THE INNOVATION PLATFORM

SPECIAL FOCUS
SPACE

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From the Moon to the ocean:
Investigating the missions, technologies, and initiatives in the space sector that are helping to address major global challenges and keep society moving

A SPECIAL FOCUS FROM
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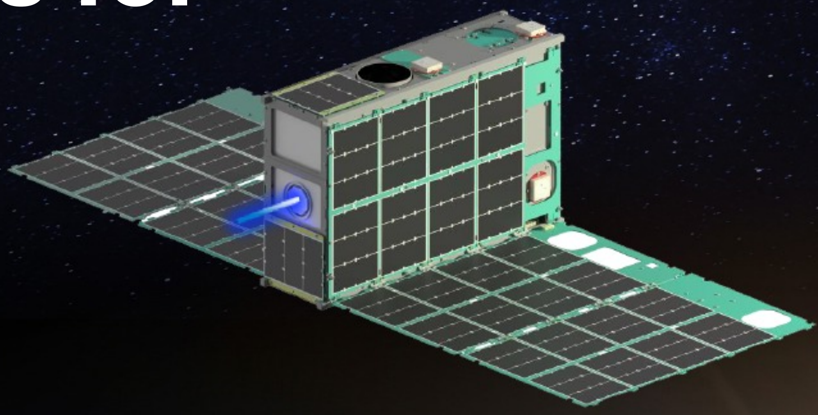

CU Aerospace, L.L.C.
3001 Newmark Drive Champaign
Illinois 61822
USA

Foreword

FROM global health to economic growth, exploration and activity in space has a profound impact on so many aspects of our lives. Worldwide, governments, space agencies and companies are collaborating to utilise space technologies and capabilities to address major global challenges, from climate change to disaster response. This carefully curated special focus publication explores a number of these challenges and shines a spotlight on the groundbreaking work taking place in the space industry. We sat down with some of the leading figures in the space sector, including experts from NASA and the European Space Agency, to discuss a number of important topics, including Earth observation, Moon and Mars exploration, space weather, space technologies and much more.

Returning to the Moon

Leading the publication, we have a conversation with NASA's Deputy Associate Administrator for Programs in the Space Technology Mission Directorate (STMD), Walt Engelund. Engelund details the many activities that the agency is running in its quest to return humans to the Moon and continue on to Mars and beyond.

To support missions like NASA's, innovation is of vital importance. In this edition, scientists from Prairie View A&M University share how they have developed and launched two first-of-their-kind space radiation measurement payloads. In addition, we hear from Champaign-Urbana Aerospace (CUA) about the multiple innovative micropropulsion systems that it has developed for future integration and flight on micro/nanosatellites.

Earth observation and disaster mitigation

Earth observation (EO) – the process of gathering information about the Earth's surface, waters and atmosphere – is vital to ensure a safe, secure, and healthy society and economy. EO data can be used to inform policy and actions across a broad range of industries, including agriculture, forestry, fisheries, health, transport, tourism and more.

Within this publication, we take a look at key EO activities taking place around the world, as well as technologies and initiatives helping to support these. For 20 years, the European Space Agency (ESA) and its partners planned and developed the EarthCARE mission, designed to make global observations of clouds, aerosols and radiation and revolutionise our understanding of how these factors affect our climate. The mission launched in 2024, and it has already produced interesting data. I had the pleasure of speaking with Mission Manager Björn Frommknecht to find out more.

Continuing on the topic of observation, Félicia Norma Rebecca Teferle from the University of Luxembourg delves into Global Navigation Satellite Systems (GNSS) and explains how harnessing their capabilities can help to transform meteorological predictions and climate analysis.

Exploring why EO technologies are vital for disaster response and prevention, RSS-Hydro discusses its new cutting-edge applications for flood planning and introduces its recent project, CeDaRs, which is backed by ESA.

Looking at how space solutions can help combat climate challenges and meet sustainability goals, the Foundation Euro-Mediterranean Center on Climate Change (CMCC) introduces its SDGs-EYES project. The project turns satellite data into smart tools to boost Europe's progress on the United Nations Sustainable Development Goals (SDGs).

Furthermore, we learn about the PITHIA-NRF project, which aims at building a European distributed network that integrates observing facilities, data processing tools and prediction models dedicated to ionosphere, thermosphere and plasmasphere research.

Space weather
Space weather is the physical and phenomenological state of natural space environments, impacted by solar activity. Severe space weather could have a detrimental impact on our society and infrastructure on Earth, and it is therefore of vital importance to monitor and predict space weather events to inform mitigative actions. ESA's Space Weather Office works to deliver timely and accurate information to enable mitigation of the adverse impacts of space weather. I sat down with Juha-Pekka Luntama, Head of the Space Weather Office at ESA's European Space Operations Centre (ESOC), to learn more about the Office's key activities.

We also take a look at VT-NigerBEAR, an international collaboration between Virginia Tech, USA and Bowen University, Nigeria, which is poised to highlight the use of High-Frequency (HF) radars on monitoring space weather.

Space data
Elsewhere in this special focus edition, The UK Space Agency shares details about its 'Unlocking Space for Business' programme, which aims to drive private sector adoption of satellite data and services by tackling barriers to adoption being faced by private sector end-users. We also hear from 3S Northumbria about the importance of increasing available space data to support space operations.

This publication is a comprehensive look at the operations and innovations on the ground and in space that enhance our daily lives and keep our society moving. The issue is jam-packed with exciting and thought-provoking pieces from some of the industry's leading voices, and I hope you find it as enjoyable to read as I have found its production.

Georgie Purcell
Editor, The Innovation Platform

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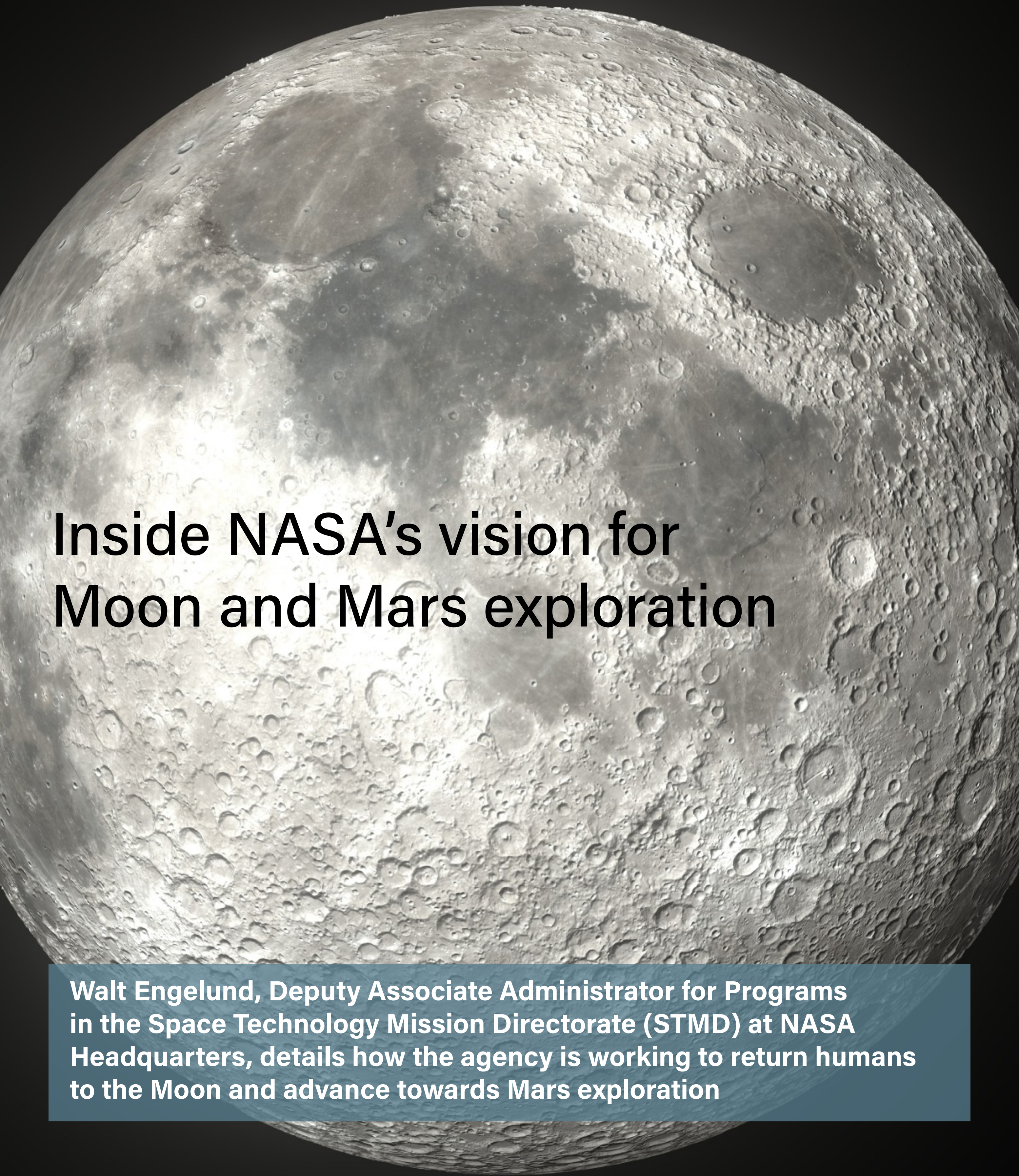

Inside NASA's vision for Moon and Mars exploration

Walt Engelund, Deputy Associate Administrator for Programs in the Space Technology Mission Directorate (STMD) at NASA Headquarters, details how the agency is working to return humans to the Moon and advance towards Mars exploration

SINCE NASA's Apollo program first landed humans on the Moon in the late 1960s, the quest to return human explorers to the lunar surface and continue on to Mars has been a topic of continuous discussion, development, and analysis. For over 50 years, NASA has explored many different architectures that would resume crewed missions to the Moon or send them on to Mars.

In September 2022, NASA published its Moon to Mars objectives, setting out an objectives-based approach to the agency's human deep space exploration efforts. Developed in close collaboration with industry, academia, international partners, and the NASA workforce, this approach focuses on the big picture – the 'what' and 'why' of deep space exploration – before prescribing the 'how.'

To help deliver on these objectives, NASA developed a Moon to Mars Architecture, setting out a roadmap of key technologies and capabilities needed to return to the Moon and venture on to Mars. This Architecture is re-evaluated and updated on an annual basis – in the form of the Architecture Concept Review cycle – to realise change in response to new technologies, discoveries, and priorities.

As NASA embarks on the next era of space exploration, its Space Technology Mission Directorate (STMD) is dedicated to advancing technologies and testing new capabilities at the Moon – many of which will prove critical at Mars. To learn more about NASA's plans for Moon and Mars exploration and the ongoing work to help achieve these goals, *The Innovation Platform* spoke to Walt Engelund, Deputy Associate Administrator for Programs in the Space Technology Mission Directorate (STMD) at NASA Headquarters.

Can you explain more about NASA's goals in Moon and Mars exploration, and particularly the Moon to Mars Strategy?

NASA has been working on technologies and mission architectures for both Moon and Mars exploration, with the idea that things we can demonstrate and do on the Moon will feed forward and help us one day to be able to send humans to Mars. NASA's Moon to Mars Architecture approach works with experts across the agency, industry, academia, and the international community to continuously evolve a blueprint for crewed exploration of the Moon and Mars.

In the past, NASA has relied on the 'owner-operator' model for most of our missions. In the new paradigm, NASA is working with industry and empowering them to do the things that they can do best and are asking them to own and operate the rockets and spacecraft, and we'll be one of many users. There is, of course, some transition and learning on both sides, but I believe ultimately it will support the growing space economy and expansion into the solar system. This will enable NASA to continue developing new technologies allowing us to explore in new ways – including new robotic and human missions to the Moon, Mars, and beyond.

How is the STMD working to support these goals?
The Space Technology Mission Directorate is focused on the development and demonstration of transformational space technologies that will enable human and robotic exploration of space, including the Moon and Mars. Much of our current focus is on infrastructure technologies, which you can think of as the basic utilities for long-term sustained presence in space and on the lunar or Martian surface. Things like advanced power, optical laser-based communications systems, deep space navigation technologies, and advanced materials and in-space manufacturing capabilities. We are also looking at new ways to land larger payloads, more precisely and safely, on the Moon and other planetary bodies including Mars.

In STMD, we work closely with our industry and agency partners to support NASA's Moon to Mars portfolio, including human exploration and robotic missions like the Commercial Lunar Payload Services (CLPS) initiative. The CLPS missions allow NASA to buy payload space on commercial lunar landers, instead of owning and operating the landers. Through this model, STMD has not only worked closely with several of the commercial companies to help them develop new technologies for their commercial lunar landers, but we have also developed and flown several of our own payloads to the surface of the Moon on their vehicles.

Can you share some examples of key missions and initiatives the STMD is currently pursuing in the area of Moon and Mars exploration?
Space power is a big push right now, and STMD is supporting the agency's development of deployable solar power arrays for the Moon, small nuclear fission reactors, and advanced power storage including high efficiency batteries and fuel cells. We also need ways to distribute power to multiple places and lunar surface assets, so we are looking at things like wireless power charging and power beaming technologies. Things that have been developed and demonstrated for use here on Earth but can be adapted for use in space.

Another capability we're developing is technology for precision navigation and landing. We have some technologies that are utilising laser light and Light Detection and Ranging (LiDAR) capabilities that we are adapting for space applications. When a spacecraft is approaching a planet's surface for landing, we can use these space LiDAR systems to precisely navigate to a particular location and also to map and avoid hazards like craters and large rocks. These systems are much like the technologies that are being deployed on autonomous driving automobiles here on Earth.

This artist's concept of Moon to Mars infrastructure shows astronauts living and working on the surface of Mars. NASA's Moon to Mars Objectives establish an objectives-based approach to the agency's human deep space exploration efforts

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What are the biggest accomplishments from the STMD in this area so far?

In the last several years, we've had a number of very successful technology demonstrations. Right now, we have something called the Deep Space Optical Communications (DSOC) experiment flying on the Psyche spacecraft out beyond Mars. Psyche is a robotic science mission to explore a metal-rich asteroid. We took advantage of some extra payload space on the spacecraft to demonstrate a new optical communications technology that uses laser light instead of traditional radio waves to beam signals back to Earth. In this case, the optical system can transmit terabytes of data over 100 times faster than the state-of-the-art radio systems at distances of almost 300 million miles away. This type of advanced communication will be useful when we send humans out to explore places like Mars and beyond.

We also successfully demonstrated something called Navigation Doppler Lidar (NDL) with two of the companies that are flying commercial payloads to the Moon. The NDL system provides very precise measures of velocity and distance to the surface during the landing phase of missions – much more so than traditional radar systems, and at the same time are much smaller, lower mass, and use much less power.

Another successful demonstration we did a few years ago was something called a 'Hypersonic Inflatable Aerodynamic Heatshield' (HIAD). Traditional spacecraft use heatshields for hypersonic entry into an atmosphere. The problem is that these headshields are typically very heavy, rigid structures and have to fit inside in a rocket fairing. A HIAD system uses an inflatable pressurised heatshield structure that folds up and packages very small, allowing us to take larger, heavier payloads into an atmosphere and land them on another planet, or even bring large things back to Earth much more efficiently.

What are your priorities for 2025?

We have been investing in power for space and, in particular, something we call fission surface power. Traditional solar power systems are limited in how much power they can provide and how long they can do it. Particularly as you get further away from the Sun at places like Mars. On the Moon, especially at the lunar South Pole, where future missions will land, solar power and batteries would be challenged to provide all of the power that we need as our exploration footprint expands. So, we're developing a small fission system that we can demonstrate at the Moon and can also be used at Mars.

We've also been working on a new high-power electric propulsion thruster. Traditional chemical rocket engines for deep space transportation can provide high thrust but they are less efficient. Electric propulsion thrusters use high current electricity, that can be provided by a source such as solar power, to generate a strong magnetic field. They then use a gas like Xenon and accelerate it through the magnetic field to provide very efficient thrust. It's been demonstrated at small scale, but we're aiming to deliver a high-power (12.5 kWatt) electric thruster, which is the kind of power level that we might one day use to send humans to Mars.

The Space Technology Mission Directorate also fosters several industry partnerships to mature innovative technologies, support the agency's goals, and energise the space economy.

You can learn more about our work and follow our progress at the Moon, Mars, and beyond here.

Walt Engelund
Deputy Associate Administrator for Programs in the Space Technology Mission Directorate (STMD)
NASA Headquarters

Texas A&M University (TAMU) Chancellor Research Initiative (CRI) expands innovative space radiation detectors

Radiation Institute for Science Engineering (RaISE) at Prairie View A&M University developed and launched two first-of-its-kind space radiation measurement payloads

RECENTLY we designed and developed two innovative space radiation payloads with lowest mass (< 1 kg) volume (< 1 U), lowest power requirements (~ 1 W), highest resolution for radiation particle measurements (with about 5 micron per pixel resolution of complementary metal oxide semiconductor (CMOS) sensors), with a unique data transmission from deep space via radio frequency waves (directly from the spacecraft). We built both of our space payloads at the NASA Johnson Space Centre in the US.

Our first payload – radiation Particle Pixel Detector (PPD) was launched into deep space onboard the Shinnen-2 spacecraft of KIT-Japan that was spun off along with the Hyabusa-2 (asteroid exploration mission) of JAXA – Japan in 2014. Our second payload - Solar and Heliospheric Assessment of Radiation Particles (SHARP) Charged Particle Detector (CPD) was launched into polar orbit onboard the Ten-Koh spacecraft of KIT-Japan in 2018 by the H2 rocket of JAXA – Japan. Both payloads successfully collected and transmitted data through the onboard spacecraft's own radio frequency communication portals. Our first payload received the highest recognition and honours from the Japanese Science and Engineering Society in 2016 for successfully collecting radiation data and transmitting from deep space onboard the Shinen-2 spacecraft near Venus' orbit.

Fig. 1a: Launch of Hyabusa-2 along with Shinnen-2 spacecraft carrying our first Radiation Particle Pixel Detector (PPD) on a deep space mission to Venus' orbit

Fig. 1b

PPD: First ever deep-space radiation measurements via radio waves

The first ever CMOS-based radiation particle detector launched to deep space has been successful and proved to be promising for several other advancements, with the following five unique features:

1. PPD payload the Shinen2 spacecraft, has been in an elliptical orbit around the Sun (migrating between Venus and Mars orbits crossing the Earth's orbit), was launched on 3 December, 2014, as part of the Hayabusa2 (an asteroid exploration mission for a second sample return objective).

2. Shinen2 spacecraft, designed and built by the Kyushu Institute of Technology (KIT-Japan), is a hexagonal shaped, 15-kg, 47 x 49 x 49-cm structure built with lightweight and durable Carbon Fiber Reinforced Polymer (CFRP) with dual batteries charged by solar panels on each side of the structure and redundant UHF transmission at 437 MHz.

3. Shinen2 proved its success by transmitting data from the Moon orbit and beyond. Shinen2's only payload is a radiation detector designed and built by Prairie View A&M University (PVAMU) in collaboration with NASA Johnson Space Centre (NASA-JSC), the University of Texas (UT-Austin), and the University of Nevada, Las Vegas (UNLV).

4. The radiation particle pixel detector (PPD), a 10 x 10 x 10-cm cube structure was designed and developed as: (i) low weight (~ 800 gr), (ii) low power (~ 1 W), (iii) high reliability over few years (~ 5+ years), (iv) high tolerance in deep-space harsh radiation environment for a broad range of temperatures (-50°C to +50°C), and (v) with a unique capability to provide data downlink over a low bit rate communication transmission to Earth (few kilobytes) from deep-space.

5. Our payload, PPD, uses two CMOS sensors and custom designed radiation-hardened field-programmable gate array (FPGA) to sustain the deep-space radiation environment with capability to estimate energy and particle flux – typically, 85% of protons and 14% of the alphas of the Galactic Cosmic Ray (GCR) composition in deep space that varies as a function of the solar cycle.

SHARP-CPD: First ever x-ray measurements with CMOS sensors

The first of its kind, SHARP-CPD payload that was built and launched as part of the Ten-Koh Spacecraft of Kyushu Institute of Technology, KIT-Japan, for Earth's Polar Orbit on October 29, 2018 by JAXA, Japan and has been in Earth's Polar Orbit at 93 degrees at an altitude of ~ 600 km.

This unique payload is comprised of six Radiation Sensors, two X-Ray Detectors, and one Particle

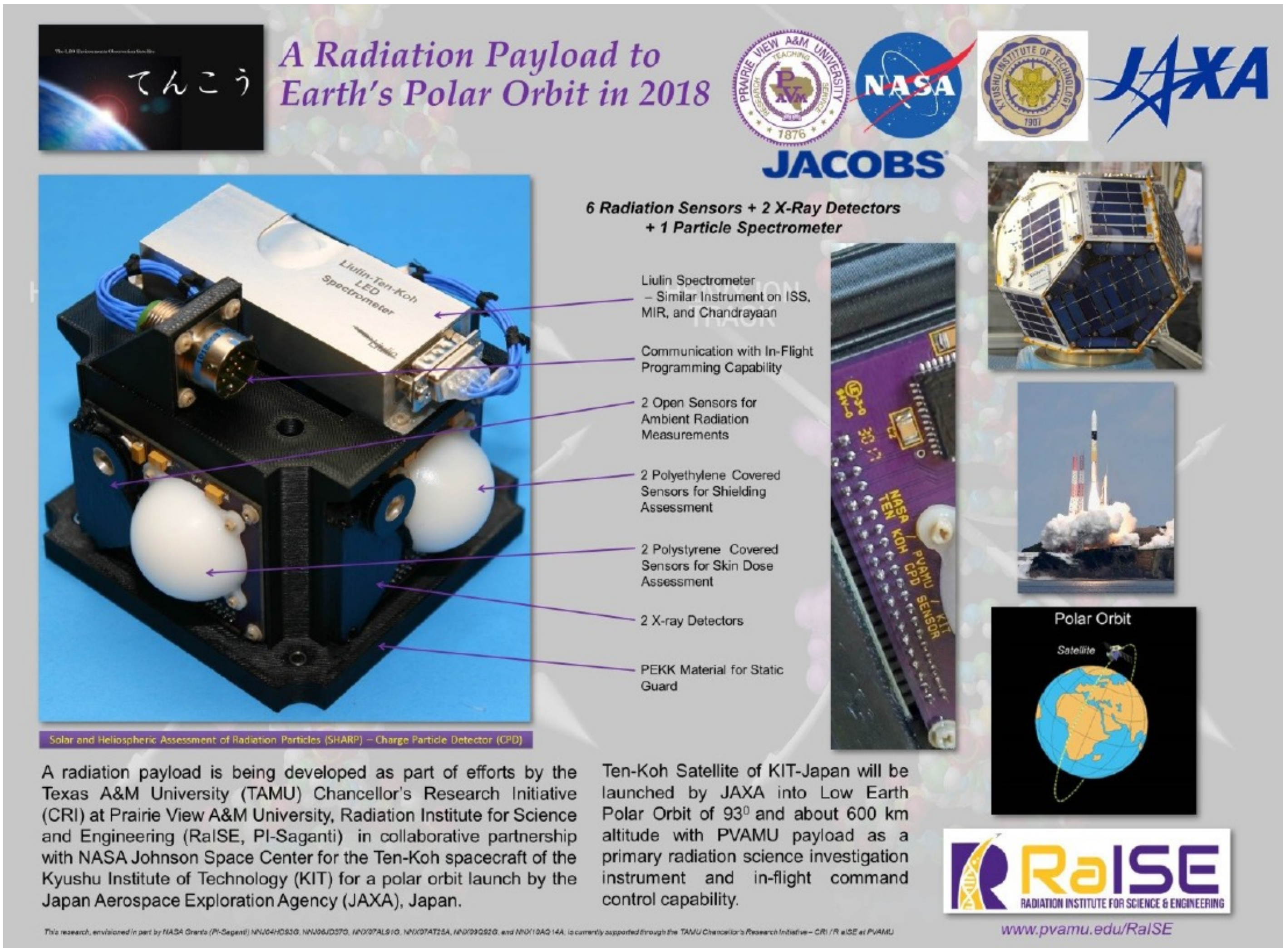

Fig. 2: SHARP-CPD

Spectrometer. This groundbreaking combination of sensors can be best categorised into seven salient features:

1. The Liulin particle spectrometer, custom developed by the Bulgarian Academy of Sciences (BAS), was designed to collect radiation measurements in conjunction with PVAMU's six other Radiation Sensors for an even more dimensional comparison.

