[SSC21-XII-02]

Arctic Weather Satellite, A microsatellite constellation for improved weather forecasting in Arctic and globally

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ABSTRACT

A consortium led by OHB Sweden has started the implementation of a prototype satellite for a possible constellation mission called Arctic Weather Satellite (AWS). This constellation of small satellites in low polar orbits would provide frequent coverage of the polar regions to support improved nowcasting and Numerical Weather Prediction (NWP) of the Arctic and Antarctic regions. The AWS mission is designed to be complementary to the existing polar-orbiting, meteorological satellites (e.g. MetOp and MetOp Second Generation (SG)), providing additional atmospheric sounding information to improve NWP on a global scale. The 120 kg AWS prototype satellite will fly in a ~600km sun-synchronous orbit and is based on OHB Sweden's InnoSat platform. The payload is a cross-track scanning, passive microwave radiometer from Omnisys Instruments with 4 frequency bands to provide atmospheric sounding information complementary to the microwave radiometers on MetOp-SG. Global data will be stored onboard the satellite for data dumps over specific regions as well as broadcasted worldwide in real time. The ground segment contains a highly innovative Digital Beam Forming Network (DBFN) ground station from Thales allowing tracking of multiple satellites simultaneously. The final constellation is foreseen to provide data with less than 30-minute latency over the entire Arctic region.

INTRODUCTION

The establishment of the Artic Task Force (ATF) by the European Space Agency (ESA) in 2016 resulted in a specific programmatic framework to support sustainable development, better knowledge of the environment and economic development while ensuring the protection of the corresponding valued Arctic ecosystems. After a series of internal studies within the Agency, it was decided in 2018 to initiate an industrial system study called the Arctic Mission System Study (AMSS).

AMSS

This study had as goal to elaborate concepts for mission architectures addressing the prioritized Arctic needs (amongst others snow and ice monitoring, improved situational awareness, climate change monitoring, logistics and transportation support and communication services). More than 80 Arctic needs were gathered with inputs provided by ESA, national delegates and industry. Next, these needs were given scores in order to rank them within four main areas i.e. Number of users, economic revenue, strategic value for the Arctic region and social benefit (such as safety, environment and scientific knowledge). Together with a detailed asset and gap analysis (is there any other future mission or terrestrial application already fulfilling this need), the main conclusion of AMSS was that an Arctic Weather monitoring system would be the best candidate to fulfil all criteria. The study concluded with a concept of a smallsat constellation of 16-20 satellites in polar orbits carrying a passive microwave sounding instrument as the most cost-effective solution.

AWS

Most recently, a Proto Flight Model (PFM) satellite received funding during the ESA Council at ministerial level in 2019 (SPACE19+) to validate such a concept and to prepare for a future constellation implementation. The program was called Arctic Weather Satellite (AWS) and its implementation phase of the PFM started in February 2021 with an anticipated launch in early 2024. The main mission objectives are to confirm the impact of increased passive microwave soundings on NWP accuracy and nowcasting, to demonstrate a cost-effective ("new space") approach and to finalise the details of a follow-on, operational AWS constellation.

This paper presents the proposed AWS mission concept, its anticipated space and ground segment design and the future benefits such a system could deliver on society at large.

MISSION CONCEPT

The Arctic Weather Satellite mission is to provide frequent coverage of the Earth's atmospheric humidity and temperature for improved nowcasting and numerical weather prediction. It consists of at several small satellites, each carrying a single cross-track scanning microwave radiometer consisting of 19 channels within the range 50 to 325 GHz.

Figure 1: AWS constellation

The key operational mission requirements of availability, timeliness, coverage, and revisit time, are intimately tied to the constellation design which is currently being performed together with ESA and the potential end customer, EUMETSAT, as part of the ongoing Phase B. The platform is designed for continuous operation with station-keeping using its onboard electrical propulsion system without impact on Instrument data collection and continuous global broadcast of its data via L-band. Together with the ground segment, instrument data availability is expected to exceed 95% for the PFM. Data timeliness is a combination of number of global data downloads per orbit, data repatriation duration, and post-processing duration. For the PFM, only one global data download per orbit is expected, though multiple downloads are being considered for the constellation. Coverage and revisit time depend upon constellation design, though an example constellation of 4 orbital planes with 4 satellites per plane is expected to achieve a revisit time over the Arctic region under 30 minutes. Of course, another key mission enabler is the carefully balanced design of the InnoSat platform to be both low-cost and reliable.

