SCOUTS missions: ESA new program for science mission based on small satellite

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ABSTRACT

This paper presents the main characteristics of the new Scout framework in ESA's Earth Observation directorate aimed to exploit and support the New Space initiative in Europe in the frame of Earth science missions. In particular, details will be provided to explain the subtle balance between the commercial new space aspects and the science traditional aspects of the Scout framework. An overview of the 4 missions selected during the first consolidation round will be given as well as the one under development highlighting for each one the innovations, applications as well as the challenges and the achievements of the development phase. More details will be presented for the mission under implementation that will be on the launch pad in 2024.

INTRODUCTION

Nowadays, the so called "New Space" paradigm has become an important reality of the international space sector both in US and in Europe[1]. Many new opportunities have been created thanks to this, based on the exploitation of technology advancement such as smallsat and cubesats utilizing Commercial-Off-The-Shelf (COTS) components and an incremental development approach resulting in fast turn around and low budgets. Up to now the vast majority of these opportunities has been created in the field of in orbit demonstration or commercial missions. The European Space Agency (ESA) has launched programs to support and incentivize the European industries to develop commercial and IOD missions exploiting the New Space paradigm. Three years ago, the Earth Observation (EO) program directorate of the European Space Agency went a step further by launching a new framework to develop scientific missions for Earth Observation exploiting the New Space initiative building up on its two characteristic pillars i.e. relative short turn around (3 years to launch) and small budget (30Meuro) compared to standard EO research missions aiming at innovative science and technology development for Earth Observation. The idea is to combine the capability and ability of European New Space industries in delivering innovations in a rapid development cycle and low-cost fashion with the more than thirty years of experience of the European Space Agency in Science missions for Earth observation.

MAIN OBJECTIVES

In this context, the aim to develop the Scout missions is twofold:

1. On one hand, ESA intends to support and expand the New Space initiative in Europe by encouraging European companies to go one step further and implement high-end innovative science missions exploiting technology and processes typical of the New Space paradigm.
2. On the other hand, ESA, by including the Scout mission in its Earth Observation program, will enlarge its portfolio of opportunities for its Member States and the science community by including low cost and quick turnaround science missions.

THE FRAMEWORK

This new framework, called Scout to highlight its exploring aspects, is organized in cycles. The first Scout cycle is already on-going with four missions selected. Each cycle involves different phases of which the first one, called consolidation, is in common and parallel for all selected missions.

One of the biggest challenges of the new Scout framework is to conciliate the New Space agile approach with high-end innovation in science data production. In fact, although the innovation is preferably almost totally concentrated on the instruments and the Earth science higher level products (Level 1 and Level 2) to contain schedule and budget, the level of innovations requested to produce Earth science data leads to higher economic and programmatic efforts not typical of the New Space paradigm.

As for all the HW development projects, the hardware (HW) cost and lead times limit the effectiveness and the possibilities to develop quick design loops[2] ending up to a minimum viable product (MVP) as well as the subsequent tests on MVP which will be used as input for the following design loops which is the typical development flow of an AGILE project. This becomes even more critical for high-end science innovative instrument HW which for the Scout program can lead to almost prohibitive multiple MVP loops for the instruments and the critical technologies.

In the case of the Scout program, ESA has introduced several measures to maintain a high level of innovation to produce high-end science data while containing budget and schedule by retaining the advantages of an AGILE approach. First and foremost, the budget has been incremented with respect to the typical budget of a New Space single mission to 30Meuro giving each Scout mission one of the highest budgets for a single mission amongst all New Space initiatives undertaken by ESA. Of course, budget is not everything: to guarantee a quick turnaround, the framework imposes quite high entry readiness levels for both technologies (TRL)[3] and science (SRL)[4]. Specifically, TRL 4 and SRL 4 are required at kick-off as admissibility criteria to the Scout framework. This allows design loops and MVPs on higher maturity equipment expediting development and containing budget.