2. One set of two radiation sensors are covered with polyethylene spheres that will be collecting data on radiation shielding effectiveness over time. `

3. Another set of two sensors are covered with polystyrene for assessing dose measurement over an extended time period.

4. There are two open sensors to gather ambient radiation measurements.

5. The SHARP-CPD payload's pioneering design also features a set of two sensors integrated with scintillating material for detecting X-rays in the polar orbit.

6. The entire frame structure is built with 3-D printed PEKK material for low-static electrical interference that allows for the best possible data collection to date.

7. Finally, this payload boasts in-flight command control capability, allowing access to manage data collection protocols of all sensors independently.

For live tracking and ten-day future predictions of Ten-Koh Spacecraft from your location, CLICK HERE.

More on Shinnen-2 and Ten-Kho from RaISE-USA.

More on Shinnen-2 and Ten-Kho from KIT-Japan.

Principal partners:
- **Professor Saganti (USA)** – Principal Scientist
- **Professor Holland (USA)** – Principal Engineer
- **Professor Cucinotta (USA)** – Principal Modelling
- **Professor Okuyama (Japan)** – Principal Architect
- **Professor Dachev (Bulgaria)** – Principal Measurements

Radiation Track Structure Detector (TSD): For the finest micro dosimetry and the highest resolution of the real-time imaging

- CMOS sensor dimensions: 0.644 cm (H) x 0.461 cm (V)
- Total active pixels: 3664 (H) x 2748 (V) = 10,068,672
- Each pixel size: 1.67 μm x 1.67 μm
- Entire unit: 10 cm x 10 cm x 2 cm (Sensor Board + Control Board) on a 3D printed holder

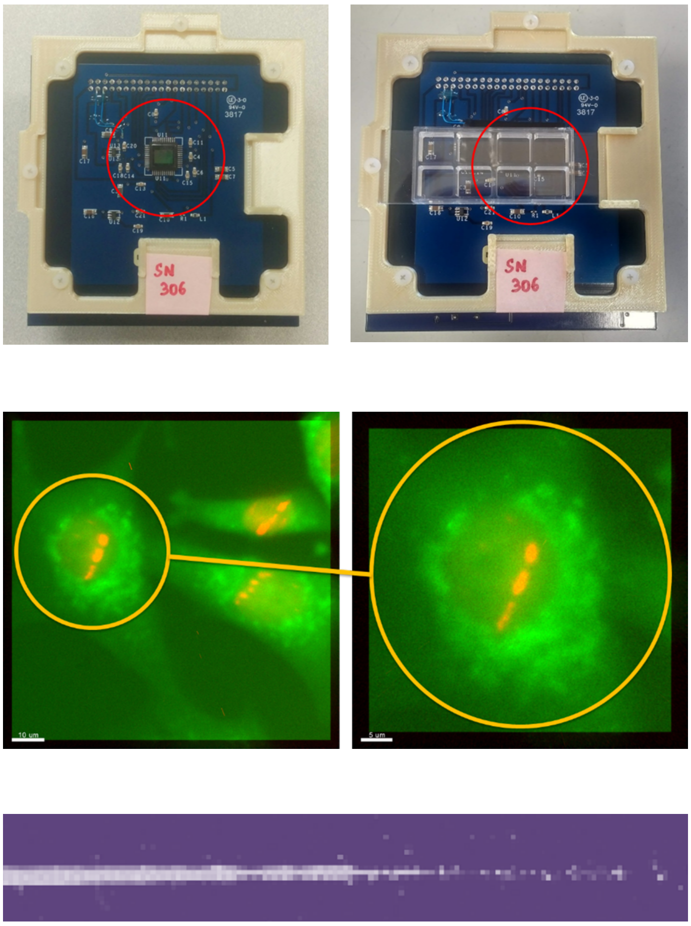

Fig. 3a: Top left is the TSD with and without the a chamber slide. Middle image is the image of the cells (mouse hippocampal neuronal cells (HT22) and Radiation Particle Trajectory of carbon ions, LET = 50 keV/um) with the particle track shown post irradiation. The lower panel is the depiction of the 55 MeV carbon ion at the micron level as seen live during carbon ion radiation at NSRL. Each pixel represents 1.67 microns

Recently, we developed a CMOS (complementary metal oxide) based space radiation Track Structure Detector (TSD) system for capturing and analysing heavy ion tracks at cellular dimensions with a 1.67 microns per pixel resolution and more than 10 M pixels on a ~ 1 cm^2 sensor.

To characterise the heavy ion particle track structure at micron level, we collected data with several heavy ions of varying energies including carbon ions at NASA Space Radiation Laboratory (NSRL) of the Brookhaven National Laboratory (BNL) – USA, and with carbon ions at the at the Heavy Ion Medical Accelerator in Chiba (HIMAC) facility – Japan. Due to recent widespread interest in particle therapy for various treatment applications, we calibrated our track structure detector for several ions, including helium, carbon, oxygen, and iron ions (55 MeV through 300 MeV) at NSRL and HIMAC. All our experiments with detector systems are augmented with biological samples making use of a custom-built chamber slide adopter designed to reside atop of the sensor unit for correlating spatial distribution of the track structure and trajectory impact at cell dimensions.

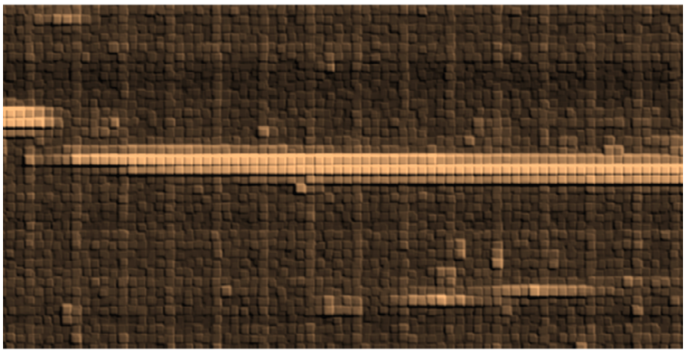

Fig. 3b: A partial Radiation Track Structure of carbon ions with 300 MeV/n at 1.67 micron per pixel resolution (about 1/2000 part of the 10 M pixel image is shown here, representing ~ 100 x 50 pixels)

Our data of particle track images at micron resolution with our custom-developed CMOS sensor units are very promising for interpreting the track length and spatial distribution of radiation at cell dimensions. Also, our data is promising for studying fragments along the particle trajectory. Results of carbon ion tracks and cell impacts will be presented along with other heavy ion track structure observations. These TSDs will be improved for 3D data at cellular dimensions in the near future and can be custom-developed for various medical applications for real-time assessment of various ground-based radiation treatment options, as well as human space exploration operations, as needed.

Research support:

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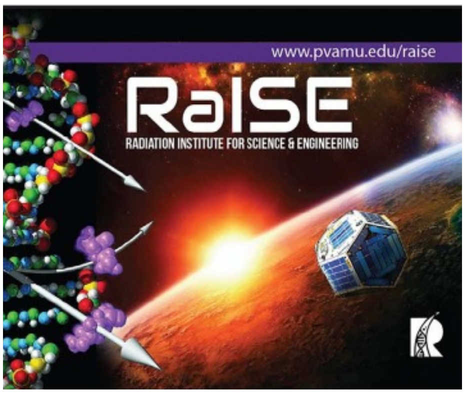
Germany - Shannon Adler contributed and compiled this publication.



Premkumar B. Saganti, Ph. D.
Regents Professor - Texas A&M University System and
Director - Radiation Institute for Science and Engineering
Prairie View A&M University a member of the Texas A&M University System
936-261-3134

New small satellite propulsion technologies nearing flight demonstration

To provide a 'responsible space' option to existing and future satellite manufacturers, Champaign-Urbana Aerospace (CUA) has developed multiple innovative micropropulsion systems that represent tipping point technologies for future integration and flight on micro/nanosatellites

THE CUA family of micropropulsion systems provide a broad range of capabilities from high thrust to high specific impulse to best suit the needs of the customer. Advantages of CUA's life-cycle propulsion solutions include:

- Collision avoidance.
- Orbit raising and lowering.
- Inclination change.
- Rendezvous.
- Drag makeup and orbit maintenance.
- Deorbiting at end of satellite useful life.

Collision avoidance and deorbiting satellites dramatically help to avoid the escalation of the growing orbital debris problem, which ultimately could lead to what is known as the 'Kessler syndrome' – a catastrophic space scenario where there is so much debris in low Earth orbit (LEO) that the probability of collision is high enough that it is no longer safe to launch spacecraft into or through the debris field.

The deorbiting capability of CUA's different technologies enables satellites to meet the U.S. Federal Communications Commission's (FCC) relatively new five-year deorbit rule. This is especially important for

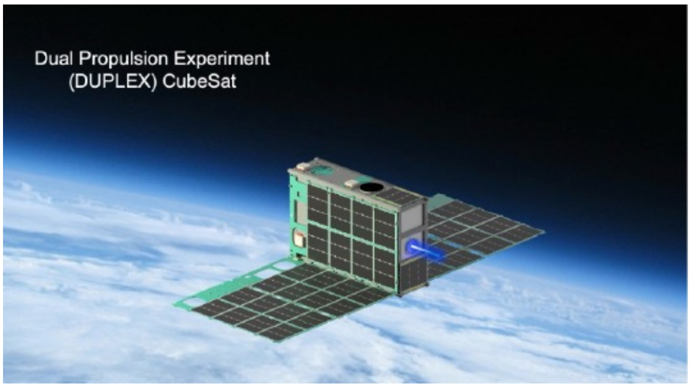


Fig. 1: Dual Propulsion Experiment (DUPLEX) CubeSat scheduled for launch and deployment in late-2025

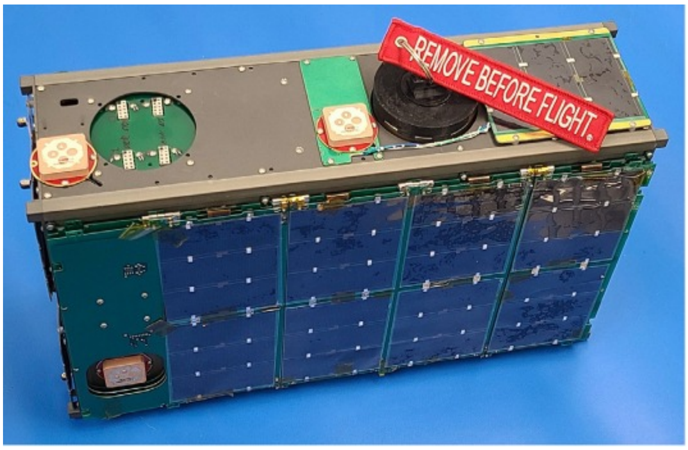


Fig. 2: DUPLEX satellite with deployable solar panels in stowed configuration

satellites having altitudes higher than atmospheric drag alone or passive deorbit deployment options can handle.

Dual Propulsion Experiment (DUPLEX) CubeSat: 2-for-1 flight demonstrator

NASA's Space Technology Mission Directorate (STMD) funded CUA for the design, fabrication, launch and in-space demonstration of the Dual Propulsion Experiment (DUPLEX) CubeSat (see Fig. 1). DUPLEX is a 6-litre-sized satellite that will perform an in-space demonstration of CUA's innovative fibre-fed pulsed plasma thruster (FPPT) and Monofilament Vaporisation Propulsion (MVP) micropropulsion technologies to provide flight heritage for these CUA systems. The satellite bus was fabricated by team partner NearSpace Launch. The DUPLEX spacecraft is manifested for launch on the NG-23 cargo resupply vehicle to the International Space Station (ISS) in September of 2025. DUPLEX will then be deployed from the ISS in the late-October 2025 timeframe. The DUPLEX flight demonstration will significantly lower the risk for future customers of the MVP and FPPT systems and raise the Technology Readiness Level (TRL) of these innovative thruster technologies. The satellite is shown in its 'stowed' configuration in Fig. 2, with deployable solar

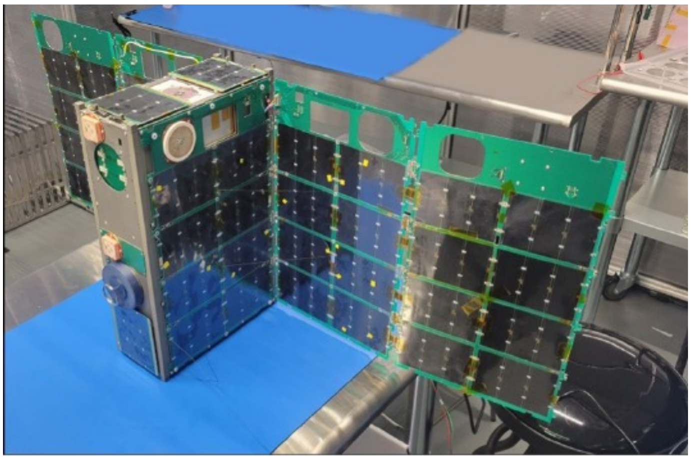


Fig. 3: Final laboratory test of DUPLEX solar panel deployment

panels extended in Fig. 3, and its final inspection in CUA's cleanroom (Fig. 4). The DUPLEX spacecraft will provide invaluable flight heritage for CUA's FPPT and MVP technologies.

Fibre-fed Pulsed Plasma Thruster (FPPT)

CUA's FPPT vaporises Teflon and accelerates the resulting ions using a high-energy 10-microsecond pulse, providing a very high specific impulse of >3,500 s. The Teflon fibre is spooled in the back of the package and fed into the centre of system (Fig. 5). The high specific impulse and total impulse are competitive with Hall and ion-thruster technologies at much lower cost and without the need for a pressurised propellant tank or valving that can leak propellant. The system also

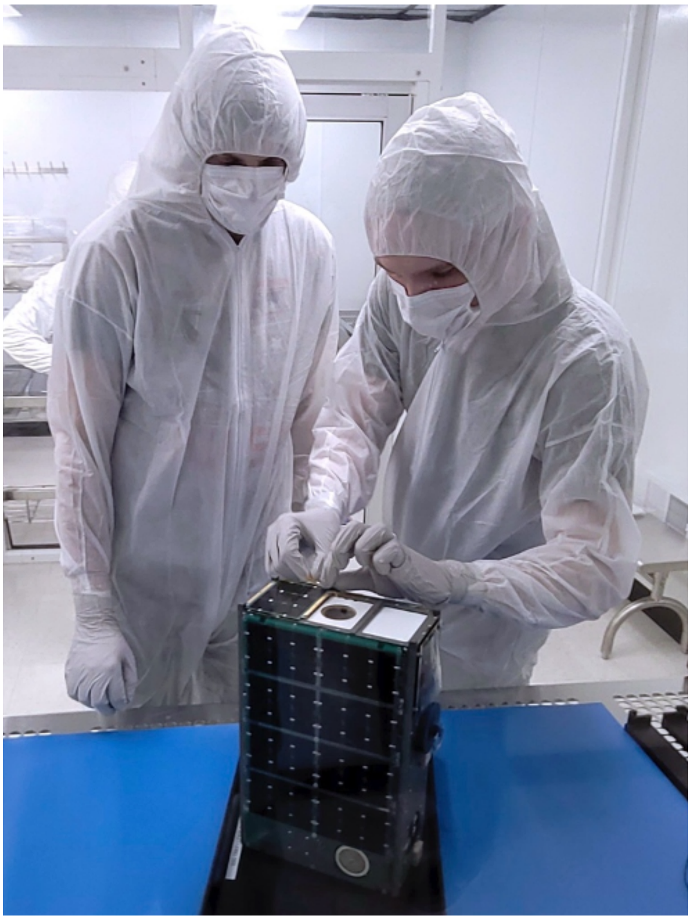


Fig. 4: Final cleanroom inspection of the DUPLEX satellite

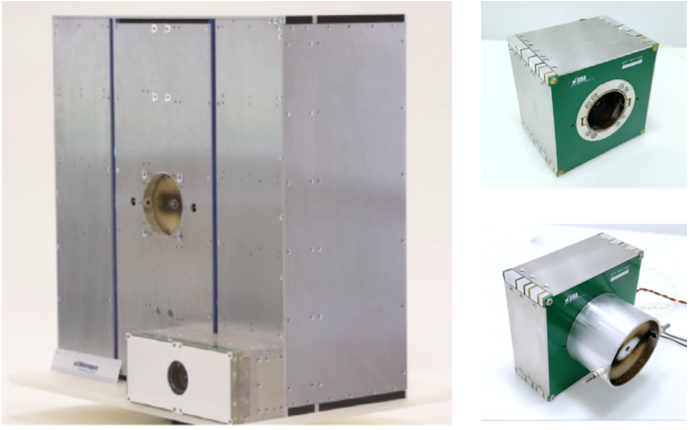


Fig. 5: Photograph of the Fibre-fed Pulsed Plasma Thruster (FPPT) 53- and DUPLEX 1.7-litre systems (left) and 0.7-litre options (right top and right bottom). The packages are all self-contained with enclosed electronics, Teflon® propellant, and thruster head

includes electromagnetic thrust vectoring (steering) of approximately ±5 degrees in the pitch and yaw axes. The FPPT, through its electromagnetic short-pulse discharge, provides a dramatic increase in total impulse to > 25,000 N-s in a 1.7-litre sized package. FPPT has now evolved into various form factors ranging from 0.7-litre to 53-litre sizes to provide a broad range of total impulses from 1,000 – 600,000 N-s, respectively. FPPT technology is a compelling option to meet many micropropulsion needs, including extended orbital manoeuvres (orbit raising and lowering), inclination change, collision avoidance manoeuvres, drag makeup, deorbiting, and even deep space capability. The newest ESPA-class FPPT can also serve as the propulsion system for active debris removal (ADR) satellites (Fig. 6).

Monofilament Vaporisation Propulsion (MVP)

The Monofilament Vaporisation Propulsion (MVP) system draws from extrusion 3D printer technology to feed and melt Delrin fibre propellant (a common polymer). MVP then uses a low power resistojet to vaporise the Delrin propellant and provide continuous electrothermal thrust with a specific impulse of 66 s. The Delrin fibre is spooled in a cylindrical configuration surrounding a core containing all the electronics inside the package. This technology retains performance characteristics competitive with other warm gas systems, but enables more accessibility to micropropulsion via dramatically reduced cost and the elimination of range safety concerns. A 0.93-litre sized MVP (see Fig. 7) has a total impulse of 265 N-s and is a compelling option to meet many micropropulsion needs, including collision avoidance manoeuvres, limited orbit raising/ lowering, drag makeup, and deorbiting.

Cubesat High Impulse Propulsion System (CHIPS): Robust multi-purpose option

CUA's Cubesat High Impulse Propulsion System (CHIPS) is a miniaturised, well-integrated propulsion solution tailored for small satellites, combining both a main thruster and a three-axis attitude control system (ACS). Utilising CUA's high efficiency resistojet (superheater) technology and non-toxic, inert propellants, CHIPS offers

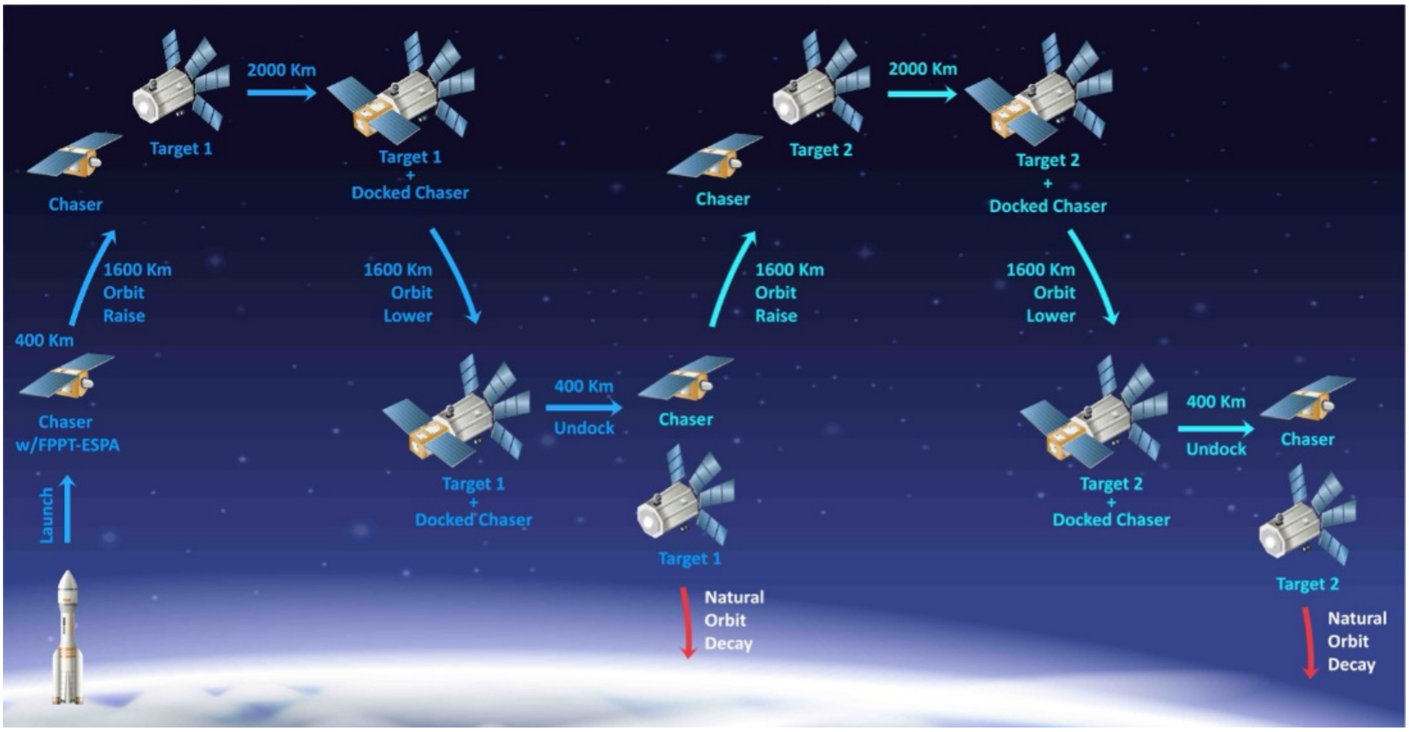


Fig. 6. Illustration of FPPT-ESPA on an ESPA-class chaser satellite with two target deorbits for active debris removal of non-operational targets

impressive performance in a compact package. Proven valving has been cycled to >120 million actuations and can be used with self-pressurising, non-toxic, and inert propellants. Waste heat from the electronics and resistojet is efficiently and regeneratively recovered to evaporate propellant, resulting in low system temperature rise (~1°C) over ten-minute operating cycles.