DESIGN

Platform

A simple selective redundant microsatellite platform from OHB Sweden has been chosen as the AWS platform. It is based on OHB Sweden's successful InnoSat platform, which has demonstrated flight heritage (GMS-T mission) since 2021 and its decades of experience in other Swedish micro satellite missions such as Astrid1/2 (1995/19998), Odin (2001), SMART-1 (2003) and PRISMA (2010)[1]. This versatile small microsatellite platform has been designed to utilise the most of the available launcher volume for a piggyback/rideshare launch, it is optimised for sun-synchronous orbits and it provides maximum possible accommodation and flexibility for payloads. InnoSat is designed and built on COTS equipment and for this mission, several selective redundant upgrades will be implemented to match the reliability figure required for the 5-year mission lifetime. The key performance factors of the AWS platform are summarised in Table 1. The InnoSat platform comes with a versatile Attitude and Orbit Control System (AOCS) including a high performing Electrical Propulsion Unit (EPU) as shown in the preliminary layout in Figure 2.

Table 1: AWS PFM System Specifications

Item	Value
Mass	120kg (total)
Volume	1050x680x800mm (stowed)
Power	160W (nominal)
Design lifetime	5 years
Data	S-band: 4000 kbps (TTC) L-band: 1500 kbps (payload)
AOCS	
Absolute Pointing Absolute Knowledge (Any axis)	Error < 290" (2 σ) Error < 190" (2 σ)
Positioning	<10m
Attitude control	> 3deg/min
Orbit control	ΔV up to 310m/s Thrust up to 1.2mN Isp up to 4500s

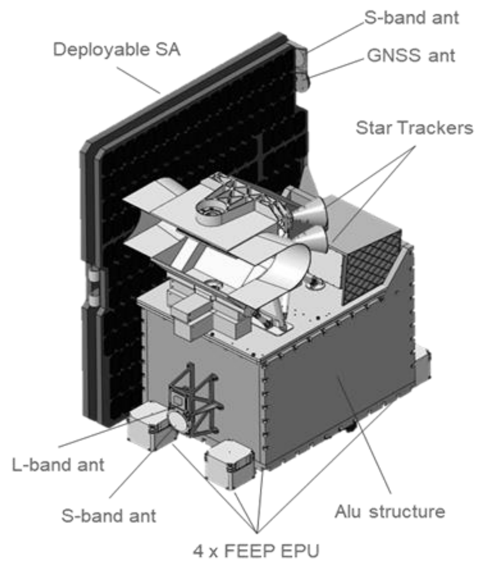

Figure 2: AWS spacecraft

Selective redundancy

The AWS mission requires a 5 year design lifetime whilst also requiring near continuous operational availability. Both impose challenging requirements on the reliability whilst maintaining the budget of a low-cost microsatellite mission. In order to balance both stringent needs whilst meeting the low-cost mission objective, a combination of selective redundancy on platform equipment and redundancy on satellite level has been selected as the most cost effective solution**.**

Flexible orbit configuration

In order to keep simplicity in the satellite design whilst guaranteeing the satellite to be able to accommodate the entire local time of ascending node (LTAN) span of the 600km SSO for the AWS constellation mission, several fixed angle deployable solar array configurations have been selected (which can be tuned according to the LTAN). This approach results in a simple design without the need of a complex Solar Array Drive Mechanism (SADM), which is considered to adding complexity to a low cost newspace mission.

Downlink modes

AWS delivers its data to the ground in three distinct data streams i.e. satellite house-keeping (HK-TM), Stored Mission Data (SMD) and Direct Data Broadcast (DDB). Whereas the SMD will contain a full orbit of instrument data dumped each orbit over Svalbard (PFM), the DDB stream will continuously transmit in quasi-real-time the instrument data over the globe and enable regional end-users to create their own regional products. Furthermore, the DDB stream will contain not only the instrument data but also ancillary (necessary for the generation of the L1b products) and instrument house-keeping data. Both the SMD and DDB streams will be transmitted over the same satellite's L-band data stream. Simultaneous transmission of SMD and DDB over the polar stations is envisaged using multiple virtual channels. All platform HK-TM will be embedded in the SMD.

Debris mitigation

At the end of the lifetime of the satellite, the orbit will be lowered and the satellite will be passivated to minimise any risk of collision past its end of life complying to the inter-national space debris mitigation requirements. In case the satellite would for any unexpected reason not be able to execute its active deorbit phase, it would still naturally de-cay well within 25 years due to its low altitude and its relatively large surface area.

Orbit control

The AWS satellite comes with four Field-emission-Electrical Propulsion (FEEP) thrusters providing up to 1.2 mN of thrust at 160W for orbit maintenance (phasing, altitude), orbit raising and collision avoidance manoeuvres. As FEEP thrusters are throttable de-vices, specific AWS operating points have been selected balancing power consumption and performance needs. The choice for FEEP technology for this mission has been made due to its suitable performance for the AWS mission (deltaV, power consumption etc.) as well as a high TRL level, accommodation flexibility and its low-cost whilst being able to use multiple FEEP's for system redundancy[2]. The AWS satellite has been designed to fulfil its mission needs with only three FEEP thrusters.

