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Nano Satellite Beacons for Space Weather Monitoring
WP 410. Prospects and Recommendations

Nano Satellite Beacons for Space Weather Monitoring: Executive Summary

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1 Preface

1.1 Document change record

Issue	Date	Notes/remarks
Issue 1.0	04 Aug2008	Extracted from final report v1.1

1.2 Purpose of Document

This document is the executive summary of the study of Nano Satellite Beacons for Space Weather Monitoring under ESTEC Contract No. 18474/04/NL/LvH.

1.3 Definitions, Acronyms and Abbreviations

L1	Lagrangian libration point 1
MEMS	Micro-Electro-Mechanical Systems
MNT	Micro- and nano-technology
RF	Radio frequency

1.4 Acknowledgements

I would like to thank all my colleagues who contributed to this study: Steven Eckersley from Astrium UK Ltd, Rickard Lundin from the Swedish Institute of Space Physics, Petrus Hyvönen from Orbitum AB, and Martin Kluge, Ulrich Prechtel and Kay Koppenhagen from EADS Deutschland GmbH. The work at Astrium UK was influenced by MSc thesis work of Kristina Larfars at Cranfield University. This work was suggested and monitored by Astrium and allowed a deeper investigation of the spacecraft issues reported in section **Error! Reference source not found..**

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2 Executive summary

This study has assessed the opportunities for using nanosats (i.e. spacecraft ≤ 10 kg) to monitor key space weather parameters. This started with a review of space weather measurement requirements and of the likely capabilities of nanosat technology to address those requirements (including using of MNT). The outcome was a set of space weather nanosat constellations, each of which addresses a focused set of measurement requirements. These constellations were then analysed to develop an outline concept for each case.

The review of capabilities looked at the current state of relevant work on MNT – looking at the development of important MNT devices such as RF components, accelerometers and power sources, at the packaging of MNT systems and of practical experience in flying an MNT spacecraft. The study also made an extensive review of current and future developments in nanosats, including the growing US and European interest in Cubesats.

The requirements review looked at requirements for space-based measurements to support space weather applications that help both space-based and ground-based services. This review consolidated the outputs of earlier ESA space weather studies and updated them to take account of recent developments in space weather services. The study identified where these measurements can be performed on nanosats and explored how to classify them.

A key conclusion was that it is not worthwhile to classify the measurements by their applicability to ground-based or space-based services. This is simply because the majority of space-based measurements have applicability to both domains. This reflects the chain of space weather from its source on the Sun to its impact on and around the Earth. The majority of the space-based measurements monitor the upstream space weather environment (e.g. solar and solar-wind measurements) which is critical to both space-based and ground-based services.

This negative conclusion is balanced by a positive conclusion – that it is possible to classify the space weather measurements into a small set of distinct spacecraft constellations: (a) two low-Earth orbit constellations aimed at ionospheric and solar observations, (b) a constellation in geosynchronous transfer orbit aimed at radiation belt and plasmasphere observations; (c) a Molniya constellation aimed at remote sensing of auroral activity, (d) a multi-orbit constellation for better measurements of the magnetospheric magnetic field; and (e) an L1 spacecraft for monitoring the solar wind and heliospheric particle fluxes.

This classification has driven the design elements of the study. These have developed a set of outline designs for each constellation and for the instruments that must be carried by each constellation. The instrument solutions are largely based on existing heritage with some extrapolation for developments in instrument miniaturisation. In one case a novel instrument concept is proposed – namely a low-resolution EUV solar imager for flare location.

The design work has outlined a nanosat concept for each constellation and explored how the nanosats might be launched, operated and de-orbited. One key issue here is the design of data links. This is always a critical issue for space weather missions since most missions have requirements for near-real-time downlink to ensure timely availability of data. Where feasible the data link designs make use of innovative ideas such as inter-spacecraft links and small ground station antennae.

Another key issue is the replacement strategy. Space weather services require continuity of data so it is important to replace spacecraft at regular intervals to reduce the risk of data failure. The use of constellations raises interesting issues about reliability – since the failure of one spacecraft will degrade constellation performance but not necessarily destroy it. Thus we had to consider how constellations could adapt to overcome failures, e.g. routing signals past failed spacecraft and adjusting spacecraft positions to optimise data sampling. This led us to consider the number of failures that each constellation could tolerate and then to model the likelihood of multiple failures (using a simple numerical model). This model allowed us to

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estimate replacement periods for each constellation and thus was central to developing the required replacement strategies (frequency of launches and need to produce multiple copies of spacecraft).

The final element in the study was to look at the prospects for using nanosats in space weather monitoring and make recommendations on how to bring those prospects to fruition. One set of recommendations is the need to develop instruments that are well suited to routine monitoring (rather than to measurements that support scientific research). We need to develop instruments that are smaller (in size, mass and power) in order to gain more opportunities to fly monitors; a key issue here is to reduce space weather sensor sizes, e.g. through simplified requirements or use of different measurement techniques. We also need sensors that are robust against extremes of space weather, in particular solar proton events. Finally we also need to reduce instrument costs. The long-term success of any programme for monitoring space weather will depend on the ability to build and replace adequate numbers of instruments.

Another set of recommendations is the need to develop ways to make best use of MNT/MEMS devices in space. This has several aspects including (a) developing methods to qualify MNT/MEMS devices for use in space, (b) developing methods to assess and mitigate radiation sensitivity of MNT/MEMS devices and (c) developing design environments and standards that are appropriate for multi-functional systems. The latter is particularly important as it will exploit synergies that can facilitate nanosat construction (e.g. reducing mass and cost) but it cuts across the traditional approach of decomposing design into separate systems. A key element in making best use of MNT/MEMS is to test and validate new devices in space; we therefore recommend establishing a programme for flight demonstration of technologies that will facilitate use of nanosats.

There is also a set of recommendations on communications links. This is a critical issue for space weather measurements because the majority of measurements have a requirement for real-time downlink. To address this problem it is important to develop European sources for low power RF systems (i.e. suitable for use on nanosats). It is also important to develop schemes for data compression; in the context of space weather data, the best way to do this is to develop schemes for on-board processing of raw data to un-calibrated physical parameters (e.g. calculation of moments for particle measurements). This exploits our knowledge of the underlying physics to make an intelligent compression of the data. It is likely to provide much better compression than mathematical schemes that have no knowledge of the data. In the longer-term we should encourage and exploit generic development of advanced satellite communication systems, e.g. on-demand links, as these will greatly facilitate data access from any spacecraft.

There are also recommendations on other important technical issues (to explore autonomous operation, to develop good methods for nanosat propulsion and for deeper study of nanosat constellation reliability) and on programmatic issues: (a) to explore and exploit the potential for synergy between operational space weather measurements and research programmes in solar-terrestrial physics, and (b) as noted above, to establish a programme for flight testing and validation of new technologies.