Phases

Each cycle of the Scout framework starts with a consolidation phase. Four missions are selected for this phase during which the consortia leading each study consolidate the science return verifying the feasibility within budget and schedule limits applicable to the framework. The main output of this phase is the Mission Requirements Document (MRD) including the definition of Level 2 and Level 1 products[5] as the higher-level data products for each mission as well as the engineering plans for the subsequent phases. At the end of this phase the outcomes are evaluated to select the missions for direct implementation. The next Scout cycle will consider additional scenarios (Risk Retirement Activities or Pathfinder approach) depending on the science and technology maturity levels versus the schedule and budget allocated.

Risk Retirement Activity (RRA)

The RRA is foreseen for those missions showing criticalities and associated risks in TRL raising activities which might jeopardize schedule adherence and low cost-to-completion of the development phase, while the consolidation phase demonstrated an initial SRL of at least 4. The main objective of the RRA is to significantly reduce the probability of occurrence of the risk to overspend and overrun the schedule by consolidating the critical technologies to reach TRL 5 at least. At the end of the RRA, provided successful achievements of objectives, the mission can be reconsidered as candidate for the development phase.

Science Pathfinder Demonstrator (SPD)

The SPD, not yet in place, is currently contemplated as a complement to the Scout framework to address those missions showing criticalities and associated risks in SRL raising activities which might jeopardize schedule adherence and low cost-to-completion of the development phase. Typical examples are those missions where the maturity of the forward and inverse models combined with the unavailability of ground campaigns do not allow a consolidated flow down of Level 2 requirements to Level 0 and raw data requirements within the cost and schedule constraints of the development phase. In this case, the risk is that the completion of the development phase within the programmatic boundaries prevents the actual in-flight Level 2 product performances from matching expectations or that meeting the full Level 2 performances requires cost and/or schedule overruns not compatible with the Scout framework. For such cases, the mission would proceed as an SPD with limited objectives such as for example no coverage or revisit requirements, but also with limited budget to assess the in-flight science return and to consolidate models. The SPD approach would not reduce the risk likelihood to not meet the overall Level 2 performance requirements. However, it would reduce the possible impacts by redefining the mission to fit in a much smaller programmatic frame. At the end of an SPD in case of proved scientific return with expected performance on Level 2 and Level 1 products, the mission could be considered for the development phase.

Development Phase (DVP)

Missions having demonstrated a very solid maturity on both TRL and SRL with no major risks identified to jeopardize schedule and cost boundary conditions are considered for the development phase. The development phase starts with phase B1 with a consolidated MRD as an input. It is constrained in a time frame of three years from the start of development to launch. This will be followed by an operational lifetime between 3 to 5 years depending on the application. A major objective of any Scout mission in the development phase is of course the ability to produce Level 2 science products to be delivered to the international science community according to needs with a free and open policy as for all other ESA Earth observation science missions. If successful, these missions are easily further scalable to mini constellations of a few satellites to achieve a higher revisit thanks to the low budget necessary to manufacture cubesats and small satellites.

Status and prospective

As already described, all phases starting from the consolidation phase but also the RRA and SPD can be just intermediate steps toward the DVP or can be the main outcome. In fact, at the end of each phase any mission can be stopped either because it cannot fit in the programmatic frame of the successive envisaged phases or because of the risk derived by the implementation of such mission. Of course, as for all New Space initiatives, halting a project is part of the normal cycle and this possibility is also what allows to go beyond and experimenting or scouting at the edge.

It is interesting to highlight that the different phases (RRA, SPD, DVP) as well as the other IOD missions under development in ESA can be considered all MVPs of a global AGILE development cycle in which, to consolidate the requirements, the overall plan goes through the implementation of intermediate steps to obtain a quick return (e.g what we get with RRA and SPD) while limiting the overall cost and development schedule by obtaining quick and inexpensive answers also from flight demonstration missions and qualification tests.

Currently 4 missions have gone through the first consolidation phase of which 2 were selected to process to the development phase while the other 2 are in the RRA phase. These are:

1. CubeMAP, an infrared triple-frequency limb sounding spectrometer and multi spectral solar occultation imager constellation of 3 cubesats for the study of the processes on the upper troposphere.
2. HydroGNSS, a multifrequency, multi-polarization, dual coherent microwave mission (GNSS-R) based on small satellite to monitor water content on land.
3. TANGO, a nadir looking spectrometers constellation of two cubesats for anthropogenic greenhouse gas emission measurement.
4. NanoMagSat, an in situ sensing constellation of three cubesats for the high and low frequency monitor of the Earth magnetic field and how it is influenced by Sun radiation.