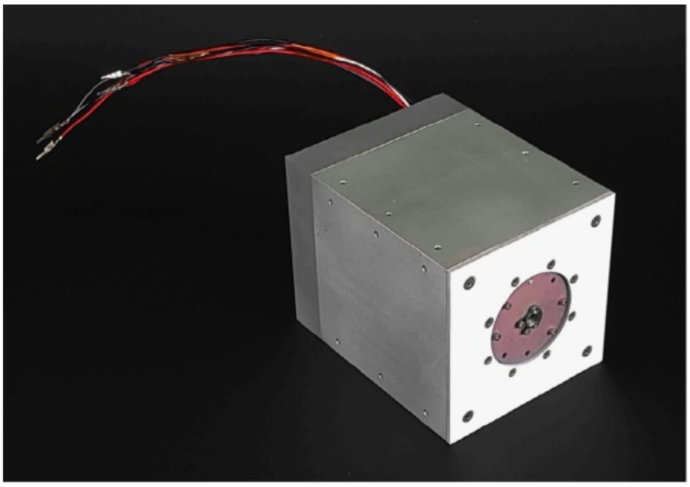


Fig. 7: Photograph of MVP flight thruster system. The package is 9.0 cm x 9.0 cm x 11.4 cm (0.93-litres) with enclosed electronics, Delrin propellant, and thruster head

CHIPS technology provides a great deal of mission flexibility with minimum risk, providing a powerful, customisable propulsion system with minimal size requirement. The all-welded CHIPS-180 (see Fig. 8) is an ultra-compact 0.54U fully throttleable system having 180 N-s of total impulse with refrigerant R134a as its propellant. CHIPS technology can be customised in size to meet customer-specific mission requirements. While CHIPS' warm-gas resistojet specific impulse is 40-50% higher than cold-gas Isp, CHIPS can also be packaged as a cold-gas-only system requiring reduced power.

The CHIPS package can incorporate up to eight ACS thrusters for 6 degree-of-freedom (6DOF) operation.

Monopropellant Propulsion Unit for Cubesats (MPUC): Safe high thrust option

CUA has developed a high thrust option using an ethanol and hydrogen peroxide monopropellant mixture. This monopropellant, designated CMP-X, is a non-detonable yet energetic COTS formulation (see Fig. 9)

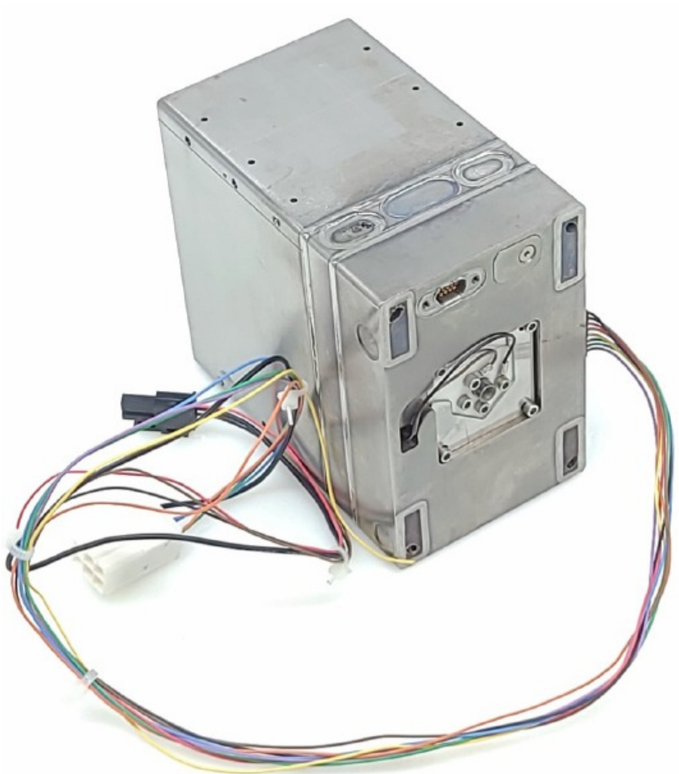


Fig. 8: Photograph of CHIPS-180 flight-ready thruster system. The package is 10 cm x 9 cm x 6 cm (0.54-litres) with enclosed electronics, R134a propellant, primary thruster and 8 ACS thrusters (having 6DOF capability)

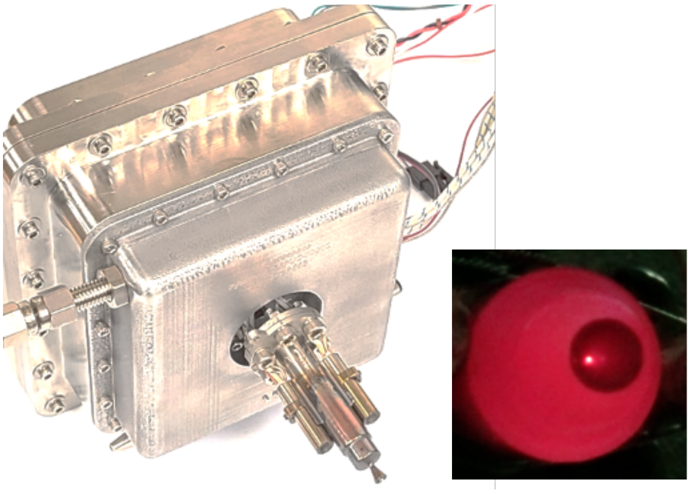


Fig. 9: Brassboard 1-litre sized MPUC system with flight qualified thruster head (left), and close-up of additively manufactured stainless steel MPUC thruster head glowing red during operation (right)

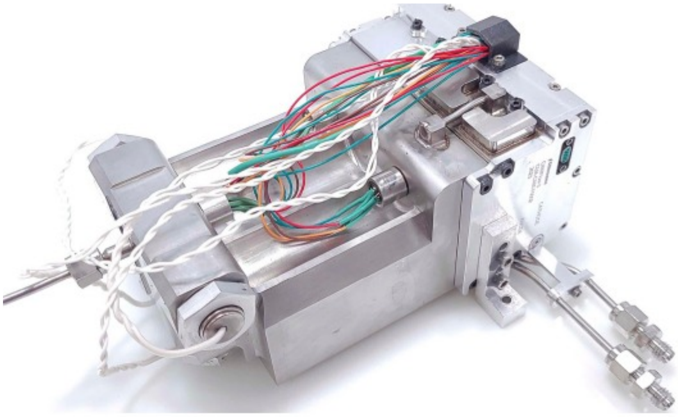


Fig. 10: Cycle Automated Mass Flow (CAMFlow) flight-ready technology provides reliably stable gas flow rate to sub-kiloWatt Hall thrusters. The body of the compact system with enclosed electronics and valving is approximately the size of a 1.5-litre box

that possesses many system-level advantages over legacy monopropellants (such as hydrazine), including lower cost, lower thermal load (approximately 900°C flame temperature, see Fig. 9), water-like viscosity, common materials compatibility, and an additively-manufactured thruster head. CMP-X is designed as a monopropellant option for customers who can accept a modest performance trade-off for the advantages of lower cost, easy transportability, considerably fewer range safety concerns, longer continuous thrust burns, freeze temperature < –33°C, and lower flame temperature, resulting in considerably less thermal soakback into the spacecraft.

CMP-X retains the ability to scale in thrust magnitude and requires minimal catalyst bed warmup time. CUA's CMP-X thrusters have demonstrated a steady 178 s specific impulse at 230 mN thrust during thrust stand testing with continuous firing times > 50 min. A 2-litre sized MPUC would have a total impulse >2,000 N-s. Other advantages include:

- Thrust can be throttled.
- The thruster and system are scalable for high thrust greater than 10s of Newtons.
- The monopropellant is non-detonable, non-explosive, and has received UN 1.4S transportation classification.
- Attitude control thrusters can be readily added.
- CMP-X is well-suited for larger CubeSats and small satellites.

Cycle Automated Mass Flow (CAMFlow) technology: Low-cost precision flow control

The Cycle Automated Mass Flow (CAMFlow) system (Fig. 10) provides reliable and well-regulated flow control for electric propulsion systems. CAMFlow uses an innovative control scheme that enables stable operation using fixed frequency Boolean valve states, even for the low flow rates necessary for sub-kiloWatt Hall effect thrusters. This methodology removes system complexity, places the onus of reliability on valve cycle life, and, combined with the fixed operational frequency, allows for a direct correlation between system life and valve cycle life. The CAMFlow control scheme was successfully tested and validated on a 600-Watt Hall thruster. This included open loop, closed loop, and cold 'hard' start operations. The control valves were cycled > 120 million pulses while maintaining a very low leak rate, thereby demonstrating long-life potential. CAMFlow units are presently focused on smaller Hall-effect or gridded-ion electric propulsion systems, however, the technology is widely applicable over a larger range of flow rates for a broader commercial market. The CAMFlow system controls the output flow rate to < ±3%. Through the use of less expensive space-rated components, CAMFlow technology provides a reliable, low-cost flow controller that is well-suited for sub-kiloWatt Hall/ion thrusters.

Future vision

CUA's family of micropropulsion systems are now developed for flight and will help the industry to provide a responsible and sustainable space environment in which the growing number of satellites can safely coexist. The CUA family of high-value (quality performance at reduced cost) system options provides a broad range of capabilities to best suit differing customer mission needs. Further, affordable propulsion options will enable future satellites life-cycle propulsion solutions to perform collision avoidance, orbital trajectory change, and deorbiting manoeuvres to impede the escalation of the growing orbital debris problem.

CUA

Dr David Carroll
President
CU Aerospace, L.L.C.

EarthCARE: How do clouds and aerosols affect our climate?

After 20 years of thorough planning and preparation, the European Space Agency's (ESA) EarthCARE mission is now in flight and has already produced interesting data. We spoke to Mission Manager Björn Frommknecht to find out more

LAUNCHED in 2024, ESA's EarthCARE mission is designed to make global observations of clouds, aerosols and radiation and revolutionise our understanding of how these factors affect our climate. EarthCARE aims to quantify cloud-aerosol-radiation interactions so they may be included correctly in climate and numerical weather forecasting models. To achieve its objectives, the satellite has four instruments and measures globally the vertical structure and horizontal distribution of cloud and aerosol fields together with outgoing radiation.

The EarthCARE satellite successfully embarked on its journey into space on 29 May 2024, aboard a Falcon 9 rocket from the Vandenberg Space Force Base in California, USA. Following the commissioning phase, the first stage of data was released to the public in January 2025.

To learn more about the significance of the mission, its complexities, and the findings so far, Editor Georgie Purcell spoke to Björn Frommknecht, EarthCARE Mission Manager.

Can you briefly summarise the EarthCARE mission and its main objectives?

EarthCARE is a collaboration project between the European Space Agency (ESA) and the Japanese Aerospace Exploration Agency (JAXA). The main objective of the EarthCARE mission is contained in the name: it is an Earth observation mission, and the CARE stands for Cloud, Aerosol, and Radiation Explorer.

We are investigating the role of clouds and aerosols and their interaction with radiation from the Sun, as well as radiation from the Earth. To accomplish that, we fly four instruments – an atmospheric LiDAR (ATLID), a cloud profiling radar (CPR), a multispectral imager (MSI), and a broadband radiometer (BBR). One of the active sensors, the cloud radar, was gifted to us by JAXA. Collaboration between space agencies and the instruments is imperative to this mission.

EarthCARE is very special for a number of reasons. The mission was selected in 2004, so it has been a long time in the making. It is a really cutting-edge technology and, today, ESA is the only agency to fly such an atmospheric

ESA's EarthCARE satellite lifted off on a SpaceX Falcon 9 rocket from the Vandenberg Space Force Base in California, US, on 29 May

LiDAR in space. We are advanced in Europe, and that is something we can be really proud of. This achievement has only been possible because of the excellent EarthCARE team efforts, facing many challenges. I have never met a team with more dedication, integrity, and professionalism than the EarthCARE one. Of course, the collaboration with JAXA has also helped us significantly, as well as collaboration with European industry.

Over the years, the mission has faced critical delays caused by major events, such as the 2011 Tohoku earthquake and tsunami that destroyed a chip factory where part of the cloud profiling radar was built, delaying the project by several years. Another challenge was caused by the war in Ukraine, as the launch was originally planned to be on a Russian Soyuz rocket, which was thus no longer available. After an intense testing process, we instead launched on the SpaceX Falcon-9 rocket successfully.

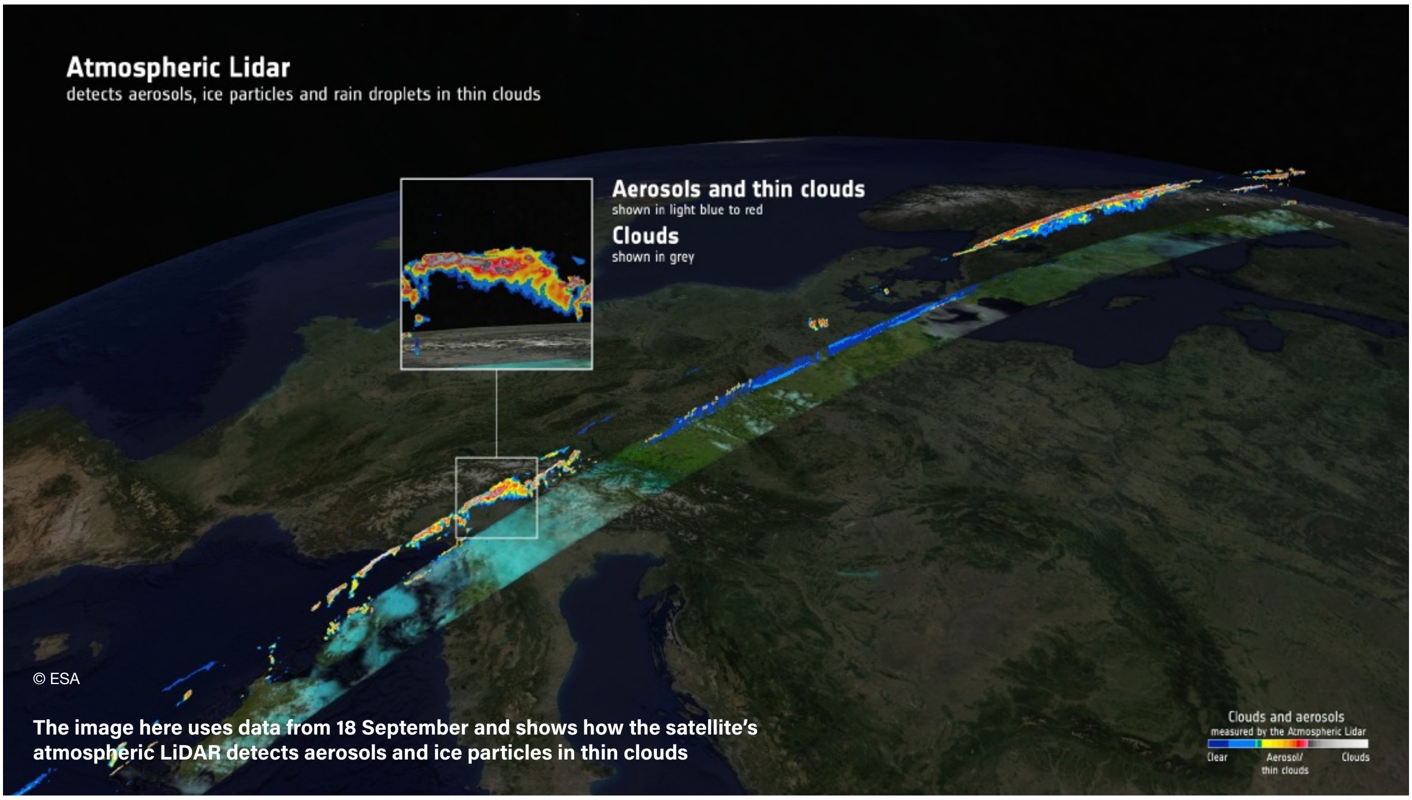
Why is it so important to shed light on the role that clouds and aerosols play in regulating Earth's climate?

For predictions of how the Earth's climate will evolve, you must make certain assumptions about cloud and aerosol behaviour, interaction with solar radiation and the thermal radiation of the Earth. However, there is still a lot of uncertainty surrounding this. Any improvement we can make in terms of this uncertainty has an immediate benefit on the climate model accuracy, especially for long-term predictions.

What is the significance of the four instruments used for the mission?

We have two active sensors, which emit radiation and can actively scan targets. The atmospheric LiDAR is like a laser pointer that emits UV light to measure distances and detects and profiles aerosols such as dust clouds, industrial pollution, sea water, and vapour. The profiling capability allows to discover their vertical structure.

The cloud profiling radar is similar, but for the clouds – it can detect clouds and see their inner structure. It can detect vertical motion, so you can see if things inside the cloud move away or towards the satellite. If it moves away, that is precipitation. This means that we can see where it rains inside a cloud. This is



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The image here uses data from 18 September and shows how the satellite's atmospheric LiDAR detects aerosols and ice particles in thin clouds

also very important information for numerical weather prediction.

To classify the profiles further, we have a multispectral imaging instrument. The width of the field of view of these active sensors, known as the swath, is relatively small (1km for the cloud profiling radar and 30m for the LiDAR). The imager, which has a swath of 150km, allows us to gather more contextual information.

The fourth instrument is the radiometer. At the very end of the processing chain, we expand the vertical profiles with the small footprint to a cube of 10x10km and 10km high and simulate what the radiation at the position of the satellite would be if our assumptions on how the clouds and aerosols interact with the radiation from the Sun and Earth were true. A major strength of EarthCARE is that these four sensors measure in the same place at the same time. Previous missions from other major space organisations, such as NASA's A-train, have used several sensors on different satellites, flying one after the other. However, as the weather changes very quickly, even just a few seconds can make a difference. We are the only ones that can measure all that in one instance, in one place. We then compare the radiation that is measured to the one we think should arrive at the position of the satellite. From this difference, we can then improve our understanding of how the clouds and aerosols interact with the radiation. This information can then be fed into both the weather and climate models.

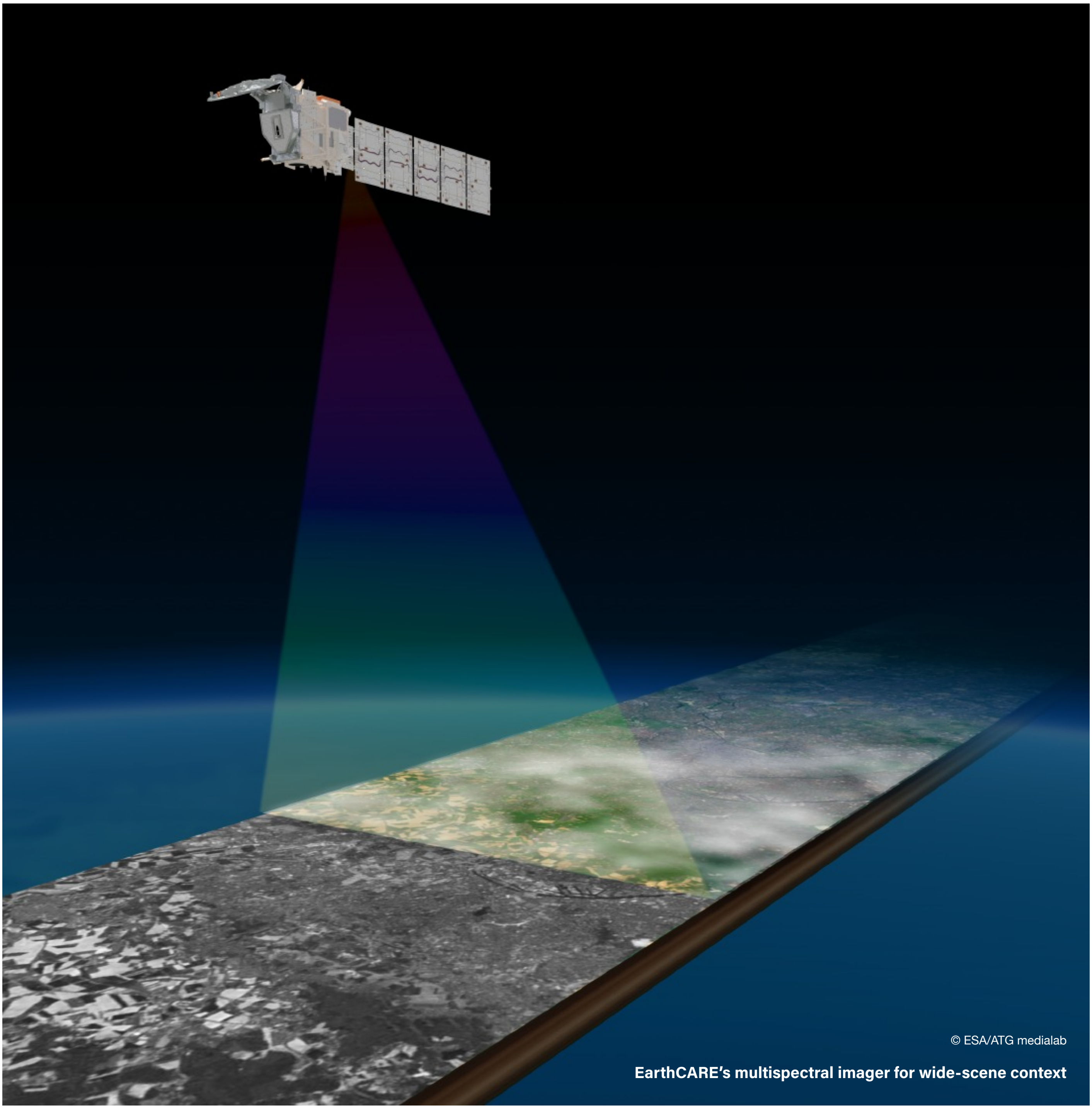
What have been the key findings from the mission so far?

