements and perhaps by increased propulsion requirements. Table 9 provides a preliminary breakdown of the overall spacecraft system budgets for the Launch configuration of the Low Level Solution in the year 2010.

Figure 8 illustrates the Launch and Replacement strategy for the three level solutions. The main reason for the replacements is due to the limited lifetime caused by the harsh radiation environment encountered by most of the spacecraft. Spacecraft failures are expected to be less frequent in comparison. Furthermore, the baseline concept has considerable ‘redundancy’ due to the relatively large number (i.e. 8 usually) of spacecraft per orbit. Therefore, the losses in terms of quantity of data or science output will not be very significant in the case of a few spacecraft failures. For simplicity it has been assumed here that all constellations will be replaced after 3.3 years. Therefore, 2 ‘replacement’ launch periods will be able to cover the 10-

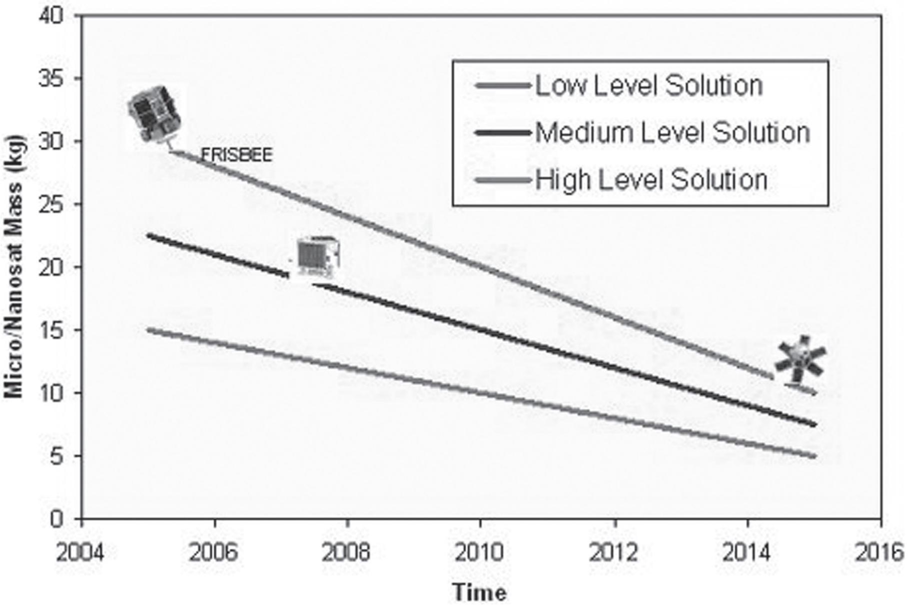


Fig. 7 Evolution of nanosatellite mass in near future due to miniaturization.

TABLE 9: *System Resource Estimates for 20 kg NACON Spacecraft (2010).*

Subsystem	Mass (kg)	Power (W)	Telemetry (kbps)
Payload	6	18	63
Propulsion	3	used only when Payload is off	-
OBC & OBDH (rad-hard)	2	4	20
ADCS (incl. GPS)	3	3	20
Structure	4	-	-
Power	1	-	-
Telecommunications	1	5	-
Total	**~ 20**	**~ 30**	**~ 100**

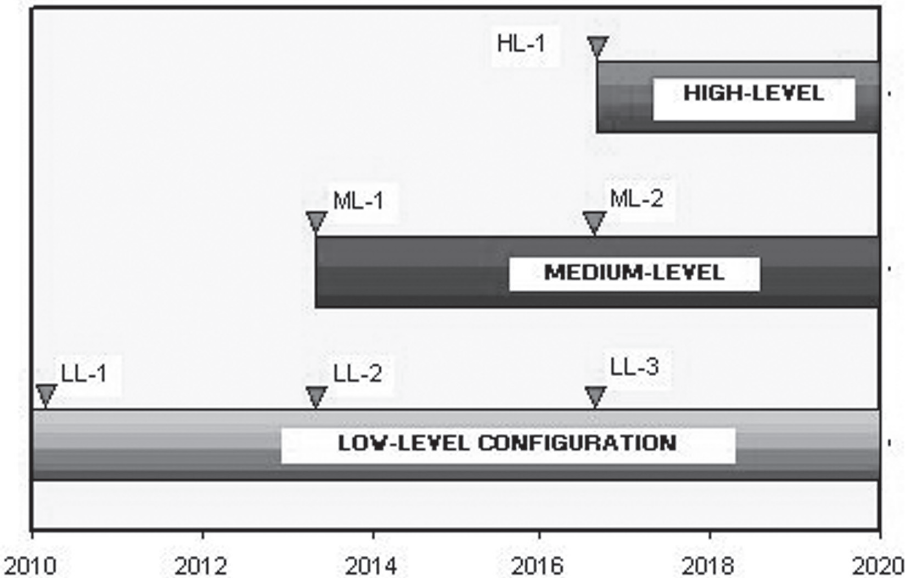


Fig. 8 Visualization of baseline launch and replacement strategy.

year operational period for the low-level solution (and one for the medium-level solution). This baseline strategy will be refined by accounting for the differences in radiation hazards for the various orbit classes.

4. Conclusion

A preliminary design of a nanosatellite based constellation for space weather monitoring is presented. The design of such a constellation is a complex trade-off of user requirements, nanosatellite capability and of the availability of miniature technologies in the future. Three different layers of possible constellation configurations are presented pending on the user group. It is shown that using current technologies and minimum technology advances, a comprehensive space weather constellation with near-real time data availability is feasible. Future work will focus on the detailed design of the space segment and on costing the proposed constellation options, including a satellite replacement strategy for a minimum 10 year mission lifetime.

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