CubeMAP, the first Scout mission selected to enter the development phase, has gone through a year of development where the project has advanced both on the TRL and the science side. Nevertheless, the very innovative instruments technology, sensing technique and very high-end science outcome unexpectedly turned out not to be compatible with the programmatic constraints of the SCOUT framework. For this reason, the development phase was halted in May 2023, to investigate other frameworks more appropriate to the specificities of CubeMAP.

HydroGNSS brings a very high level on innovation both at technology level thanks to the multifrequency, multi-polarization, dual coherent acquisition, and at science level, being the first attempt of L2 processors based on these innovative measurements for the evaluation of the ECVs. Thanks to its solid raising plan for TRL and SRL HydroGNSS was proposed for DVP and it is now well under way toward the launch readiness in Q2 2024.

TANGO and NanoMagSat, during the consolidation phase, showed criticalities related to technology development. These 2 missions were therefore proposed by ESA to undergo RRA. The RRA progress nominally with within Q3 2023, at which point these 2 missions will be evaluated for the DVP.

In addition, ESA is already planning the next Scout cycle during which the consolidation phase will allow the next 4 candidate missions for development to be identified, giving continuity to the framework.

In the following paragraphs, more details on the technologies and the science objectives of these four missions are given.

MISSIONS GONE THROUGH CONSOLIDATION PHASE

CubeMAP

CubeMAP's main scientific objective is to understand and quantify processes in the upper troposphere, study its variability and contribute to trend analysis in its composition and effects on climate.

CubeMAP focuses on the observation of the tropical latitudes of -30 to 30 degrees latitude, to retrieve key radiative important gases (H_2O, CO_2, CH_4, O_3, N_2O) as well as aerosol and air mass (Figure 1).

The lifetime of 2 years is derived from the need to cover more than one full annual cycle, while the target mission extension to 4 years is required to sample the El Niño Southern Oscillation and the quasi-biennial oscillation.

CubeMAP aims at addressing a number of highly relevant scientific questions, which require specific observational capability of a limb sounding mission, namely:

- how water vapour in the upper troposphere and stratosphere (UTS) responds to and interacts with climate change,
- how the chemical composition in the UTS responds to increasing emissions,

- how estimates of surface greenhouse gas (GHG) emissions can be improved through better knowledge of GHG and ozone in the UTS,
- how climate change affects stratospheric ozone and its recovery.

The space segment consists of a constellation of three 12U Cubesats embarking a Thermal InfraRed (TIR) spectrometer (HIROS) and a Visible Near IR (VNIR) Hyperspectral Solar Disk Imager (HSDI) flying on low inclination orbits at 550 km altitude.

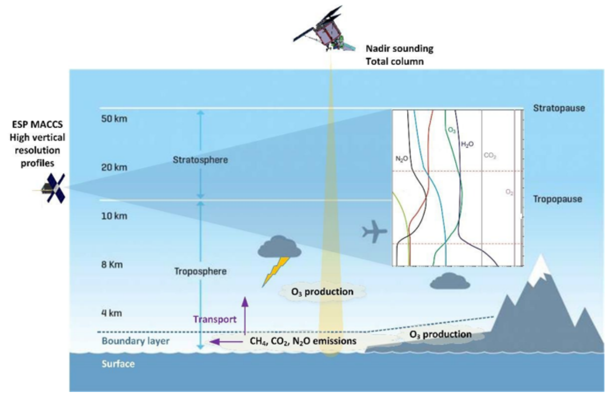

Figure 1:CUBEMAP reference operative scenario

The Mission study is carried out by a consortium led by GomSpace (DK) as prime contractor with Rutherford Appleton Laboratory (RAL-SFTC, UK) as sub-contractor.

HydroGNSS

Essential Climate Variables (ECVs) are key parameters of the Earth system identified by the Global Climate Observing System (GCOS) to help understand and predict climate change, to guide mitigation measures, and to assess risks, in association with the united nation Convention of Climatic Change (UNFCCC), Intergovernmental Panel on Climate Change (IPCC) and World Meteorological Organization (WMO). Soil Moisture, Biomass and Permafrost are some of the key terrestrial ECVs identified by GCOS, the ESA EO Science Strategy and the ESA Climate Change Initiative (CCI) programme[6] for their relevance to understanding the global hydrological cycle.