In October last year, we published synergistic images. These demonstrate that, only by using both active sensors together, you can gain a full picture of clouds and aerosols, including their structure and the radiative part. Already, we have been able to see where the atmosphere heats or cools the Earth's climate. This is a preliminary result achieved just six months after launch, but the scientists are already very excited. This is a proof of concept that both the quality of the sensors is as expected and that there is a very high probability that we will get the scientific results we are aiming for. The public release of Level-1 data started in January, with Level-2 data following in March. Already, the results are very promising.

Have you encountered any difficulties since the launch? If so, how have they been overcome?

One of the main challenges directly after the launch was the preparation for our calibration and validation campaigns. We must externally validate and calibrate our measurements, which we can achieve by using planes that fly under the satellite. The satellite is much faster than a plane – it flies at 7km per second, whilst the plane flies at around 900km per hour. You must be in the right place at the right time. We had six major calibration campaigns, which were a collaboration of many European countries and the US. It was a monumental effort and a very nice example of collaboration.

These campaigns require careful and thorough planning. We had very well-defined target dates for the instruments to be ready to compare measurements. That was a major challenge. The preparatory phases for the radar, imager and radiometer were quite quick and we ran ahead of schedule, but the ATLID was ready with just one day margin. That was a very interesting and very intense experience. Again, it was an excellent collaboration between industry, ESA, and JAXA.



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EarthCARE's multispectral imager for wide-scene context

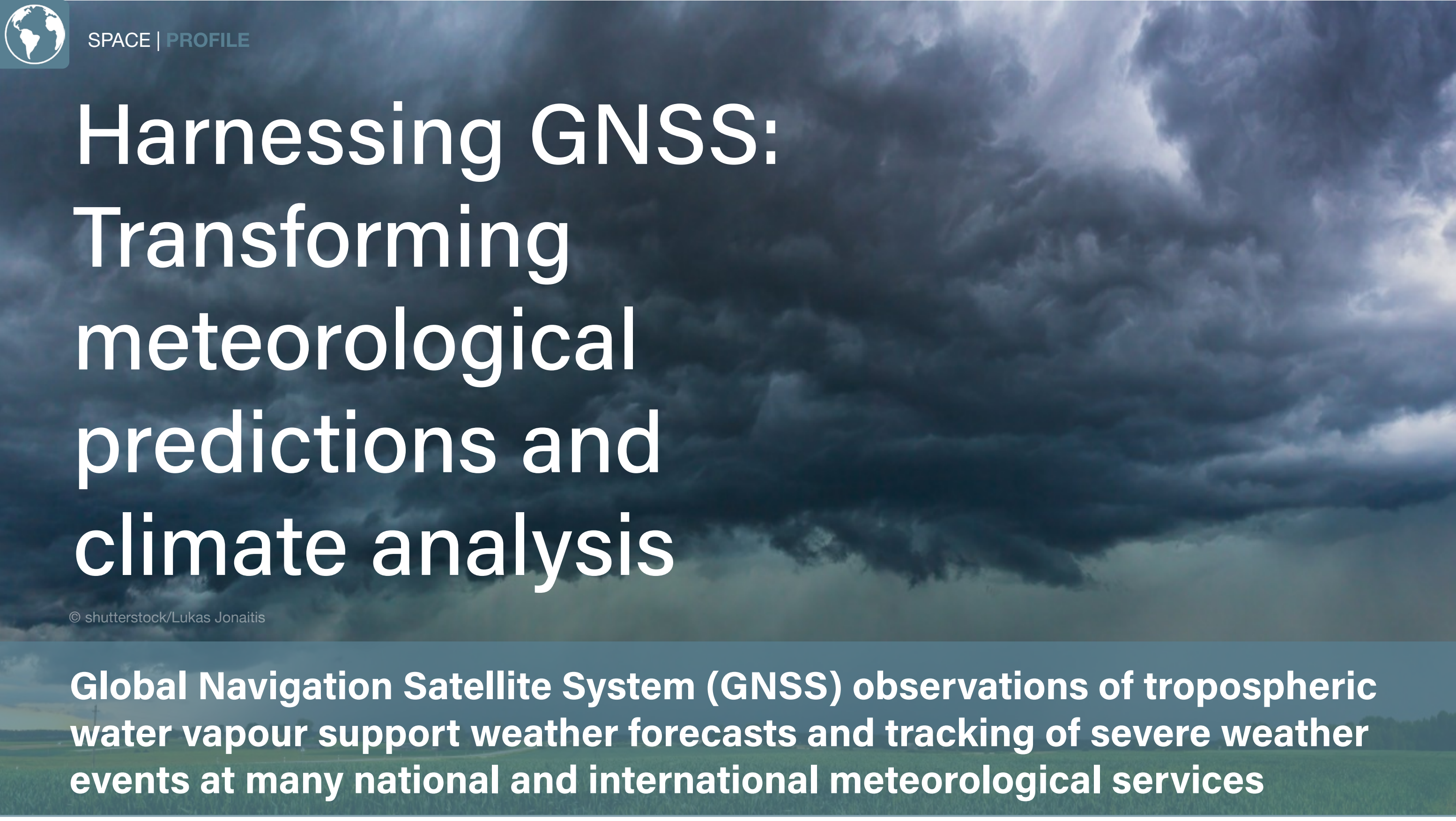
For the ATLID, certain steps must be followed to ensure that the light reflected by the aerosols is centred in the receiving telescope, thus maximising the measurement quality. This was successful and the instruments were so well calibrated that the on-ground and airborne equipment then had to be readjusted.

What's next for the mission? When is it expected to end?

The first batch of Level-2 data was released on 17 March. These are single-sensor and two-sensor products. The further you go down in the processing chain, the more sensors you combine to generate products. Before the end of the year, we will release the full synergistic products, with three- and four-sensor synergy. These are the next major milestones.

As we have to fly relatively low, meaning 400km in height, our life-limiting factor is the propellant usage. The nominal mission lifetime is three years from launch, which would bring us to May 2027, but we have indications that the lifetime could be extended, subject to our Member States' approval, which we hope to obtain.

Björn Frommknecht
EarthCARE Mission Manager
European Space Agency



Harnessing GNSS: Transforming meteorological predictions and climate analysis

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Global Navigation Satellite System (GNSS) observations of tropospheric water vapour support weather forecasts and tracking of severe weather events at many national and international meteorological services

GLOBAL NAVIGATION SATELLITE SYSTEMS (GNSS) have become ubiquitous in modern technology and data-driven societies and support many more applications beyond positioning, navigation, and timing (PNT) activities.

The role of GNSS in weather forecasting

As the GNSS signals travel from their mostly mid-Earth-orbiting (MEO) satellite transmitters to the receivers either on low-Earth-orbiting (LEO) satellites or terrestrial tracking stations, they experience various atmospheric effects. Tropospheric signal delays are among the most significant contributors to positioning errors in GNSS, exerting a crucial influence on accuracy once orbital and satellite and receiver clock uncertainties have been addressed.

When GNSS signals travel through the troposphere, roughly the lowest 15km of the atmosphere, they encounter varying levels of water vapour, temperature, and pressure that slow and bend their paths. This effect is typically decomposed into two components: a relatively stable hydrostatic delay linked to atmospheric pressure, and a highly variable wet delay driven by water vapour.

Advanced GNSS processing strategies rely on mapping functions to project these delays experienced in the line-of-sight between receiver and satellite into zenith delays, while stochastic models estimate wet delay fluctuations and horizontal gradients. By separating these terms and carefully tuning random walk or similar constraints, GNSS analyses can capture both gradual and rapid changes of water vapour in the atmosphere.

As atmospheric water vapour is the dominant natural Greenhouse gas, it is a key parameter for studying climatic changes, but as it is also a determining factor for weather, precipitation in particular, water vapour estimates from GNSS play a key role in modern weather forecasting. GNSS-derived atmospheric products, such as Zenith Total Delay or Precipitable Water Vapour estimates, help pinpoint the time and location of precipitation when assimilated into numerical weather prediction (NWP) models. This leads to meteorologists being better able to anticipate storms, tropical cyclone behaviour, or heavy rainfall, and ultimately refine severe weather warnings. Because water vapour plays a direct role in precipitation processes, timely GNSS-derived atmospheric products often lead to more accurate rainfall predictions, local wind forecasts, and storm timings. Moreover, with densely distributed GNSS networks it becomes possible to enable tomography-like methods, producing three-dimensional reconstructions of water vapour fields. These are particularly interesting for studying some of the physical processes in storms.

Applications in climate research and long-term monitoring

Beyond operational meteorology, GNSS plays an increasingly important role in climate research. Long-term records of tropospheric delays provide high-resolution datasets that capture gradual shifts in moisture distribution, informing studies of extreme precipitation, changes in cloud cover, temperature, and moisture feedbacks. These records are especially valuable as they offer continuous, round-the-clock observations, complementing other observation systems such as radiosondes or satellite remote sensing, which may not be as frequent or spatially dense.

Recognising the need for such long-term tracking, the Intergovernmental Panel on Climate Change (IPCC) highlights the importance of consistent observations of atmospheric water vapour to understand climate variability and change.

The era of multiple GNSS constellations

By employing the observations from multiple GNSS constellations: GPS, GLONASS, Galileo, BeiDou, QZSS and IRNSS, analysts achieve better spatial coverage and more frequent sampling, improving the resolution of atmospheric estimates. These insights help identify localised phenomena like convective cells or sea breeze fronts that might otherwise be missed by conventional meteorological observations. Moreover, in areas with sparse weather station networks, GNSS adds a critical low-cost supplement, boosting our understanding of short-lived weather extremes and long-term climate variations.

Navigating complexity

Despite these advances, tropospheric modelling remains complex due to the dynamic nature of moisture transport and the rapid onset of convective events. Stochastic constraints, such as random walk noise models for wet delay, may not always align with real atmospheric variability, leading to underfitting during sudden moisture surges or overfitting in more stable conditions. Ongoing research is exploring adaptive constraints that shift according to near-real-time meteorological indicators, thereby capturing abrupt gradients more faithfully.

Overall, tropospheric delays remain integral to GNSS accuracy and serve as a gateway to broader atmospheric applications. Continuous improvements in modelling these delays, employing multi-constellation data, and adapting to near-real-time forecasts have driven major strides in meteorological and climate-focused research. High-frequency products benefit users who require quick, precise locations – such as aviation, disaster response, and data assimilation in numerical weather models – while long-term records track how water vapour patterns evolve across seasons, years, and decades. As methods continue to refine tropospheric variability parametrisation, GNSS stands poised to enhance both real-time navigation and the long-term monitoring of Earth's changing climate.

GNSS meteorology by the GGE

The GGE boasts an established capability in the processing of GNSS observations for the retrieval of atmospheric water vapour for operational assimilation into NWP models, special studies of severe weather events, and long-term monitoring.

For near-real-time (NRT) applications, i.e., operational assimilation, processing happens within minutes to hours of data capture, placing special emphasis on timeliness and reliability. GNSS data can be collected from regional to global station networks in minutes and then processed, providing updated solutions every 30 or 60 minutes with five to 15 minutes delay estimates.

In fast-moving scenarios like navigation for ground or airborne vehicles, but also storm tracking, the GNSS-derived atmospheric products may be updated at high frequency in real-time, i.e., from seconds to a few minutes. Such frequent updates, often used in weather now-casting, are essential because the water vapour distribution, temperature profiles, and local weather patterns can shift drastically, especially during convective storm developments.

For long-term monitoring applications it is the consistency and homogeneity of the coordinate reference frames, GNSS satellite and bias products, and processing strategy and error mitigation modelling that are of highest concern, as any changes in these can make the derived climate record unreliable. To prevent erroneous interpretations, careful homogenisation of these records is needed as with most other climatological data.

The GGE offers:

- GNSS data processing expertise and capabilities for meteorological real-time, near-real-time and long-term atmospheric product retrievals
- Consultancy for atmospheric applications of GNSS in real-time, near-real-time and long-term monitoring
- Consultancy on GNSS ground-station installations and data handling solutions for atmospheric and other monitoring applications
- High-level expertise and capabilities on GNSS-derived product assimilations into numerical weather prediction models, e.g., Weather Research & Forecasting Model (WRF) and WRF Data Assimilation (WRFDA)
- High-level expertise in geodetic and geospatial technologies and associated data analyses, as well as their applications

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Félicia Norma Rebecca Teferle
Full Professor
Geodesy and Geospatial Engineering
Department of Engineering
Faculty of Science, Technology and Medicine
University of Luxembourg
+352 4666 44 5790

Every drop counts: How space tech innovations are revolutionising Earth observation

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With new applications and a project backed by the European Space Agency, RSS-Hydro is poised to revolutionise the field of Earth observation

IMAGINE a world where floods are detected and alerts are sent with pinpoint accuracy weeks in advance, where urban development is meticulously planned based on real-time environmental data, and where the impact of climate change is tracked with unprecedented detail. This is not science fiction; it's the rapidly evolving reality powered by groundbreaking innovations in space platforms, satellite communications (satcom), and Earth observation (EO) missions. Companies like Luxembourg-based RSS-Hydro, with cutting-edge applications like FloodSENS and its new project CeDaRS, supported by the European Space Agency (ESA), are at the forefront of this revolution, demonstrating the transformative potential of an 'all-in-space' approach to understanding and managing our planet.

For decades, Earth observation from space has provided invaluable data for weather forecasting, environmental monitoring, and disaster response. However, recent technological leaps are ushering in a new era of capabilities, making EO more precise, timely, and accessible than ever before.

The dawn of advanced space platforms

The traditional model of large, monolithic satellites is being disrupted by the rise of smaller, more agile platforms. CubeSats and SmallSats, often deployed in constellations, offer increased revisit times, meaning they can image the same area much more frequently. This high temporal resolution is crucial for dynamic events like flood monitoring, where near real-time data is

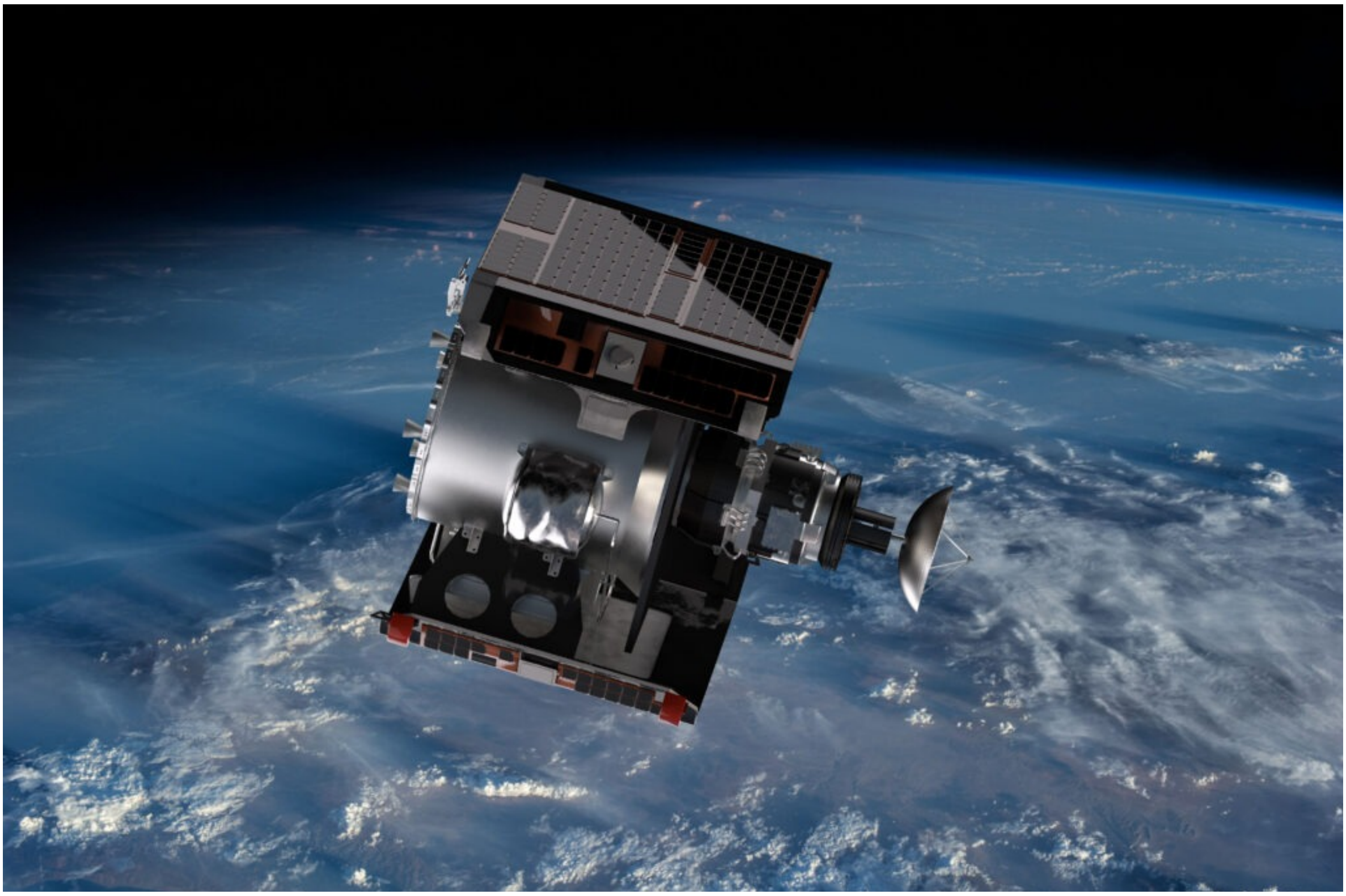


Illustration of D-Orbit's ION carrier: Infrastructure-as-a-service

essential for effective response. Furthermore, these smaller satellites can be launched more affordably, democratising access to space-based data collection. Companies are also exploring innovative platform designs, including cloud computing infrastructure and modular systems, allowing for greater flexibility and adaptability in orbit.

Satcom supercharging data delivery

The sheer volume of data generated by advanced EO missions demands robust and high-speed communication links. Advancements in satcom are meeting this challenge. Laser communication promises significantly higher data transfer rates compared to traditional radio frequencies, enabling the downlink of massive datasets in a fraction of the time. Inter-satellite links, where satellites communicate directly with each other, create resilient networks that can bypass terrestrial infrastructure, ensuring data reaches users even in remote or disaster-stricken areas. The development of software-defined satellites allows for on-orbit reconfiguration of communication payloads, providing the flexibility to adapt to changing data demands and user needs.

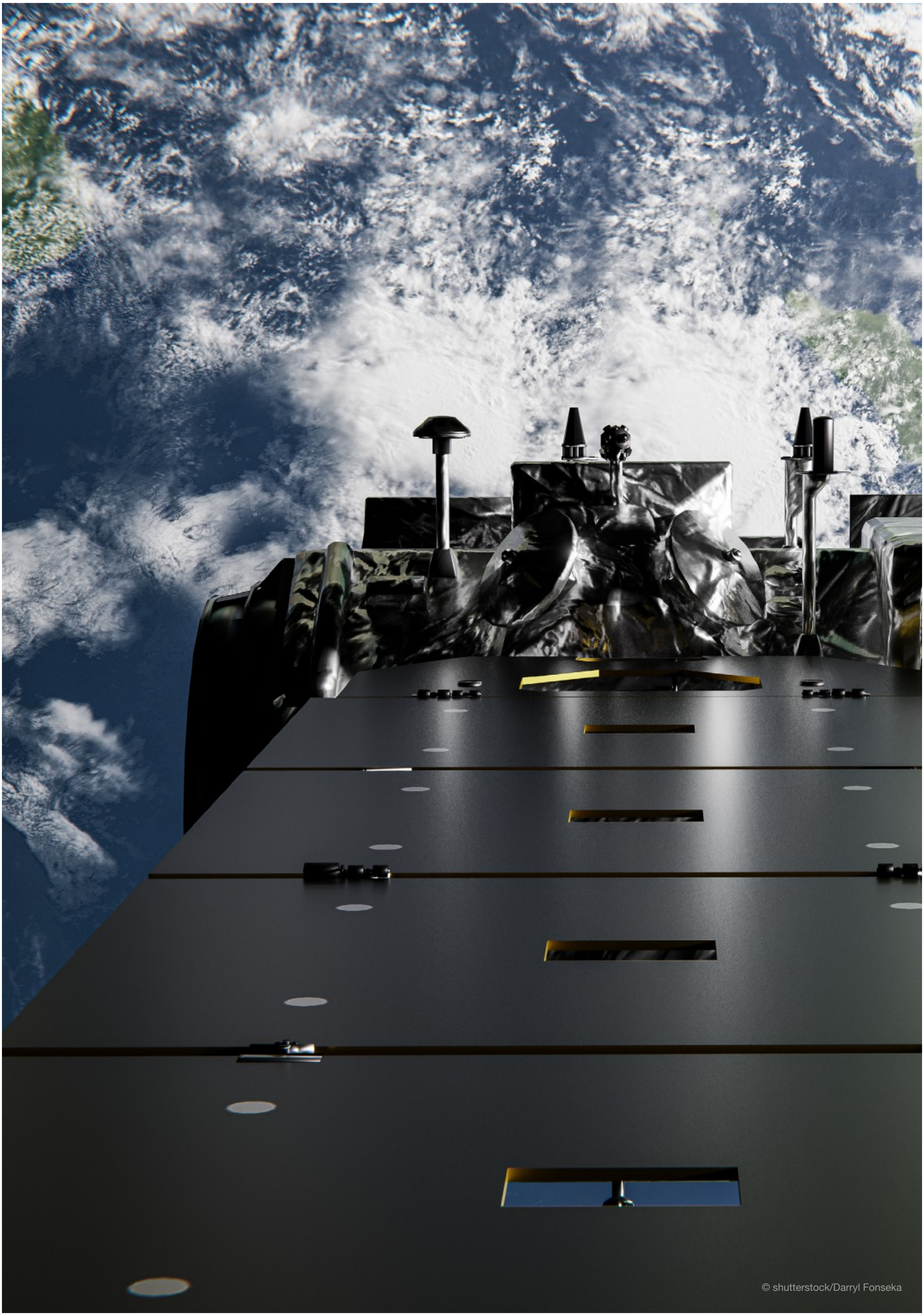
Earth observation missions: A new level of detail

The EO missions themselves are undergoing a radical transformation. Hyperspectral imaging, capturing data across hundreds of narrow spectral bands, provides a far more detailed 'fingerprint' of the Earth's surface, enabling precise identification of vegetation types, soil composition, and even water quality. Synthetic aperture radar (SAR) technology and other microwave systems, a cornerstone of many flood mapping applications, can penetrate clouds and darkness, providing critical information during severe weather events when optical sensors are limited. The integration of artificial intelligence (AI) and machine learning (ML) on board satellites allows for real-time data processing and analysis, extracting actionable insights before the data even reaches the ground. This on-orbit intelligence is crucial for rapid disaster assessment and environmental change detection.