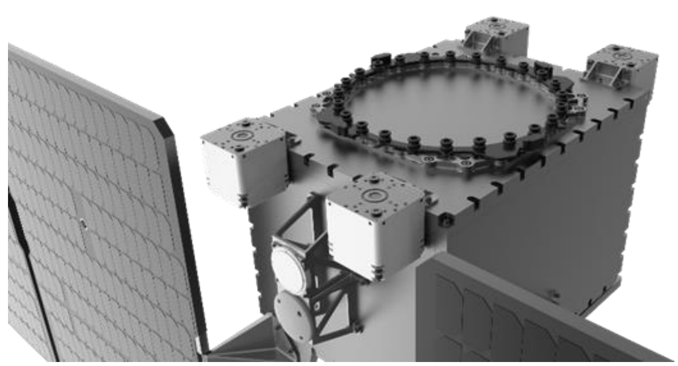

Figure 3: 4x FEEP EPU on AWS

Constellation autonomy

The space segment is required to be operationally autonomous for at least 4 days, but all possible further reduction in commanding improves the economic viability of the constellation operations. Onboard command scheduling is performed with Mission Timeline (PUS 11) or Position Scheduler (PUS 22). MCS monitors the satellites between S-band passages via the housekeeping telemetry downlinked continuously via the L-band DDB. The need for regular S-band contacts is driven by the necessary frequency of station-keeping command updates. The commanding period is being optimised by Mission Analysis during Phase B. Otherwise, S-band contacts are only required for emergencies. Failure identification and recovery using the selective redundancy is handled with a classic hierarchical FDIR software as used on multiple previous OHB Sweden missions. Recovery is performed at lowest possible level with intention to fail-operational where possible**.** Furthermore, options are being considered to further enhance autonomy in terms of autonomous orbit control (such as station keeping, collision avoidance and orbit constellation phasing).

Payload

The AWS instrument is a cross track radiometer with four independent receiver horns (54, 89, 166/138 and 325 GHz) feeding one scanning reflector rotating at a constant speed of 45 RPM.

Compared to the MicroWave Sounder (MWS) on METOP SG, also a cross track microwave sounder, the channels below 50 GHz are dropped, and the 229 GHz receiver is substituted by one at 325 GHz, thus two transitions on the important water line are observed. The Arctic Weather Satellite will provide 8.5 - 40 km spatial resolution at nadir, depending on frequency.

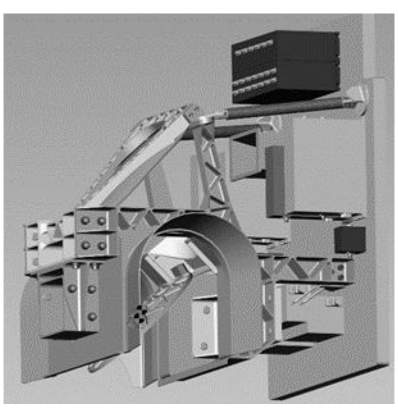

Figure 4: AWS Instrument layout

In terms of system design, the AWS instrument is designed with redundancy for the common control and power functions whilst the receivers are single string, thus providing "graceful degradation" should one or more of receiver channels fail prior to mission end.

Major difference compared to MWS is that complex optics has been removed and spatial separation of the receivers is used instead of advanced frequency selective materials. A remapping process will allow to use measurement data in the same way as for MWS but the data will also be possible to use without remapping in future NWP models.

The spatial separation of the receivers allows for a much more compact instrument and will also reduce losses in the receiver chain, thereby significantly improving the sensitivity. The instrument front-end receivers will also be operated at a slightly lower temperature, further improving their sensitivity. The instrument aims for state-of-the-art short-term stability and calibration accuracy with a fully protected wedge shaped calibration target.

GROUND SEGMENT

The AWS Ground Segment architecture is set up for operating the AWS Space Segment and relies on three major components as illustrated in **Error! Reference source not found.**. The **Svalbard Ground Station (SGS)** is the main Space to Ground interface with both conventional S-band ground stations for TC/TM and a novel L-band Digital Beam Forming Network (DBFN) for both payload (SMD and DDB) and HK-TM downlink. The **Mission Control Segment (MCS)** contains all vital functions for monitoring and control of the satellite (i.e. Flight Dynamics System (FDS), Operations planner and automation Satellite Control System (SCS)). Lastly, the **Payload Data Ground Segment (PDGS)** serves to process, archive and disseminate the L0 and L1b products.