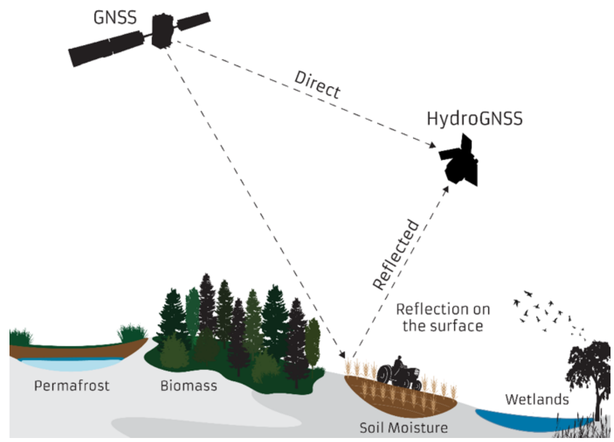

Figure 2: HydroGNSS ECV Targets

Figure 2 illustrates the four ECV targets for HydroGNSS. GNSS reflectometry (GNSS-R) is a remote sensing technique consisting of using L-band GNSS signals (from GPS, Galileo, etc.) as bi-static radar sources to sense geophysical parameters on the ground. Measurements are collected and processed by the instrument into a “Delay Doppler Map” (DDM) that can be corrected and inverted into Level 2 products such as ocean wind speed, as demonstrated on UK TechDemoSat-1 (TDS-1) and CYGNSS[7] missions. Data from these two missions were also successfully used to prove the effectiveness for sensing parameters over ice, snow and land, hence showing the potential for the HydroGNSS target applications. The rationale for the HydroGNSS ECV targets is described below:

- Soil Moisture – both indicator and driver of land-air interface processes, important for climate, agriculture and weather forecasting. Due to its criticality, a number of current and future missions also target hydrology, such as MetOp, SMOS and SMAP, Biomass, and Sentinel satellites, but more measurements are still required to meet ECV targets. HydroGNSS offers the special advantages of GNSS-R to provide complementarity with cost efficiency that lends itself to long-term continuous monitoring.
- Inundation/Wetlands – their status affects run-off and flood evolution. This ECV also allows assessment of wetland environments health which is a source of methane production.
- Freeze/Thaw – the timing of the freeze/thaw cycle of the permafrost active layer has a major effect on methane release and CO_2 uptake.
- Biomass – influences climate and is a vital parameter affecting CO_2 uptake, particularly in higher latitude forests.

HydroGNSS comprises of a constellation of two small satellites.

The mission is developed by a consortium led by SSTL (UK) with the support of Tor Vergata University (IT), CNR/IFAC (IT), Finnish Meteorological Institute (FI), Institut d'Estudis Espacials de Catalunya (ES), National Oceanographic Centre (UK) and the Nottingham Geospatial Institute (UK).

TANGO

The TANGO satellites work together on achieving the following goals:

- Measure and monitor moderate to strong emission of CH_4 ($\geq$ 10 kt/yr) and CO_2 ($\geq$ 5 Mt/ yr) at spatial resolutions small enough to monitor individual large industrial facilities (300mx300m), with an accuracy to determine emissions on the basis of a single observation.
- Complement Sentinel-5 (in MetOp-SG) and Copernicus CO2M observation for the verification of the Paris agreement and global stock takes.
- Attribute surface fluxes of specific emission types based on the combination of CH_4, CO_2
- NO2 observations at high spatial resolution.
- Exploit the use of CO_2/NO_2 ratio observations to estimate CO_2 emissions from offshore NO_2 sources.
- Demonstrate a distributed monitoring system that can pave the way to future larger constellations allowing for enhanced coverage and temporal resolution.

The TANGO mission will enable industry and policy makers to monitor greenhouse gas emissions, as well as assess the effectiveness of mitigation strategies, for sources that constitute 40% of the global emissions in key sectors such as power and energy. This is of particular importance for CH_4, as it offers the most significant potential for near term emission reduction to meet the global warming target of below 2°C.