RSS-Hydro: Pioneering integrated space solutions

RSS-Hydro exemplifies the power of these integrated space solutions. It is developing an all-in-space service solution, called FloodPin, that leverages satellite imagery, combined with hydrological know-how and AI, to provide accurate and timely flood insights and impact assessments. This capability is a gamechanger for disaster preparedness and response, allowing authorities and communities to take proactive measures to mitigate damage and save lives.

Furthermore, their project CeDaRS (Comprehensive space-tech powered Disaster Response Solution), supported by ESA, highlights the importance of advanced data processing and analytics. Extracting meaningful information from the vast amounts of EO data requires sophisticated algorithms and infrastructure.



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CeDaRS, in this context, represents the development of tools and techniques to transform raw satellite data into rapid and actionable intelligence for various applications. For RSS-Hydro, the focus is on flood detection and alerting, but CeDaRS will pave the way for an all-in-space EO solution infrastructure to enable smarter, more secure, and more sustainable services for a vast number of application domains, such as infrastructure monitoring, disaster and environmental management, urban planning and, more generally, for civil security,

Focusing on disaster management, the innovation of CeDaRS lies in an all-in-space processing architecture for rapid disaster intelligence. By deploying advanced algorithms directly in orbit on satellite infrastructure, it drastically reduces the latency in generating and delivering critical information following a disaster. This approach bypasses traditional ground-based processing bottlenecks, enabling near real-time insights – such as event mapping and initial impact assessments – to reach stakeholders within minutes. This speed and efficiency are crucial for timely and effective emergency response across various disaster types.

The broader impact: A smarter, more sustainable future

The convergence of advanced space platforms, high-throughput satcom, and sophisticated EO missions is creating a paradigm shift in how we interact with our planet. This 'all-in-space' approach offers numerous benefits:

- Enhanced disaster management: Early warning systems for floods, wildfires, and other disasters become more accurate and timely, allowing for better preparedness and response.
- Urban planning and infrastructure management: Real-time data on urban sprawl, traffic patterns, and infrastructure health allows for smarter and more sustainable development.
- Environmental monitoring: Tracking deforestation, pollution, heatwave impacts, and other environmental changes with unprecedented detail enables more effective conservation efforts and policy decisions.
- Climate change monitoring: Comprehensive and continuous Earth observation provides crucial data for understanding the complex processes driving climate change and for monitoring the effectiveness of mitigation strategies.

Looking ahead

The synergy of advanced space platforms, high-throughput satellite communication, and sophisticated EO missions is driving a paradigm shift, leading to new service architectures and business models akin to cloud service provision. This convergence is fundamentally changing how we interact with our planet.

The field of space-based Earth observation is poised for even more dramatic advancements. The integration of data from multiple satellite constellations, combined with *in-situ* sensors and ground-based information, will provide an even more holistic view of our planet. The increasing use of AI and cloud computing will further enhance data processing and accessibility, making EO insights available to a wider range of users.

As companies like RSS-Hydro continue to innovate and push the boundaries of what's possible, the 'all-in-space' vision of a comprehensively monitored and understood Earth is rapidly becoming a reality. This new era of Earth observation promises a future where we are better equipped to manage our planet's resources, respond to challenges, and build a more sustainable and resilient world for all.

RSS-Hydro

Guy Schumann
CEO & Founder
RSS-Hydro

The Project: CeDaRS

RRS-Hydro

Contact Details
Guy Schumann
Founder & CEO
+352 621 136 249
gschumann@rss-hydro.lu

CeDaRS: Revolutionising flood response with all-in-space AI and satellite constellations

A new era in disaster management is dawning with CeDaRS, an ESA-backed project led by RSS-Hydro, transforming flood response with unparalleled speed

In an era of increasing flood risks, advanced, real-time monitoring is crucial. Countries and global communities need precise, rapid flood insights for effective response. Enter CeDaRS (Comprehensive space-tech powered Disaster Response Solution) – an ambitious project backed by the Luxembourg Space Agency (LSA) and the European Space Agency (ESA) that is set to revolutionise how we perceive and react to disasters, particularly floods. CeDaRS is designed to establish a cutting-edge 'all-in-space' Earth observation solution infrastructure, transforming raw satellite data into actionable intelligence for a vast array of applications, with a primary focus on rapid disaster intelligence.

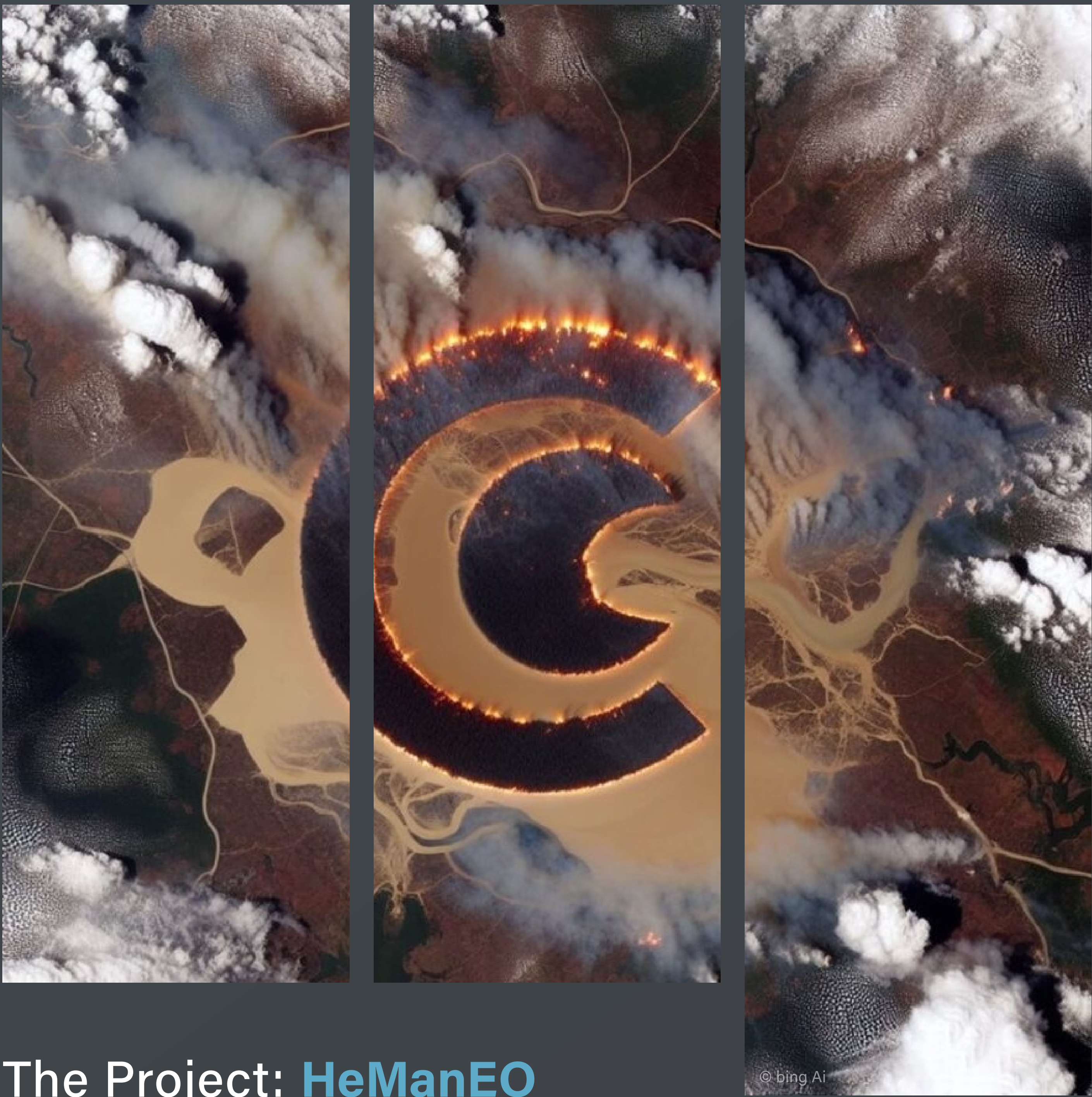
Delivering critical intelligence to aid with disaster management

At the heart of CeDaRS's flood monitoring capabilities lies RSS-Hydro's expertise, building upon its proven FloodSENS algorithm and the FloodPin service, currently under development. A key focus of CeDaRS is to develop and test the approach for all-in-space processing of FloodSENS. This involves leveraging a cutting-edge space infrastructure that includes a constellation of high-resolution satellites, providing frequent revisits and detailed imagery, as well as advanced space cloud infrastructure.

This on-orbit processing capability for FloodSENS, a highly advanced machine learning algorithm, is instrumental in rapidly and accurately detecting flooded areas from satellite imagery. Its ability to reconstruct flood extents, even under challenging conditions like partial cloud cover, significantly enhances the reliability of flood mapping. Following this initial processing, CeDaRS will include a sophisticated post-processor to further refine the data and derive actionable insights specifically tailored for the FloodPin service.

The ultimate goal is to get that critical intelligence down to any device or platform within a latency that is acceptable for emergency response and search and rescue operations. This means delivering vital flood information, such as affected areas and potential impact, with unprecedented speed directly to first responders, disaster management agencies, and humanitarian organisations in the field. To further increase the reliability and robustness of this service, RSS-Hydro is actively collaborating with leading universities, research and technology organisations as well as a diversity of technology companies of various sizes.

This ongoing research focuses on investigating a truly multi-sensor, multi-mission flood mapping approach, fusing data from various satellite types and missions. This commitment to collaborative research underscores CeDaRS's dedication to pushing the boundaries of flood science and providing the most accurate, resilient, and rapidly deployable solutions for global flood preparedness and response. CeDaRS promises a future where disaster response is not just reactive, but proactively informed and strategically executed, saving lives and protecting livelihoods.



The Project: HeManEO

RRS-Hydro

Contact Details
Guy Schumann
Founder & CEO
+352 621 136 249
gschumann@rss-hydro.lu

HeManEO: RSS-Hydro-led ESA project ensures trustworthy Earth observation for business

RSS-Hydro's HeManEO, supported by ESA, is transforming satellite data into secure, auditable environmental intelligence, crucial for businesses navigating complex information compliance landscapes and risk management

In an increasingly data-driven world, the demand for trustworthy and compliant environmental intelligence is paramount, especially for sectors navigating evolving environmental, social, and governance (ESG) regulations. This critical need is addressed by HeManEO (Health Management with Earth Observation), an innovative project led by RSS-Hydro and supported by the Luxembourg Space Agency (LSA) and the European Space Agency (ESA), which aims to transform raw Earth observation (EO) data into highly reliable and legally compliant products for a diverse range of business clients.

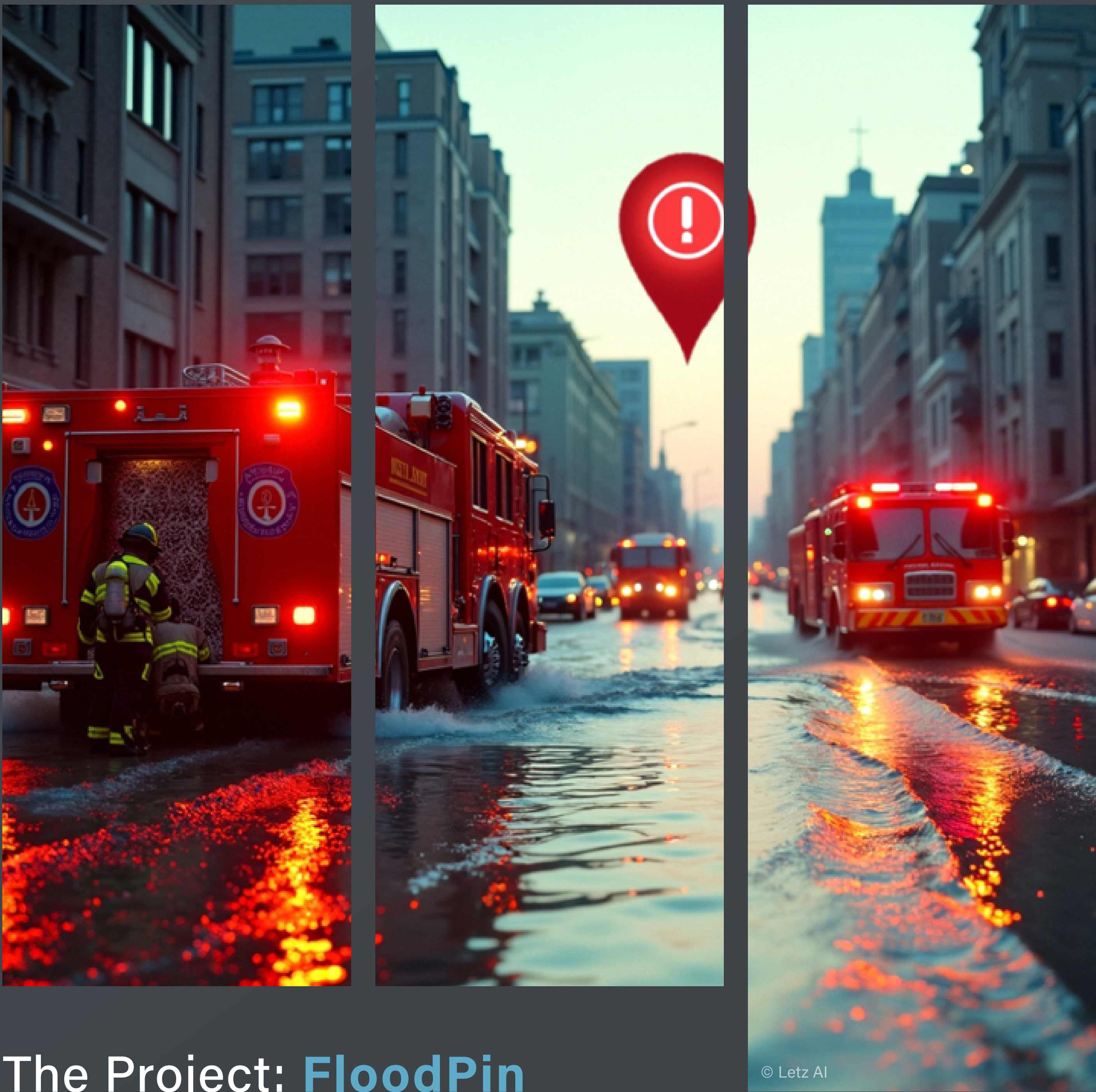
Highly reliable EO data for businesses

HeManEO targets major corporations, the financial sector, and risk management organisations as well as the humanitarian sector, offering authenticated data and sources for analytical applications focused on risk assessment, disaster prevention, and robust ESG measurement and reporting, through data and information health monitoring.

At its core, HeManEO leverages RSS-Hydro's proven in-house algorithms and applications, including the advanced EO algorithms FloodSENS and FireSENS. FloodSENS, also central to RSS-Hydro's FloodPin and ESA CeDaRS projects, is instrumental in rapidly and accurately detecting flooded areas from satellite imagery, even under challenging conditions. Similarly, FireSENS provides crucial insights into fire events. RSS-Hydro manages the block of the HeManEO architecture, where these algorithms process satellite mission EO data on premise or a cloud platform to produce detailed GIS map layers for both flood and fire events.

A key differentiator for HeManEO is its integration with a Digital Authentication and Traceability Service (DATS) engine, provided by RSS-Hydro's technology development partners. This integration ensures end-to-end authentication, providing unparalleled data security, compliance, immutability, and non-repudiation. Critically, in addition to data source verification and algorithm workflow monitoring, this includes robust cybersecurity measures through comprehensive network and computing resources monitoring, safeguarding the integrity of the information throughout its lifecycle.

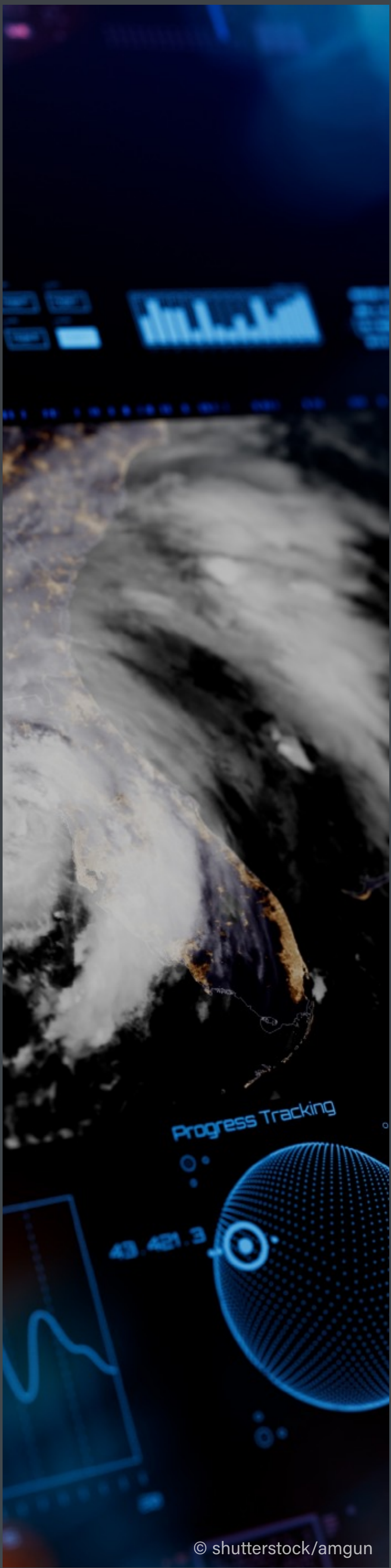
This level of trustworthiness is particularly vital for sectors like re-insurance, which demand EO applications that are not only technically sound but also legally compliant for critical risk assessment and claims processing. Through HeManEO, RSS-Hydro and ESA are setting a new standard for accessible, reliable, and auditable environmental intelligence, empowering businesses to make more informed decisions in an unpredictable world.



The Project: FloodPin

RRS-Hydro

Contact Details
Guy Schumann
Founder & CEO
+352 621 136 249
gschumann@rss-hydro.lu



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Near real-time flood insights: RSS-Hydro's FloodPin leverages AI and multi-sensor satellites

In an era of increasing flood risks, advanced, real-time monitoring is crucial. Countries and global communities need precise, rapid flood insights for effective response

RSS-Hydro's FloodPin service marks a pivotal advancement in flood monitoring and rapid impact assessment, seamlessly integrating cutting-edge space technology with sophisticated artificial intelligence (AI). At its core lies FloodSENS, a highly advanced machine learning algorithm meticulously trained on diverse flood events and locations globally. This powerful algorithm harnesses the immense potential of satellite imagery and hydrological expertise to generate accurate and timely flood insights.

All-in-space solution for flood management

What truly sets FloodPin apart is its remarkable flexibility and efficiency. The service will operate as a purely 'all-in-space' solution, leveraging direct satellite-to-satellite communication and on-board processing capabilities to drastically reduce the latency in delivering critical information. This means that, within minutes of a flood event, stakeholders can receive near real-time insights, enabling swift event mapping and initial impact assessments. This all-in-space approach is particularly vital for wide-area monitoring and rapid response in remote or inaccessible regions, bypassing traditional ground-based processing bottlenecks.

However, FloodPin's capabilities extend beyond this. It can also integrate satellite data and other auxiliary data on the ground, offering enhanced localised detail and precision for specific areas of interest. This hybrid approach allows for a comprehensive understanding of flood dynamics, combining broad-scale overviews with granular insights, thereby catering to a wider range of user needs – from national disaster management agencies to local community responders and even the insurance sector for detailed impact monitoring.

To further increase the reliability and robustness of the FloodPin service, RSS-Hydro is actively collaborating with leading universities and other research organisations as well as big and small tech companies. This ongoing research focuses on investigating a truly multi-sensor, multi-mission flood mapping approach. By fusing data from various satellite types (e.g., optical, radar, microwave) and missions, RSS-Hydro aims to overcome the limitations of individual sensors and ensure continuous, high-fidelity flood monitoring even under challenging conditions like persistent cloud cover or dense vegetation. This commitment to collaborative research underscores RSS-Hydro's dedication to pushing the boundaries of flood science and providing the most accurate and resilient solutions for global flood preparedness and response.

SDGs-EYES - Seeing change: How satellite data elevates SDG monitoring

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SDGs-EYES turns satellite data into smart tools to boost Europe's progress on sustainability goals

THE SDGs-EYES project (Sustainable Development Goals – Enhanced monitoring through the family of Copernicus services) is a Horizon Europe research and innovation action (RIA) designed to strengthen Europe's capacity to monitor SDGs using Copernicus data. By developing a portfolio of decision-support tools for SDG indicators monitoring, SDGs-EYES aligns with the EU Green Deal priorities and promotes an inter-sectoral approach to sustainability monitoring, directly supporting climate-action objectives with satellite-driven solutions.

Seven services have been developed under the SDGs-EYES umbrella to demonstrate how its methodology and tools can enhance reporting of SDG 13 (Climate Action), SDG 14 (Life below Water) and SDG 15 (Life on Land). The SDGs-EYEs services have been co-designed with national statistical offices, environmental agencies, and forest managers, thus bringing researchers and community experts together with different stakeholder communities.

SDGs-EYES operates within the framework established by the United Nations and national statistical systems for SDG monitoring.

The vision in action

To translate its overarching ambition into tangible outcomes, SDGs-EYES focuses on interlinked objectives:

- **Enhancing access and usability of Earth observation data**
  SDGs-EYES has built a scientific and technological framework to generate robust and accurate data to monitor indicators. By aggregating and processing data from Copernicus's six core services, along with space-based and *in situ* sources, the project makes Earth observation (EO) data more accessible, usable and actionable.

- **Improving the quality of SDG indicators**
  The project demonstrates Copernicus-enhanced measurement for seven indicators across three SDG goals (SDGs 13, 14 and 15).

- **Building stakeholder capacity for societal impact**
  To maximise relevance and usability, SDGs-EYES delivers service-oriented data products co-designed with end-users, including public authorities, researchers, and environmental agencies. This collaborative approach ensures the tools are fit for purpose in real-world decision-making and reporting contexts.

These objectives converge to realise the project's overarching ambition: to develop user-friendly, precise and efficient tools that enhance the monitoring, reporting and use of SDG indicators across Europe.

Building the blocks: The SDGs-EYES framework

SDGs-EYES brought research and industry experts together with stakeholders from various communities to co-develop a scientific, technological and user engagement framework for monitoring SDGs indicators.

SDGs-EYES methods and tools have been designed to be:

- User-driven – over a series of workshops and consultations, end-users provided feedback, thus ensuring the maximisation of their uptake and impact in the methodology design.

- Science-driven – bringing together already existing data and enriching them using other sources from EO and Copernicus leads to a sound scientific and technological framework to enhance indicators monitoring and reporting.