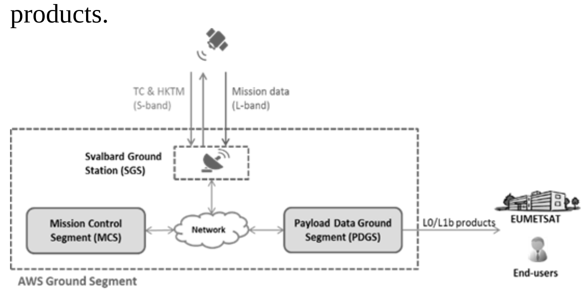

Figure 5: AWS Ground Segment

Thanks to a cloud base-infrastructure, all ground segment operations are centralised in a unique location. An Operations Center located in Tromsø, Norway will operate the whole system with a 24/7 monitoring of the data processing chain.

As AWS is a low-cost "new-space" mission, a cost effective approach has been chosen consisting of:

- PDGS and MCS as a cloud-based infrastructure, providing a highly reliable solution with sufficient level of redundancy
- significant reuse of existing building blocks, such as the CCSDS Layer management module software,
- strong industrial experience (DEIMOS/RDA) with a significant background in end-to end system performance simulators and processing chains,
- MCS and S-band ground contacts As-a-Service (AaS) provided by KSAT, not fully dedicated to a single mission.

DBFN

Thales Alenia Space (TAS) DBFN technology is used for L-band reception (HKTM, SMD, and DDB). The system consists of a flat 256-element array with no moving parts providing a high reliable solution with very little or no preventive maintenance in harsh environmental conditions as on Svalbard. After L-Band signal digital conversion, all signal acquisition and processing is fully digitalized. With this single flat array reception system, it is possible to track multiple satellites simultaneously on the same frequency band with minimum separation angle thanks also to beam-nulling, serving the future AWS constellation needs.

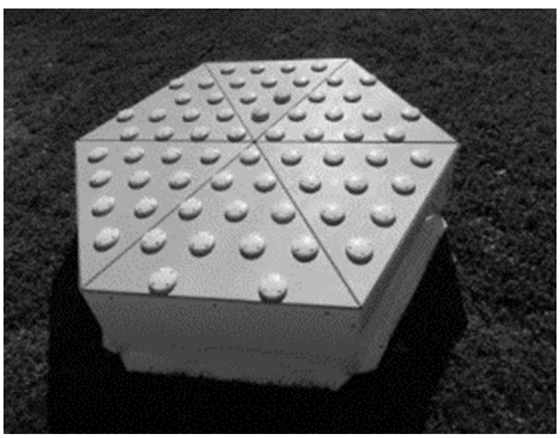

Figure 6: DBFN Arial port

IMPACT AND FUTURE OUTLOOK

In modern society, accurate weather forecasts are an essential resource often taken for granted. Its usage is widespread from ordinary daily decision taking (e.g. what clothes to wear) to more industrial practices in agriculture, transportation and in the energy sector. Weather predications have become a vital source of information throughout society and it is therefore of utmost importance it is well maintained and available for everyone around the globe.

Meteorologists around the globe use both the data from geostationary satellites as well as the few satellites in polar orbit to produce as accurate weather forecasts as possible for all locations on earth, including the Arctic. Weather prediction accuracy however in this region are far behind from what can be found around the equator due to two reasons. First, whilst the conventional geostationary satellites (at 36 000km from the equator) provide images every 15 minutes, their visibility is limited at higher latitudes, resulting in poor performance from these images in the forecasting models. Secondly, whilst the polar satellites (e.g. Europe's MetOp) satellites do return data over the poles as they orbit the Earth pole to pole, it takes more time to scan the globe (up to 24 hours). Water vapour in the atmosphere (vital to weather forecasting) can change relatively quick. Therefore, an urgent need for more frequent data over the Arctic is in place to improve our current forecasting.

It must be noted that the Arctic Weather Satellite mission will not only serve the Arctic region of more atmospheric temperature and humidity information but the entire globe as well. AWS will complement the existing polar weather satellites such as MetOp and its counterpart, the US NOAA Joint Polar Satellite System.

For the first time ever, an almost constant stream of temperature and humidity from every location on earth will be provided allowing very short-range weather forecasting ("nowcasting") in the Artic. All enhancements which AWS brings will impact better understanding of climate change, support information-based decision policy and allow better predications and tracking of (extreme) weather. The latter resulting in increased safety and efficiency in various industrial practices.

References

1. Larsson, N, "InnoSat and MATS – An ingenious spacecraft platform applied to Mesospheric Tomography and Spectroscopy", IAA Small Satellites for Earth Observation, Berlin, 2015.
2. Ciaralli, S. and Hallock, A, "Mission-driven selection of the propulsion system for the InnoSat platform", Sp2020-0353, Space Propulsion 2020+1 conference.