The data from TANGO will provide input to the Copernicus Atmospheric Monitoring Service (CAMS) [8] on anthropogenic CO_2 and CH_4 emissions.

The mission development is carried out by a consortium led by ISIS with the participation of TNO, SRON and Royal Netherlands Meteorological Institute.

The TANGO observing technique is based on two push-broom Spectrometers (Figure 3).

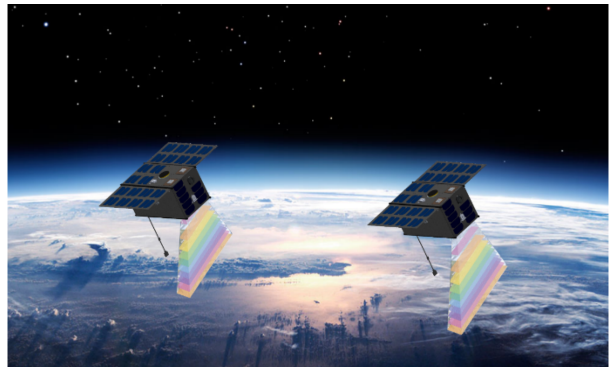

Figure 3: TANGO operational scenario

NanoMagSAT

Building on the experience drawn from the ongoing ESA SWARM mission, NanoMagSat intends to permanently monitor the Earth's magnetic field and ionospheric environment with unprecedented spatial and temporal resolution (Figure 4).

The three overarching objectives of the NanoMagSat mission are:

- to allow the international community to further improve the survey and long-term monitoring of the many components of the geomagnetic field as well as of the ionospheric environment,
- to address key open science questions and societal-related issues, only partly or not addressed by previous missions so far,
- and to demonstrate the possibility of using low-cost nanosatellite constellations to achieve such goals on a permanent basis.

It will more specifically aim at:

- Better monitoring, investigating and predicting the Earth's main field for science and societal applications,
- Improving our knowledge of the Earth's lithospheric field for science and societal applications,
- Improving our knowledge of the Earth's ionospheric and magnetospheric currents for space weather science and applications, as well as for sounding the electrical conductivity of the deep Earth (Figure 4),
- Monitoring the state of the ionospheric environment for space weather science and applications, also investigating Extremely Low Frequency (ELF) whistlers produced by lightning in the neutral atmosphere,

- Investigating the impact of incoming magnetospheric currents on the physical state of the ionosphere and thermosphere,
- Recovering the signal of oceanic lunar tides for sounding the electrical conductivity of the deep Earth as well as for global warming studies.

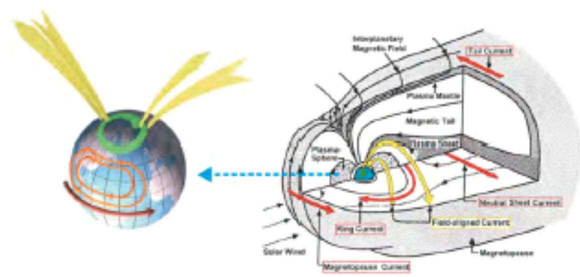

Figure 4: Earth magnetic field and magnetosphere

The Scout-NanoMagSat mission is a space network of geomagnetic observatories. It uses the following instruments to monitor the Earth's magnetic field:

- A Miniaturised Absolute Magnetometer (MAM) co-located with 2 star trackers at the tip of a deployable boom situated on top of the satellite,
- A High Frequency Magnetometer (HFM) located within the satellite body,
- 4 Needle Langmuir probes which deploy at the bottom of the satellite along the nadir face,
- Dual-frequency GNSS data (the GNSS itself is considered part of the platform due to its dual use).

The mission is carried out by a consortium led by Open Cosmos with the participation of IPGP, CEA LETI, University of Oslo and COMET Engeneria.

CONCLUSIONS

The paper presents the Scout framework, the new ESA framework that exploits New Space initiative to develop high-end science missions for Earth observation. The way ESA has conciliated the AGILE approach of New Space with very innovative high-end instrument development has been highlighted including how ESA's thirty years of experience in Earth Science mission development is synergically combined with the New Space paradigm expertise of the European industry in this new framework.

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