The structure of the SDGs-EYES project is provided in Fig. 1, and it can be summarised in the following main components:

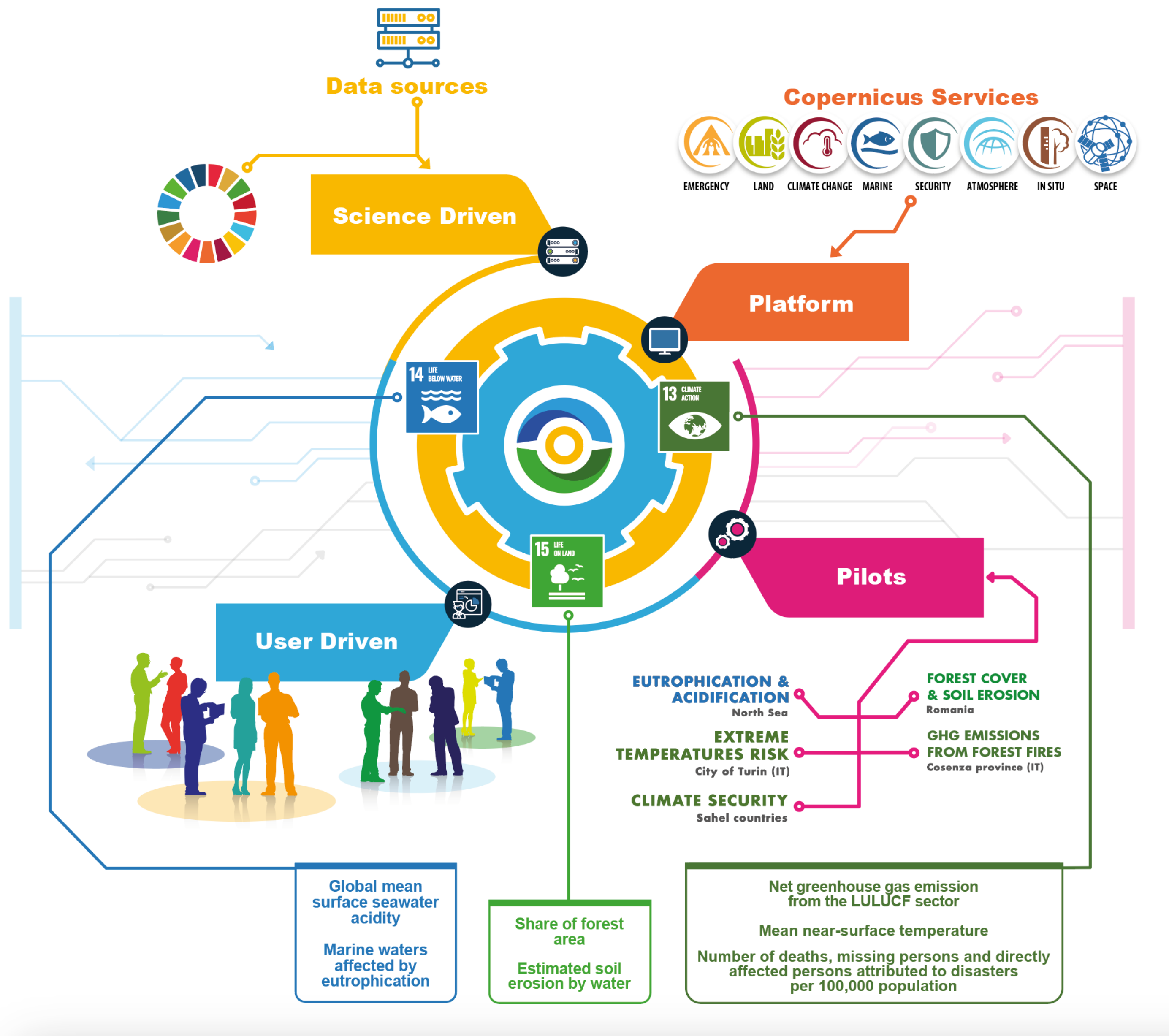

Fig. 1: The SDGs-EYES project structure

- **Data integration platform** - A platform for the aggregation and processing of multiple EO data sources, including satellite, *in situ*, numerical models and data analytics.

- **Pilots demonstration** - Five pilot projects have been implemented to demonstrate, evaluate, and assess the services developed in real-world contexts.

The platform

The platform is cloud-based, cost-effective, and features an intuitive interface, making it accessible even to smaller administrations. It offers a faster and potentially more reliable alternative to traditional national inventories, which typically report SDGs indicators annually.

The pilots

SDGs-EYES solutions are demonstrated through four EU and one non-EU pilot areas. The location of the pilots is shown in Fig. 2.

Pilot 1 - Greenhouse gases (GHGs) emissions from forest fires

This pilot advances SDG monitoring, reporting, and accounting for GHGs emissions resulting from forest fires. Leveraging Copernicus burnt-area, biomass and scorch-height products – alongside *in situ* calibration data – it produces high-precision emission maps to support SDG 13 reporting. It highlights the importance of closer collaboration between research institutions, national statistical offices, forestry experts, private companies, and policymakers to improve GHGs emissions tracking across the EU.

Pilot 2 - Extreme temperature risks in urban areas

Focusing on the urban heat-health nexus, this pilot develops a Copernicus-based tool that maps climate hazards alongside demographic, socio-economic, health, and built environment data. The integrated risk assessment informs planning and response strategies for extreme temperature events in urban areas, directly underpinning SDG 13 resilience efforts.

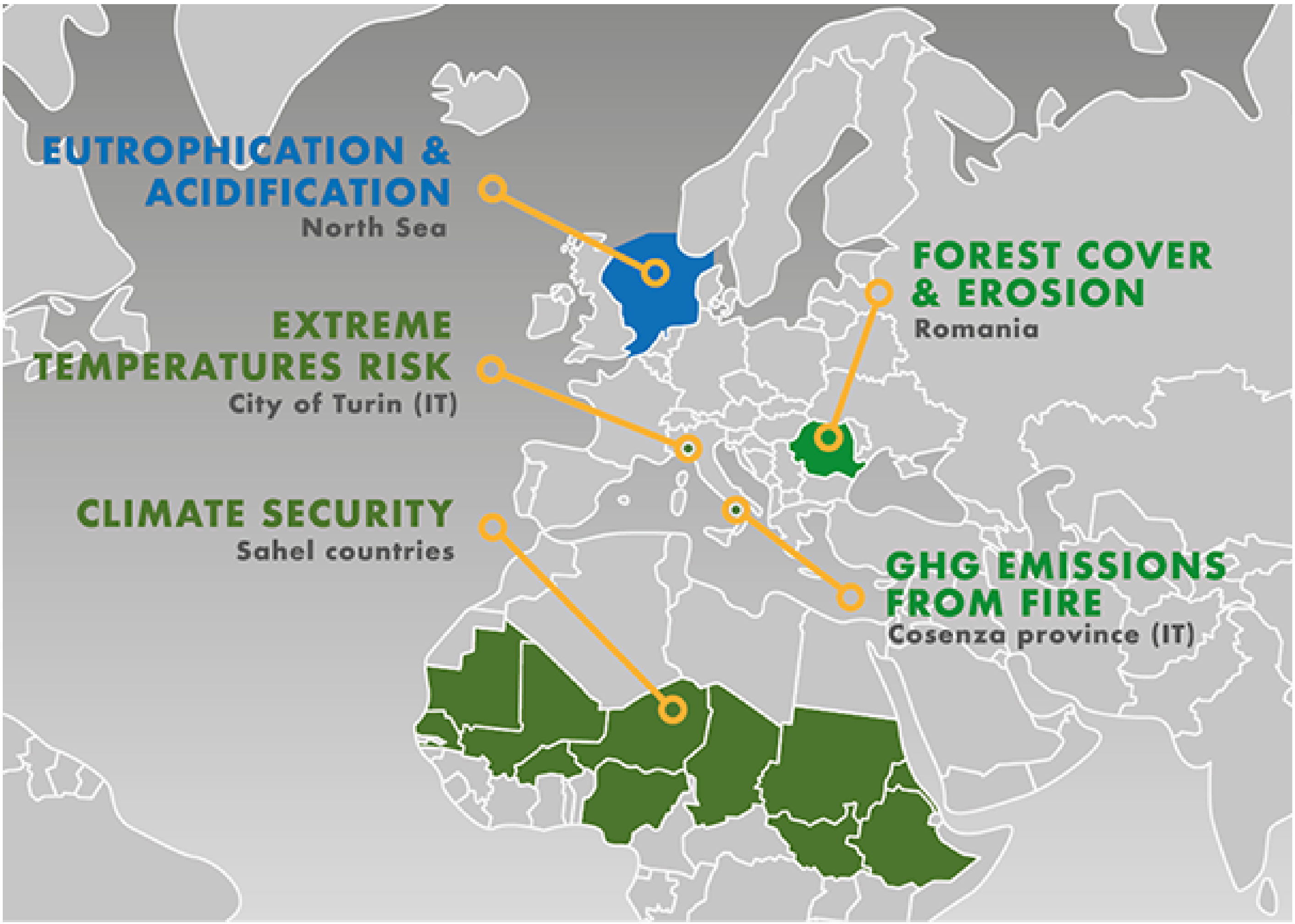

Fig. 2: Pilot location

Pilot 3 - Eutrophication and acidification in the North Sea

Focusing on marine SDGs, this pilot exploits Copernicus Marine Service datasets – together with satellite, *in situ* and model outputs – to generate high-resolution maps of seawater acidity and nutrient-driven eutrophication. The resulting indicators enhance SDG 14 monitoring, guiding policy on coastal eutrophication, acidification hotspots and sustainable marine resource management.

Pilot 4 - Forest cover and erosion

Employing time-series Sentinel imagery and machine-learning classifiers, this pilot quantifies forest cover dynamics and pinpoints soil-erosion risk zones. By automating the detection of deforestation, degradation and erosion hotspots, it strengthens SDG 15 indicators on terrestrial ecosystem health and land-use sustainability.

Pilot 5 - Climate security in the Sahel

This pilot focuses on assessing disaster impacts, including affected buildings and communities in the Sahel region (part of sub-Saharan Africa), to support climate security and disaster resilience. These datasets feed SDG 13.1.1 ('affected persons per 100,000') and inform resilience and security policies for vulnerable Sahelian populations.

Actionable insights: The SDGs-EYES service framework

The SDGs-EYES project has developed a suite of advanced, Earth observation-driven services, each designed to enhance the monitoring and reporting of specific SDG indicators across climate, marine, and terrestrial domains.

1. Greenhouse gas emissions from forest fires (EFF)

This service automates near-real-time estimation of GHGs emissions (CO_2, CH_4 and others) from forest fires. It uses Copernicus burnt-area, biomass, and scorch-height products, calibrated with *in situ* data, to produce high-resolution emission maps. This advances national reporting under IPCC and UNFCCC[1] Guidelines, enhancing EU-wide data compiled by the European Environment Agency.

Target indicator: EU SDG indicator 13.21 'Net greenhouse gas emissions of the land use, land use change and forestry (LULUCF) sector' and UN indicator 13.2.2 'Total greenhouse gas emissions per year.'

2. Heat-health nexus risk (HHR) in urban areas

This service integrates climate hazard metrics (temperature, humidity, precipitation), demographic, socio-economic, health, and built-environment data into a Copernicus-based tool. The result is high-resolution risk maps that support urban resilience and health-focused adaptation strategies.

Target indicator: it advances the old EU SDG indicator 'mean near-surface temperature deviation' by developing a comprehensive heat-health risk indicator.

3. Affected buildings and people (ABP)
This innovative EO-based service quantifies disaster impacts, such as damaged structures and affected populations, following floods or extreme events in the Sahel. It fills a crucial data gap, supporting resilience policy in fragile regions by translating EO data into humanitarian-relevant indicators.

Target Indicator: UN 13.1.1 'Number of deaths, missing persons, directly affected persons per 100,000.'

4. Sea surface acidity (SSA)
Using Copernicus Marine Service data along with satellite and *in situ* systems, this indicator tracks pH levels in the North Sea. It enables monitoring of ocean acidification trends, which is critical for marine ecosystem conservation.

Target indicator: EU definition 'Global mean seawater surface acidity,' reflects the UN indicator 14.3.1 'Average marine acidity (pH) measured at agreed suite of representative sampling stations.'

5. Marine waters eutrophication
This service maps coastal eutrophic zones within the EU's Exclusive Economic Zone (EEZ) using remote sensing and oceanographic models. Outputs include the total area (km^2) and proportion (%) of eutrophic waters to inform marine ecosystem health strategies.

Target indicators: based on the EU definition 'Marine waters affected by eutrophication,' also reflects the UN indicator 14.1.1(a) 'Index of coastal eutrophication.'

6. Forest cover change (FCC)
By leveraging high-resolution Sentinel imagery and change-detection algorithms, this service identifies not only forest extent but also alterations in forest cover, including deforestation, afforestation, and degradation hotspots.

Target indicator: recalling the EU definition 'Share of forest area,' is also UN indicator 15.1.1 'Forest area as a proportion of total land area.'

7. Soil erosion by water (SEW)
Using satellite data, terrain models, and hydrological analyses, this service maps areas affected by severe water-driven soil erosion. This feeds into broader assessments of land degradation and sustainable land management policies.

Target indicator – recalling the EU definition 'Estimated soil erosion by water - area affected by severe erosion rate,' UN indicator 15.3.1 'Proportion of land that is degraded over total land area.'

Key takeaways

Co-design approach
SDGs-EYES services have been developed through a sustained co-design process, ensuring they respond directly to the needs of end-users, including national statistical offices, environmental agencies, and forest managers. Regular workshops and webinars enabled the integration of user feedback, ensuring alignment with existing monitoring frameworks and reporting standards.

Integration of EO data
The project harnesses EO data from Copernicus core services, combined with *in situ* sources, to deliver accurate and timely SDG indicators monitoring data. It focuses on six enhanced indicators across three interconnected SDGs – SDG13 (Climate Action), SDG 14 (Life Below Water) and SDG15 (Life on Land) – as well as a cross-cutting indicator assessing the exposure of vulnerable communities to extreme climate events. A key output is the SDGs-EYES platform, offering analysis-ready datasets and tailored tools for a wide range of stakeholders.

Stakeholder engagement
The active engagement of policymakers, researchers, public authorities, and private sector actors has been central to the pilot design and implementation. Their involvement ensures that services are practical, impactful, and ready for real-world application.

Capacity building
By promoting long-term data reliability and supporting user capability, SDGs-EYES helps lay the foundation for widespread adoption of EO-based solutions in SDG monitoring, driving sustained impact well beyond the project's duration.

SDGs EYES

Manuela Balzarolo
Project coordinator
Foundation Euro-Mediterranean Center on Climate Change (CMCC)

Unlocking the future of upper atmosphere and near-Earth space research: Innovations and impact of PITHIA-NRF

PITHIA-NRF integration project provides access to research facilities, to data collections and scientific models and to all possible tools required by the research community for enhanced understanding and modelling of the physical mechanisms underpinning the interconnected regions of the Earth's plasmasphere, thermosphere and ionosphere

PITHIA-NRF (Plasmasphere Ionosphere Thermosphere Integrated Research Environment and Access services: a Network of Research Facilities) is the European Research Infrastructure that aims at facilitating research and development in the domain of the Upper Atmosphere and near-Earth space environment. PITHIA-NRF provides researchers access to a testbed for experimentation with data and for the development of validation of new scientific models that can be transformed, as a future step, to operations, useful for services dedicated to Space Weather monitoring and forecasting and to Space Situational Awareness.

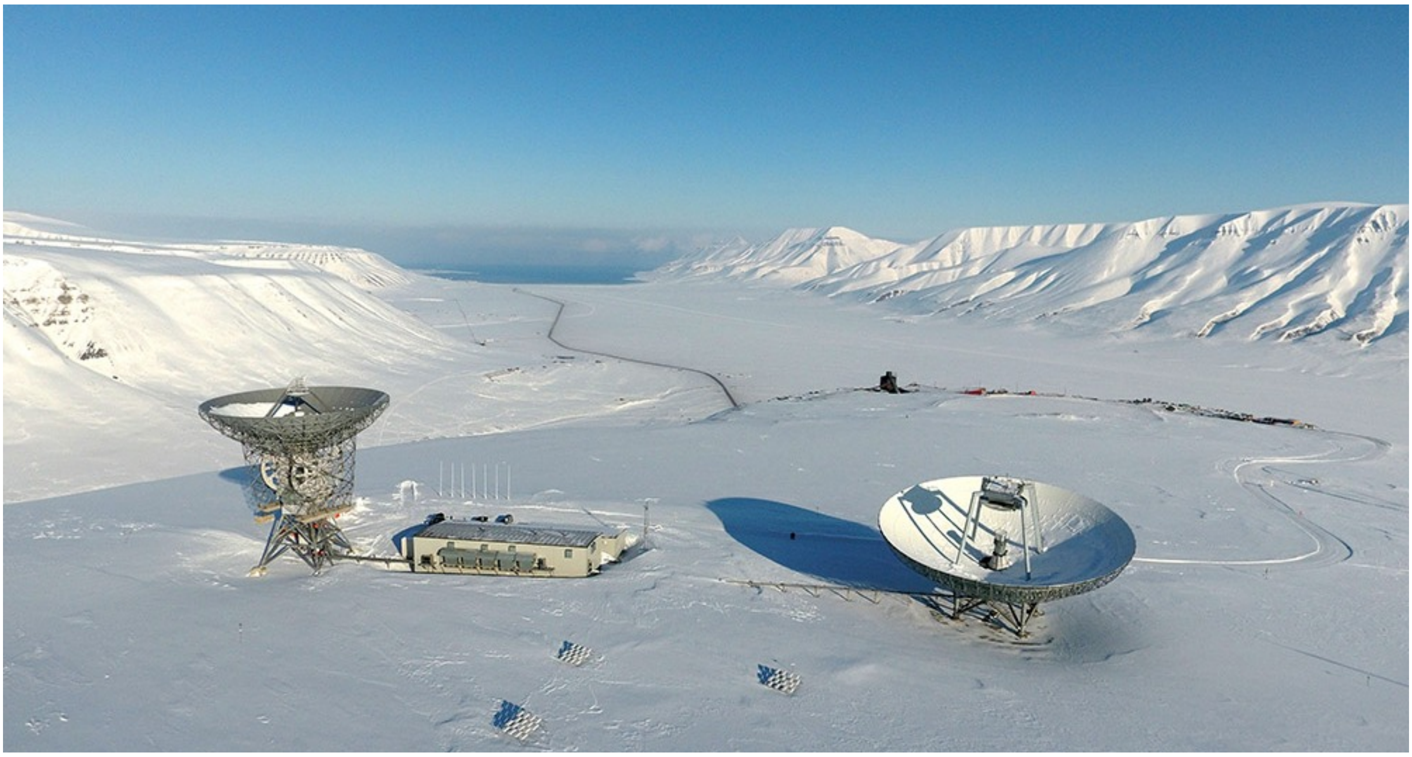

Fig. 1: EISCAT Svalbard Radar. https://eiscat.se/about/sites/eiscat-svalbard-radar/

Fig. 2: The LOFAR Superterp https://science.astron.nl/

Key innovations of PITHIA-NRF

1. Integrated European research infrastructure

PITHIA-NRF establishes a comprehensive European network of experimental facilities - the PITHIA-NRF nodes - by integrating national and regional research infrastructures, including facilities like EISCAT, LOFAR, Ionosondes, Digisondes, GNSS receivers, Doppler sounding systems, riometers, and VLF receivers. This integration facilitates coordinated observations and data sharing across Europe, advancing the study of the ionosphere, thermosphere, and plasmasphere.

2. Open access to data and tools

The project provides open access to data, and scientific models. Through the PITHIA-NRF e-Science Centre (eSC), researchers can access FAIR (Findable, Accessible, Interoperable, Reusable) data, standardised data products, a suite of data processing, prediction tools, and workflows, promoting collaborative research and innovation.

3. Standardisation and interoperability

PITHIA-NRF emphasises the development of standards for data interoperability, including data models and domain ontologies. This standardisation ensures that data and tools from various sources can be seamlessly integrated and utilised across different research platforms.

4. Transnational access (TNA) programme

The project offers a Transnational Access programme that subsidises external researchers to utilise PITHIA-NRF nodes. This initiative supports hands-on and remote projects, enabling researchers to conduct experiments, collect data, and analyse results using the project's tools and services provided by the nodes and by the eSC.

5. Comprehensive training and capacity building

PITHIA-NRF provides organised and systematic training through workshops, schools, webinars, and on-site sessions. These training programmes are designed for project partners, students, scientists from countries with limited space research infrastructure, and engineers from private companies, fostering a skilled community in upper atmosphere research and near-Earth space science.

6. Integration with European Open Science Cloud (EOSC)

By connecting with the EOSC, PITHIA-NRF ensures long-term preservation and accessibility of observational data. This integration supports the advancement of knowledge in ionospheric, thermospheric, and plasmaspheric research domains, especially regarding long-term studies.

Impact and future prospects

PITHIA-NRF's innovative approach in integrating diverse research infrastructures, standardising data and tools, and promoting open access significantly enhances the capabilities of the scientific community to study and understand the upper atmosphere and the near-Earth space environment.

By facilitating collaborative research and providing comprehensive training, the project not only advances current scientific knowledge but also lays the groundwork for future innovations in space weather research and related technologies. TNA projects

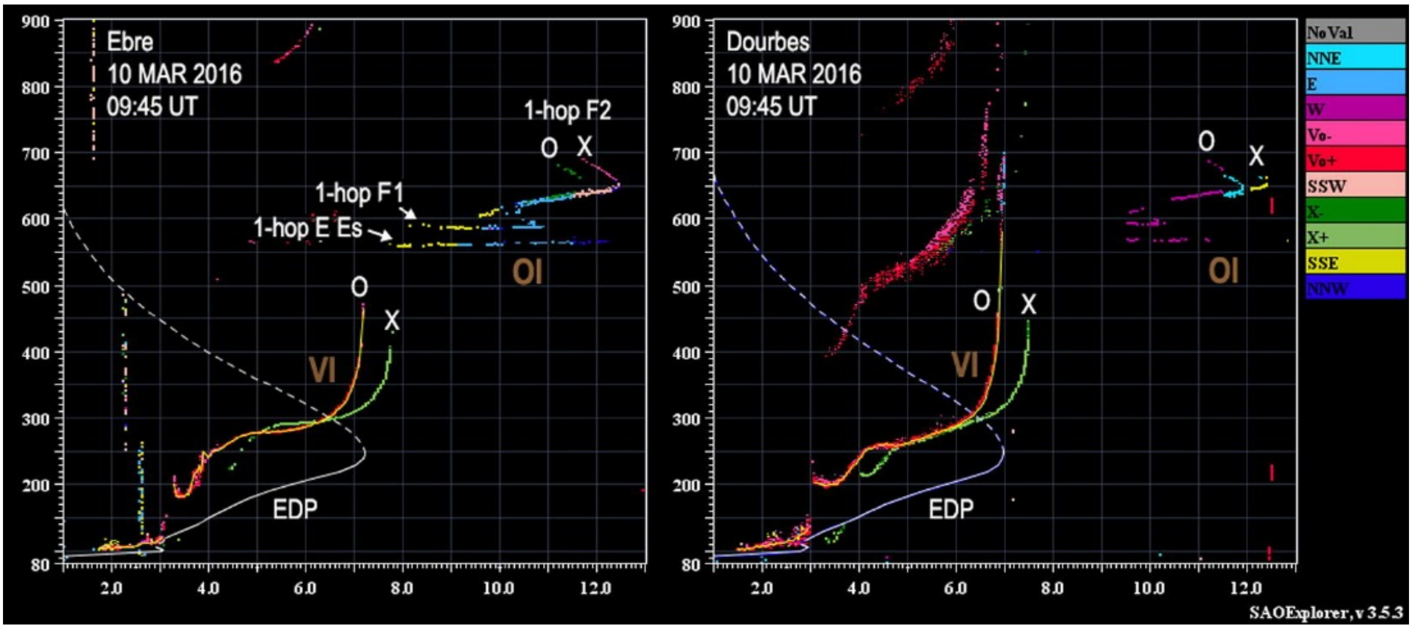

Fig. 3: Synchronised vertical (VI) and oblique (OI) incidence HF soundings from the European network of ionosondes, exploited in PITHIA-NRF to monitor travelling ionospheric disturbances (TIDs). The Figure shows VI + OI ionograms at Ebre (left) and Dourbes (right) recorded simultaneously. For more details the reader is referred to the Verhulst *et al.* (2017), publication in Advances in Space Research, https://doi.org/10.1016/j.asr.2017.06.033.

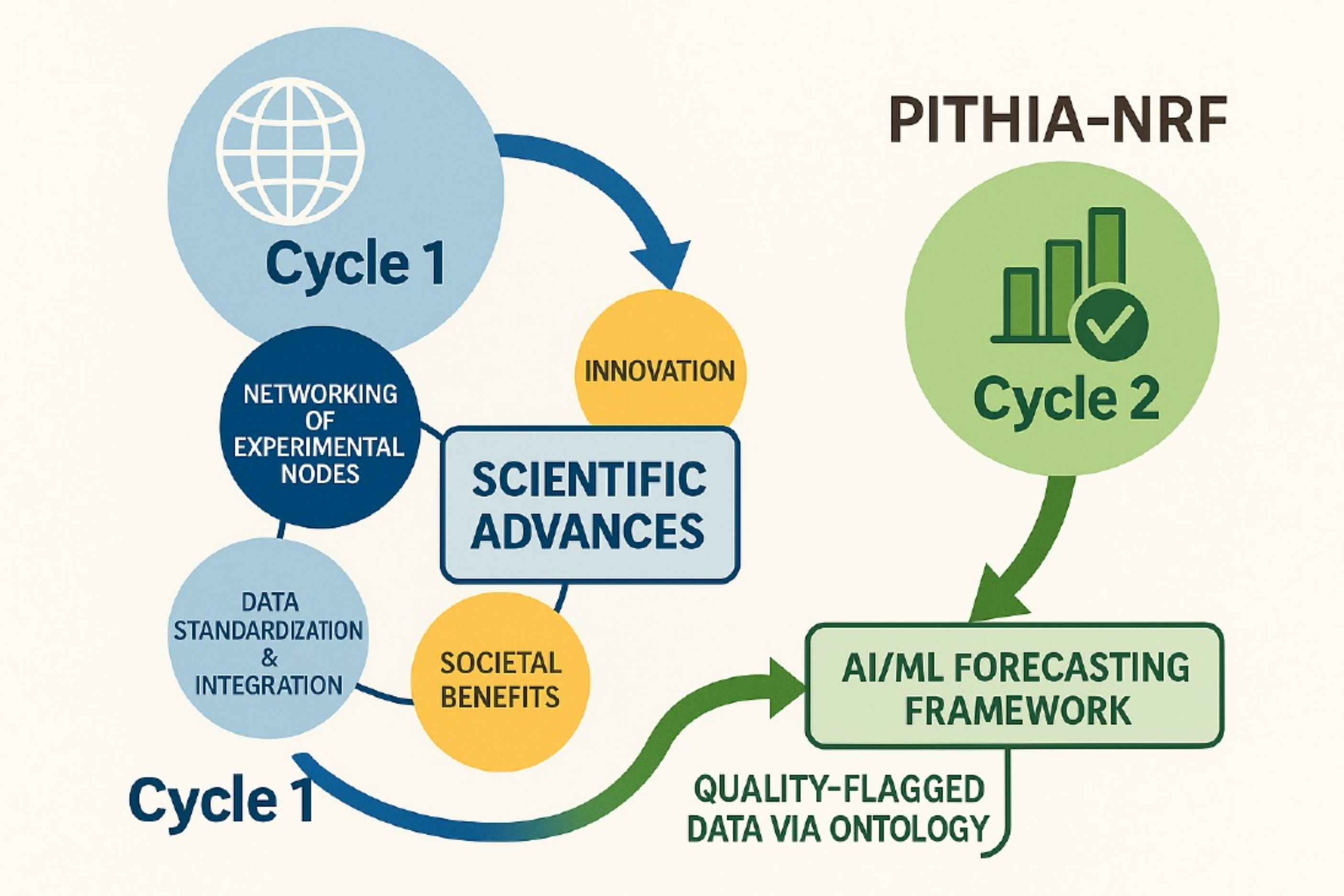

Fig. 4: The outlook for PITHIA-NRF developments

implemented in PITHIA-NRF nodes demonstrated research advances in multi-instrument data analysis, in the development and validation of scientific models, in ionosphere–interplanetary medium imaging methods, and in the calibration of new instruments (more details to be found in the article published by Belehaki et al. (2025) in Advances in Space Research.[1]

Based on these successful developments, PITHIA-NRF has the potential for enormous impact on structuring the scientific community, producing innovation, providing societal benefits, and influencing future governance and funding decisions. The main achievement that drives all impacts comes from scientific advances.

However, a key additional benefit, especially for the operations domain, is the possibility provided by the PITHIA-NRF ontology to characterise data products with quality flags. This could meet the requirements of the Space Safety and Security Programme of the European Space Agency and of the European Union Space Programme, who need data with controllable quality, a very complex procedure that requires cleaning, curation, transformation and integration among other workflows and it is planned to be achieved by the PITHIA-NRF community in a follow-up project. Such development, together with the availability of tools to retrieve massively archived data, would extremely support future AI/ML modelling developments where the use of clean data and the availability of archived data are instrumental for the reliability of the models' performance and the retraining process.

The establishment of an AI/ML modelling framework is the next major goal for the PITHIA-NRF community to address the critical requirement for real-time forecasts with specified accuracy regarding ionospheric disturbances and irregularities, atmospheric drag effects and the plasmasphere dynamics depending on geomagnetic activity.

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1. https://doi.org/10.1016/j.asr.2024.11.065

Dr Anna Belehaki
Ionospheric Group
Institute of Astronomy Astrophysics, Space Applications and Remote Sensing
National Observatory of Athens
Greece

Advancing Europe's space weather monitoring capabilities

Juha-Pekka Luntama, Head of the European Space Agency's Space Weather Office, details the Office's key activities helping to advance user knowledge of space weather and inform actions to protect infrastructure from its adverse impacts

SPACE weather is the physical and phenomenological state of natural space environments, impacted by solar activity. It is primarily driven by behaviour near the Sun's surface which can affect Earth's space environment. In addition to the Sun, variations in non-solar sources of energetic particles, such as galactic cosmic rays, are also considered as space weather.

Severe space weather could have a detrimental impact on our society and infrastructure on Earth, with the potential to cause disruption to electrical power grids, transport, and satellite operations. It is therefore of vital importance to monitor and predict space weather events to inform mitigative actions.

The European Space Agency's (ESA) Space Weather Office works to provide owners and operators of critical spaceborne and ground-based infrastructure with timely and accurate information to enable mitigation of the adverse impacts of space weather. It recognises the importance of constant monitoring of the Sun and the space environment from a range of vantage points. Building on Europe's well-established experience and assets for space weather observations and modelling, the Space Weather Office is developing a federated space-weather service-provision concept, avoiding duplication and ensuring that existing assets and resources play a key role in ESA's space weather system. These services are being delivered through the Space Weather Service Network.

To find out more about the work of the Space Weather Office, Georgie Purcell spoke with Juha-Pekka Luntama, Head of the Space Weather Office at ESA's European Space Operations Centre (ESOC).

What is the main objective of the Space Weather Office?

Its main objective is to develop the capability for Europe to help protect infrastructure and society from the impact of solar events and space weather. In addition, we can test and validate the results of these developments before they are transitioned into the operational framework for space weather services that Europe will hopefully be establishing in the near future.

Can you outline some of the key focuses and priorities of the Office at present?

There are three key areas of focus currently. It is important to start by discussing user engagement, because everything we do is driven by user needs. We are constantly in contact with the users – we present them with all the developments, products, services, and tools that are being produced in the framework of the space weather activities in the Space Safety Programme. We collect user feedback and take this into account

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in the further development and adjustment of those services to ensure they meet the needs of the users. A critical aspect of operational space weather is that the information provided to the users is actionable. It's not enough that we just tell them that there is something interesting happening in space; the users must be able to make decisions based on the information that we provide.

The second area that we're working on is the capabilities to provide this information. The most challenging part of space weather is forecasting solar events and their impacts on Earth. This is the area where we need more capability development. We can detect solar events when they happen, as long as we have sufficient space weather monitoring systems on ground and in space. But, in some cases, executing an efficient mitigation action to protect the sensitive infrastructure takes more time than we have after a solar event has been detected. This means that we would need to be able to give a reliable warning of an imminent solar event before it takes place. Such warnings require better understanding of solar physics than what we have today. We work very closely with our colleagues in the ESA Science Directorate who are working with missions like the Solar Orbiter, which produce better science and advances in science. We then utilise those advances to make the operational space weather capabilities better.

The third and final area is the observation systems. We are building the capability for Europe to improve our non-dependence in monitoring space weather and space weather impacts, so that we can facilitate those services to the end users.

Can you tell us more about the Space Weather Service Network and how it is progressing?

I think the Space Weather Service Network development will remain a work in progress, as there will always be room for improvement. The keyword here is 'network' – the service is networking the European space weather capabilities. We have already brought in more than 50 European space weather expert groups and institutes, research centres, and industry to collaborate to utilise the space weather monitoring data and produce the space weather products and services for the users.

We recently held a meeting where the participants of the network presented the achievements from the first period of the Space Safety programme. There have been huge steps forward in the capability that this network can provide to the end users. The next challenges will be in the area of user interfacing – making this information easy to access so that users can make decisions based on the information very quickly.

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“We want to conduct studies to develop the space weather models, and models that contain heliophysics, further”

It is a ‘research to operations’ (R2O) platform, helping to transition the science and engineering prototypes of the service capability into something which is ready to be transitioned into the operational framework. We will continue developing this network further in the next period of the programme.

What are the main challenges when it comes to monitoring space weather and how are you addressing these?

The main challenge is that we still have very little observation data. It may look like we have a lot of satellites and missions, but, if we compare space weather to the network of monitoring the weather, we only have a fraction of the sampling points. Currently, we are trying to make a forecast based on very little information at the end. We are working to build further capability, both in space and on the ground. We have to keep in mind that a lot of space weather observations can be done from the ground, which is an area at the fringes of the space agency activity. We are doing this where we know that there are gaps in the European and ground-based observation capabilities.

One of the flagship space-based missions in our programme is Vigil. This is a completely new capability to observe the Sun from the side, from the Fifth Lagrange (L5) point. Other missions in progress currently include the Aurora mission to monitor the Aurora, and Sword, which is designed to measure Earth’s radiation belts. Very importantly, we also collaborate internationally with our colleagues particularly in the US, but also in Korea, Japan, South Africa, and Australia. We ensure that we co-ordinate the development of capabilities to avoid duplication. We focus on certain complementary missions and observations, and then we exchange data. This is a win-win-win situation – everybody wins when we have better coverage, more data, and can exchange the data and utilise it together.

What are your hopes for the future?

In terms of space weather forecasting, there are high hopes that utilising artificial intelligence (AI) will give us better space weather forecasts. Also, because time is critical for space weather forecasting, we can develop models that are faster to execute. Very recently, ESA inaugurated the ESA Space High Performance Computing (HPC) environment at ESRIN in Italy. Essentially, this is an ESA-owned supercomputer that we will utilise to improve our space weather forecasts. This is very closely linked to the long-term objective to ensure we can utilise data from all the upcoming space weather missions.

We want to conduct studies to develop the space weather models, and models that contain heliophysics, further. The goal is to have what we would call an ‘end-to-end space weather capability’ – when we detect something in the Sun, we would have a complete data processing chain to see what the impacts on Earth would be. For example, we would immediately be able to produce an estimate of how much this event will impact the power grids or another critical piece of infrastructure on Earth.

For the space weather monitoring, in addition to the European space weather missions, we hope to see South Korea build a mission that would put the spacecraft in the Fourth Lagrange (L4) point, which is opposite from the L5 point where the ESA Vigil mission will be. When we have further observation points around the Sun, we hope that we can make our forecasts of the solar events much better than what we can do today.

Is there anything else that you think needs to be addressed in order to allow space weather monitoring to accelerate?

As I mentioned at the beginning, Europe does not yet have an operational European space weather service. ESA is a development agency, and, whilst we have developed the capability and can test and validate it, we don’t yet have a location for this capability to operate 24/7. Establishing this would be critical for Europe, because we know from studies that a big space weather event can cost Europe hundreds of billions of euros. ESA is in dialogue with the European Commission on this topic and we foresee that the European Union and European Commission would become the governing body of such an operational space weather system in Europe.

Juha-Pekka Luntama
Head of the Space Weather Office
European Space Agency

VT-NigerBEAR: An HF radar for monitoring space weather over the African continent

An international collaboration between Virginia Tech, USA and Bowen University, Nigeria is poised to highlight the use of High-Frequency (HF) radars on monitoring space weather

THIS initiative emphasises advancing these techniques in equatorial Nigeria, a region characterised by unique ionospheric phenomena like the equatorial electrojet and ionisation anomalies, which are critical for understanding space weather impacts on low-latitude regions.

The near-space environment of Earth is dominated by the collision of magnetised plasma that constitutes the solar wind with Earth's protective magnetic field. Turbulent conditions in the sun give rise to explosions of energy and matter, such as Coronal Mass Ejections (CMEs). The most powerful events result in compression and distortion of the volume of space carved out by the magnetic field, called the magnetosphere. Energy couples from the solar wind into the magnetosphere, where it is released in spectacular auroral displays and a range of other effects, some of them potentially harmful to humans in space and to technological systems.

Importance of space weather and space weather radar monitoring

The term 'space weather' encompasses both the study of the variable conditions in Earth's space environment and their impacts. The latter include such well-known effects as radiation hazard to humans in space and to crews on high-altitude aircraft in the polar regions, disruption of electrical distribution systems, scintillations on the signals used for global navigation satellite systems (GNSS aka GPS) leading to unacceptable errors, and disruption of communication links and over-the-horizon (OTH) radar surveillance systems. As humanity ventures forth into space, it is imperative that the science of space weather advance to provide both knowledge of and protection against the harmful effects of space weather.

Scientific instruments are operated both from satellite platforms and from the ground to observe space weather effects. These include a category of High Frequency

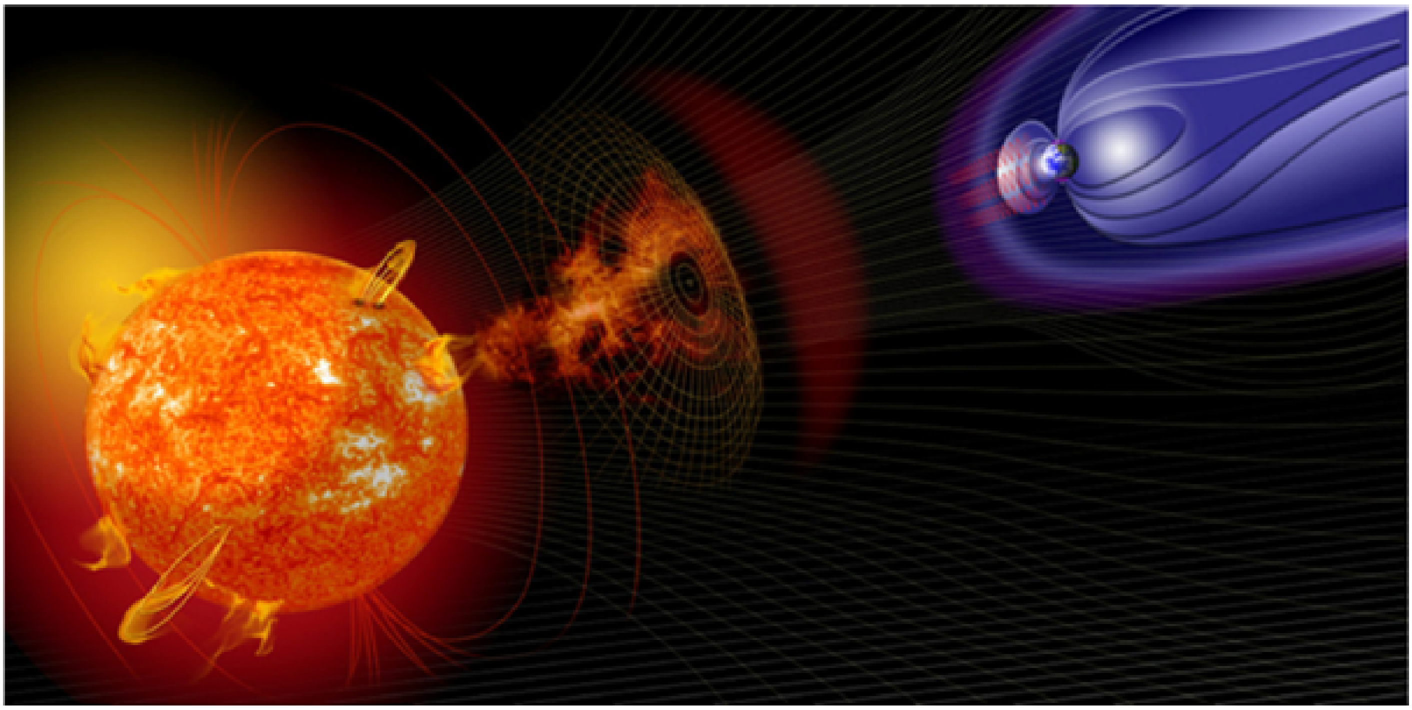


Illustration of a Coronal Mass Ejection (CME) about to collide with Earth's magnetosphere

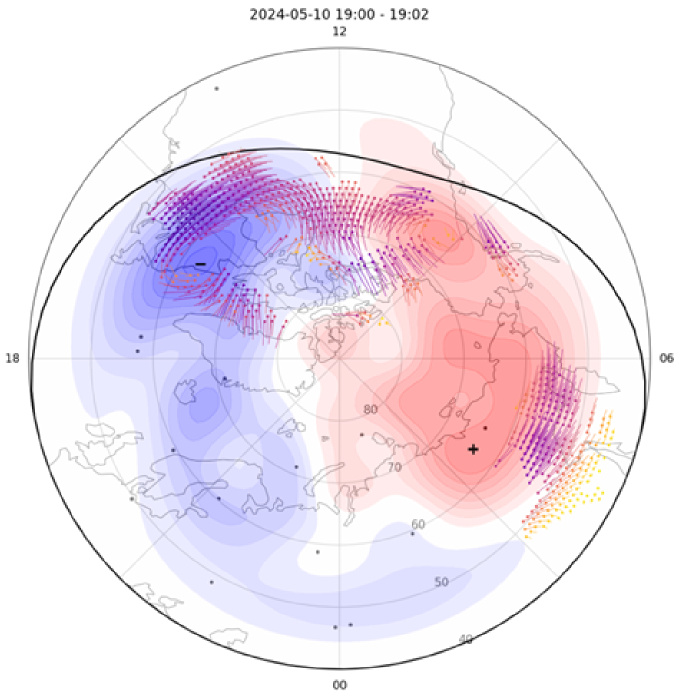
Photograph of an auroral display over the site of the SuperDARN radar near Saskatoon, Saskatchewan, Canada

(HF) radar that makes measurements based on the backscattering of radio wave signals from the partially ionised plasma of the ionosphere at altitudes between 90 and 600km. The ionosphere effectively presents a screen for monitoring processes occurring throughout the vast volume of the magnetosphere.

An important manifestation of the coupling of the solar wind to the magnetosphere is the circulation of ionospheric plasma over large areas approximately centred on the north and south magnetic poles. This motion is analogous to winds in the lower atmosphere and can be depicted with maps that are very similar to tropospheric weather maps, with cells of high and low pressure driving the circulation.

However, the processes are electrical in nature, with pressure measured in kilovolts and speeds often measured in kilometres per second. The plasma circulation pattern is very sensitive to solar wind factors and expands and contracts with the level of disturbance in the magnetosphere. The international collaboration known as Super Dual Auroral Radar Network (SuperDARN) operates a network of HF radars as a space weather radar system that measures plasma motion in the ionosphere and maps the pattern of global circulation.

In addition, the sensitivity of HF propagation to ionospheric conditions affords many possibilities for observing disturbance effects related to space weather. The first HF radar was built in Labrador, Canada, in the 1980s. The international collaboration known as SuperDARN dates from the 1990s when partners from six countries agreed to deploy radars in the auroral zones and operate them on a common schedule to produce data for merging into a single stream shared by all.



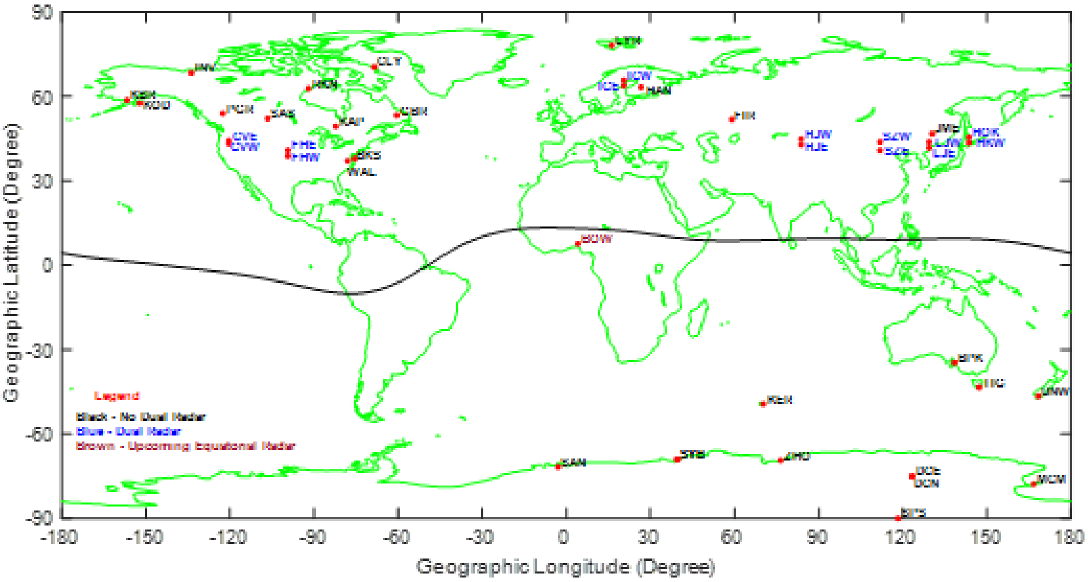
Map of the plasma circulation in the ionosphere in a two-minute interval derived from SuperDARN radar observations. The plasma flow in the North American sector converges on a channel that is directed towards the north magnetic pole

The collaboration now counts over 35 radars, ten countries, and 17 participating institutions and the radar coverage extends from polar latitudes through the auroral zones to the mid-latitude regions.

Transition of space weather radar monitoring to equatorial Nigeria

Space weather effects are prominent in the ionosphere in the vicinity of the geomagnetic equator. The special geometry of the magnetic field results in strong plasma flow and electric current in a belt that encircles the globe, as well as the formation of bubbles in ionospheric density that become structured and pose hazards for communication systems. It is known that geomagnetic storms penetrate the equatorial zone and cause disturbance effects in the ionosphere, some similar to those at high latitudes and some unique. The monitoring of space weather effects in the equatorial zone with ground-based instrumentation is very limited as landmass is limited, and much of that is inaccessible.

The plan to construct a space weather radar in Nigeria, specifically the Virginia Tech-Nigeria Bowen Equatorial Aeronomy Radar (VT-NigerBEAR), represents a major step forward in expanding capabilities to address this gap. The HF radar technique originally developed for the high latitude regions can be readily adapted to conditions in the equatorial ionosphere.



A map showing the location of VT-NigerBEAR on the campus of Bowen University in Iwo, Nigeria. Other SuperDARN space weather radar locations around the world


A 3-Dimensional diagram of the completed VT-NigerBEAR facility

Ongoing construction of VT-NigerBEAR

The initial concept of VT-NigerBEAR was formulated beginning in 2018 during discussions between Prof. W.A. Scales (Virginia Tech) and Prof. O.S. Bolaji (Bowen University), facilitated by their graduate students. Support was then provided by Bowen Vice Chancellor, Prof. J. Ogunwole, to begin the project on Bowen's campus in Iwo with help of the Bowen Physics Programme through Profs. Bolaji, and O.O. Ajani. The radar design was begun by the VT SuperDARN group, lead by Prof. J.M Ruohoniemi and Mr. Kevin Sterne. A visit to Bowen by Prof. Scales in 2019 solicited further support from Bowen and, in addition, the Nigerian National Space Research and Development Agency (NASRDA) through Prof. B. Rabiu. A second visit by VT representatives in 2022 witnessed the Commissioning of VT-NigerBEAR by the Vice President of the Federal Republic of Nigeria, Prof. Yemi Osinbajo, who praised the broad national strategic benefits of the facility to the Nigerian science and technology community.

The name VT – NigerBEAR reflects the shared heritage and the hope for productive scientific collaboration within the international scientific community. VT-NigerBEAR will be the first radar on the SuperDARN design operating at low latitudes, and it will have a field of view that extends eastward across the continent. This initiative will not only be transformative for Nigeria; it will enable research across Africa and provide links to international research on both the low-latitude and global aspects of space weather.

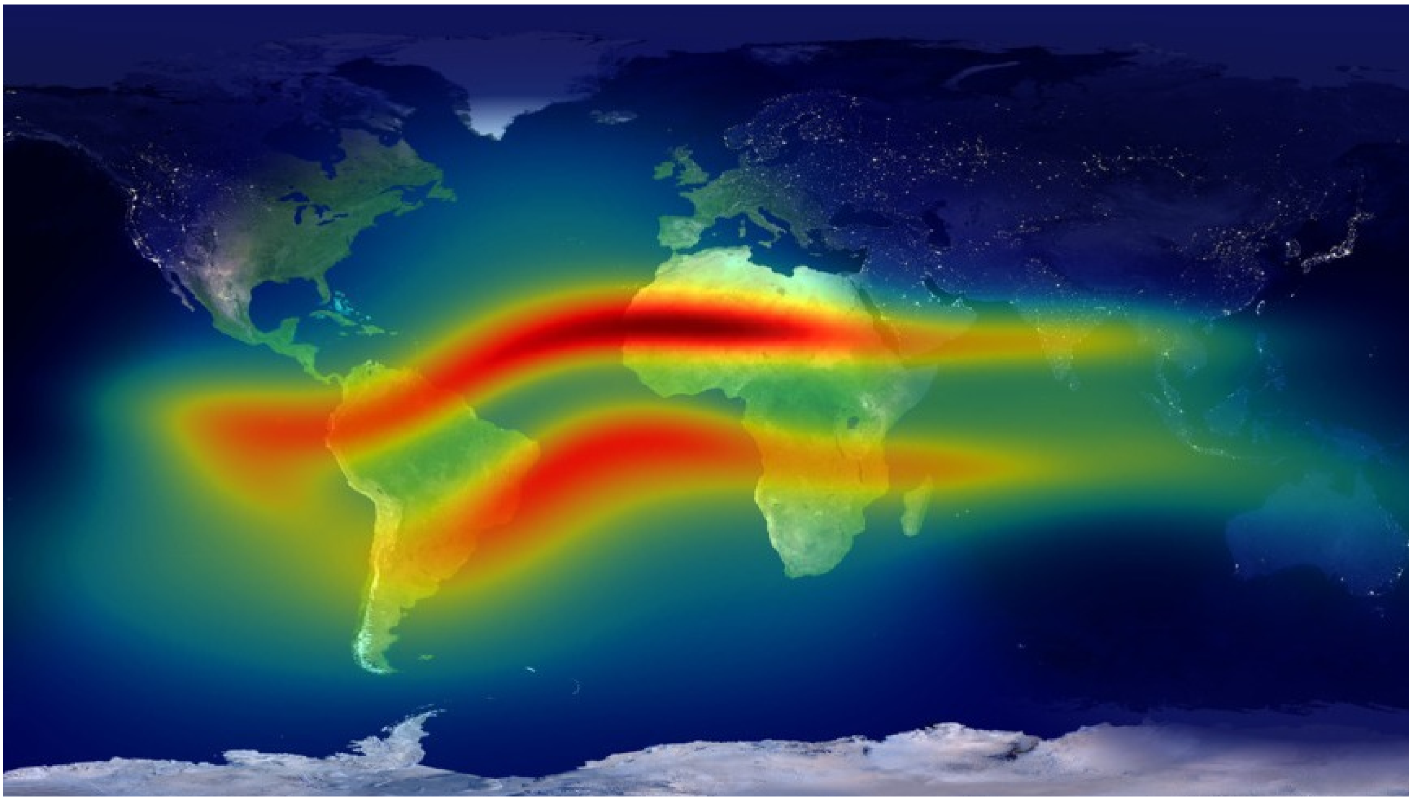
It is important to note that communication and navigation technologies, town planning, resources, and disaster management are highly dependent on satellites operating in the space environment. Understanding the space environment through data collection and analysis has become a vital part of protecting our technologies in space and on Earth from the devastating effects of space weather and lower atmospheric forcing. VT-NigerBEAR can provide this essential service to the African low latitudes that house about 80% of African landmass through monitoring space weather activity to provide information for early warnings and forecasts about space weather and associated conditions in the lower atmosphere.

In addition to providing continuous monitoring, the VT-NigerBEAR radar, in co-ordination with the SuperDARN radars and other instrumentation, will enable new lines of research on the coupling of disturbance effects between the high and low latitude regions. VT-NigerBEAR will allow the assessment of phenomena such as ionospheric irregularities and thermospheric winds. Measurements of these kinds are very new to the low and equatorial latitudes in the African space weather community.

The scientific and technical concepts of VT-NigerBEAR

The ionosphere at equatorial latitudes is highly dynamic, owing to the horizontal orientation of the lines of force of the geomagnetic field. This special geometry results in a belt of heightened conductivity along which flows a strong electric current known as the equatorial electrojet (EEJ). Instabilities are triggered, which lead to the structuring of ionospheric plasma and disruption of radio wave propagation. The effects bear some similarity to the space weather at auroral latitudes in that the interplay of plasma, electric fields, neutral winds, and currents leads to mass displacement of plasma and the formation of density gradients and density irregularities that cause errors on radio wave systems such as GNSS.

The concept of the new radar is to adapt the HF technique developed at high latitudes, where the geomagnetic lines of force are nearly vertical, to the African equatorial zone, where they are nearly horizontal. The conditions for HF backscattering with a SuperDARN-type radar are readily satisfied in the equatorial ionosphere. The observation of backscatter from the ionosphere directly registers the presence of enhanced meter-scale density irregularities.



The Equatorial Ionospheric Anomaly (EIA)

By virtue of the Doppler shift imposed on the signal, the radar can measure the plasma flow velocity in the equatorial electrojet. The propagation of the HF signal itself is extremely sensitive to ionospheric conditions.

A second backscatter mode that involves reflection by the ionosphere to the ground and a return along the same path will provide a means to monitor all manner of ionospheric disturbance. Construction of the VT-NigerBEAR radar will bring the full capabilities of the SuperDARN technique to bear on the study of space weather effects in the low latitude ionosphere.

All SuperDARN radars operating at high latitudes utilise two arrays of antennas that have a mostly east-west orientation in order to form a beam that can be scanned electronically in azimuth about the direction of either the north or south magnetic pole. The antenna design produces peak antenna gain at a fairly low elevation angle. The second array does not transmit but receives a backscattered signal that can be compared with the main array's signal to determine the elevation angle of the backscatter.

This configuration is appropriate for high latitudes with its nearly vertical geomagnetic field lines. The condition for backscattering is that the HF signal propagates orthogonally to the field lines where meter-scale density irregularities are encountered.

A SuperDARN-type radar operating in the ionosphere at equatorial latitudes must satisfy the same backscattering condition. With the field lines now horizontal and running north-south, the arrays need to be oriented in a north-south sense in order to form a beam that is directed east or west so that the HF signal is directed across the field lines at the appropriate angle. The VT-NigerBEAR radar will be directed eastward to look across the bulk of equatorial Africa.

At the equator, scanning in elevation is of heightened importance, as the electrojet will pass directly over the site on an east-to-west arc. [5] + [6] Consequently, the VT – NigerBEAR radar will be configured with three arrays oriented north-south, all of which are capable of transmitting and receiving. In addition, the antennas have been re-designed to increase sensitivity over a wider range of elevation angles. These are the most significant adaptations for operating at the equator.

Benefits to the Nigerian and international space weather community

VT-NigerBEAR is poised to become a cornerstone of space weather research in Nigeria, providing critical support for other space weather studies and measurements. By integrating with GPS receivers, magnetometers, meteorological instruments, and other tools, VT-NigerBEAR will enhance our understanding of space weather phenomena and their impacts on technological systems. VT-NigerBEAR will be capable of scanning in azimuth to cover the peaks in ionisation density that occur at latitudes just above and below the equator. This phenomenon, known as the Equatorial Ionization Anomaly (EIA) is due to upward plasma drift at the equator that also stimulates the formation of plasma voids known as bubbles. The HF radar will be sensitive to perturbations in the ionosphere that accompany, and help to explain, these dramatic features.

By combining VT-NigerBEAR's high-resolution data on plasma density bubbles with GPS TEC measurements, researchers can better understand the mechanisms behind scintillations – rapid fluctuations in GNSS signals caused by ionospheric irregularities in the low latitudes. This integration will improve models for mitigating GNSS errors, benefiting applications such as aviation, maritime navigation, and precision agriculture. Magnetometers provide insights into the strength and direction of Earth's magnetic field, while VT-NigerBEAR measures plasma flows and electric currents. Together, these instruments offer a comprehensive view of storm-time ionospheric dynamics.

A novel area of research enabled by VT-NigerBEAR is the study of how Sudden Stratospheric Warming (SSW) events influence ionospheric irregularities in low-latitude regions. Traditionally studied in polar and mid-latitude regions, these events have been hypothesised to affect equatorial plasma dynamics. VT-NigerBEAR will also detect atmospheric gravity waves and tides — the former via the ground backscatter mode and the latter via reflection from meteor trails drifting with winds at mesospheric altitudes — providing insights into their sources and propagation characteristics. VT-NigerBEAR will provide direct evidence of the coupling of ion motions and neutral winds, potentially uncovering new mechanisms of energy transfer between the lower atmosphere and the ionosphere.

The VT-NigerBEAR radar will operate continuously (like the SuperDARN radars) and generate a rich database of observations for understanding space weather effects in the equatorial zone. The flow of plasma in the equatorial electrojet across the African sector will be monitored with a spatial resolution of kilometers and a temporal resolution of seconds. The measurements will include vertical drift of the ionosphere, enhancing our understanding of how this parameter controls the ionospheric density distribution, plasma instability, the formation of irregularities, and the onset of scintillations. The high-quality, continuous data provided by VT-NigerBEAR will be invaluable for validating and refining existing space weather models and enhancing the accuracy of space weather forecasting.

VT-NigerBEAR's data will enable comparisons with high- and mid-latitude observations, revealing how space weather effects vary across different regions. This global perspective improves our understanding of data variations around low, middle, and high latitudes. Its unique location in the equatorial region, combined with its advanced capabilities, makes it an invaluable asset for advancing scientific knowledge and fostering collaboration both within Nigeria and internationally.

Summary

VT-NigerBEAR represents a landmark achievement for the Nigerian and international space science communities. By addressing critical gaps in observational coverage, enabling groundbreaking research, and fostering collaboration, the radar will significantly advance our understanding of space weather and atmospheric dynamics. Its impact will extend beyond scientific discovery, contributing to the protection of technological systems, the development of skilled workforces, and the promotion of sustainable development.

Through VT-NigerBEAR, Nigeria is poised to become a global leader in low-latitude space science, while the international community benefits from enhanced capabilities to monitor and mitigate the effects of space weather on modern society.

Authors

1. W.A. Scales
Center for Space Science and Engineering Research
Bradley Department of Electrical and Computer Engineering
Virginia Tech, Blacksburg, Virginia

2. J.M Ruohoniemi
Center for Space Science and Engineering Research
Bradley Department of Electrical and Computer Engineering
Virginia Tech, Blacksburg, Virginia

3. K. Sterne
Center for Space Science and Engineering Research
Bradley Department of Electrical and Computer Engineering
Virginia Tech, Blacksburg, Virginia

4. O.S. Bolaji
College of Agriculture, Engineering and Science,
Physics Programme, Bowen University, Iwo. Nigeria

5. Babatunde Rabiu
1 National Space Research and Development Agency, Abuja, Nigeria
2 College of Agriculture, Engineering and Science,
Physics Programme, Bowen University, Iwo. Nigeria

6. J.B. Fashae
College of Agriculture, Engineering and Science,
Physics Programme, Bowen University, Iwo. Nigeria

7. O.O. Ajani
College of Agriculture, Engineering and Science,
Physics Programme, Bowen University, Iwo. Nigeria

VIRGINIA TECH

BOWEN UNIVERSITY
(of the Nigerian Baptist Convention)

Professor Wayne Scales
Virginia Tech

Unlocking Space for Business: How the UK Space Agency is transforming industries with satellite solutions

The UK Space Agency discusses its "Unlocking Space for Business" programme, aiming to enhance the adoption of space data and services to drive operational efficiencies, improve customer experiences, and support sustainability

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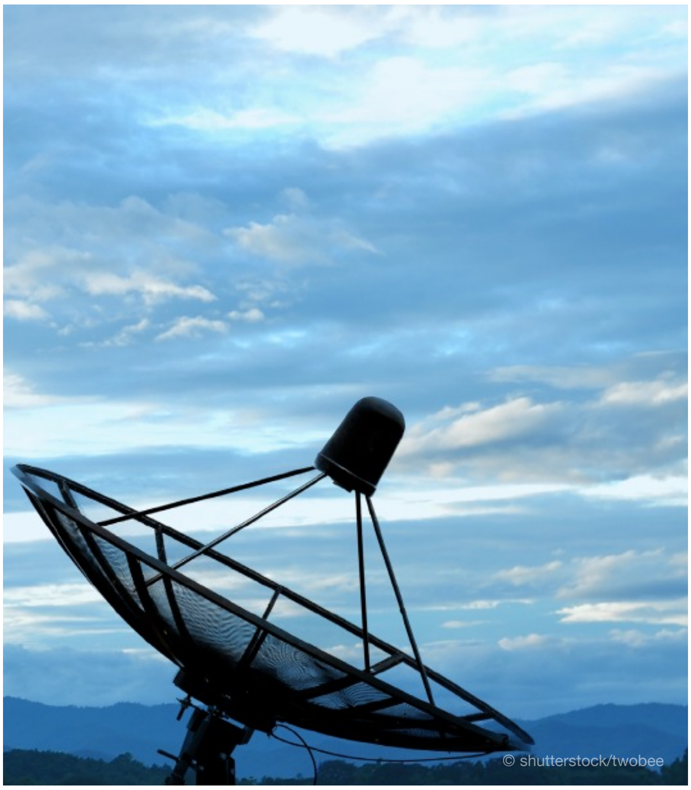
IN AN era where data drives decision-making and innovation, the integration of satellite technology into business operations has emerged as a transformative force.

Recognising this potential, the UK Space Agency (UKSA) has introduced the "Unlocking Space for Business" programme to facilitate the adoption of satellite solutions across various industries. By leveraging the capabilities of space data and services this programme bridges the gap between the emerging space sector and commercial enterprises, empowering them to harness new technologies and unlock unprecedented opportunities for success.

Following the announcement of their new grant call, *The Innovation Platform* spoke with the Unlocking Space for Business team at the UKSA to discover how the programme could revolutionise the way industries operate, making the vast possibilities of space accessible to all.



Can you provide an overview of the UK Space Agency's Unlocking Space for Business programme and its primary objectives?

Unlocking Space for Business is a UK Space Agency programme which aims to drive private sector adoption of satellite data and services by tackling barriers to adoption being faced by private sector end-users, which is preventing the sector from delivering greater benefits for businesses, citizens, and the environment.

Since its launch in October 2023, the Unlocking Space for Business programme has taken a demand-led approach to supporting financial service and transport & logistics companies to realise operational, customer and environmental benefits through the adoption of innovative satellite solutions.

Unlocking Space for Business has engaged more than 350 organisations in the financial services and transport and logistics sectors, supporting their understanding and exploitation of business benefits through networking events, tailored exploration workshops, learning and development, and government funding for pilot projects.

Why should UK businesses look to use space solutions, and how do these motivations differ across various industries?

Satellite products have historically been focused on defence, scientific and weather applications, but have evolved into a key enabler of commercial innovation, with a global market size of £320bn.[1]

The emergence of private space industry driven by commercial interest and innovative business models, referred to as New Space, is driving down the cost of investment in space and simultaneously increasing the development of value-adding applications. Many UK businesses are already using and benefiting from satellite solutions in their organisations, enabling transformation, delivering real-time insights, improving operational efficiency and supporting sustainability reporting.

For example, in the financial services sector, insurance companies are using satellite imagery to verify insurance claims, saving time and money that would be spent on in-person verification, which enables more precise and timely claim resolutions for customers.

In the transport and logistics sector, fleet operators are using high-precision location services to track vehicles and assets in real-time, which improves overall fleet management.

Could you elaborate on the potential economic benefits businesses might gain by working with the space sector, including job creation, revenue generation, and access to new markets?

The Unlocking Space for Business programme identified four key business benefits of using satellite-enabled solutions:

- Driving revenue growth - addressing technology gaps which need to be closed to bring new commercial solutions to the market;
- Enhancing operational and financial efficiency- including unreliable forecasting leading to inefficiencies and delayed action, and frequent travel and on-site visits to remote locations driving up costs and operational complexity;
- Improving customer retention - generic customer strategies and experiences are posing challenges to engagement and loyalty, as well as disruptions and delays in resolving customer issues; and
- Addressing environmental obligations, as companies are facing growing pressure to report on climate and nature-related risks, traditional assessments, monitoring, and compliance are resource-intensive and fragmented.

Unlocking Space for Business grant-funded project case studies clearly demonstrate how UK businesses have realised these benefits. Being a demand-led programme, Unlocking Space for Business Grant projects had an end-user-led approach which encouraged embedded collaboration between end-user organisations and space suppliers to de-risk innovative pilot projects for businesses and deliver tangible benefits. This encourages long-term, fruitful relationships and partnerships between end-users and suppliers, creating competitive advantages for organisations.

Home insurer Admiral, in collaboration with ground movement specialist SatSense and engineering consultant Optera, used satellite-derived imagery data to remotely monitor and assess subsidence risks across UK properties. The potential impacts are significant, given Admiral's portfolio of over 1 million home insurance customers and more than ten years' experience in handling subsidence claims.[2]

Rail software company OneBigCircle is transforming rail safety and efficiency through a satellite imagery-powered solution that detects vegetation overgrowth, land movement and flood risks across the UK's critical railway infrastructure. Using hyperspectral Earth observation sensors which capture a wide range of details on the ground — beyond what the human eye can see — the system can detect subtle environmental changes that signal potential hazards. This satellite imagery is combined with AI, machine learning and ground-based videos to provide real-time monitoring, risk assessment and event triage for rail operators.

How does the Unlocking Space for Business programme align with the UK Government's broader strategies for economic growth and scientific advancement in the space sector?

The UK Space Agency aims to provide support to UK space companies across their investment journey, with an emphasis on supporting companies from start-up to scale-up, to maximise delivery against economic growth. The Unlocking Space for Business programme provides interventions at the latter end of this journey, with a focus on the commercialisation of downstream space solutions that can be readily adopted by end-user businesses.

Unlocking Space for Business forms part of a wider Unlocking Space programme, which is focused on growing the UK space sector through championing the benefits of space to government, business, defence and investor groups, catalysing investment into the UK's high-potential space sector and supporting economic growth. This aligns with the Government's Plan for Change, supporting the growth of the wider UK economy.

Can you specify the types of businesses that can benefit from the programme? What kind of training or resources does it offer to participants?

The Unlocking Space for Business programme is focused on supporting end-user organisations with programme interventions. These were developed in response to identifying challenges and barriers to businesses that were looking to get into the space sector, and include:

- Organisations are not aware that satellite solutions opportunities may be relevant to their business performance and perceive them as too expensive;
- The right information to inform ROI is not being presented to decision makers in a way that is evidence-based, easily digestible, trusted and comparable against alternatives;
- Products being offered are not easily accessible, used and integrated by businesses to realise target benefits, taking up too much time, money and resources.

Following an assessment of these market failures, the Unlocking Space for Business programme developed a number of targeted interventions to support UK businesses' adoption of downstream space applications.

The programme held a series of bite-sized learning and development webinars for current or potential users of satellite data and services within the financial services and transport and logistics sectors. These sessions explored everything from the procurement and integration of different types of satellite data to the specific use cases for these two sectors. Short summary videos are available for financial services and transport and logistics businesses.

The programme has also hosted seven in-person insight and networking events and four industry roundtables, working closely with trade bodies and other organisations, bringing together stakeholder groups and demonstrating the possibilities of adopting satellite solutions. Alongside this, we have delivered 42 tailored workshops to 27 end-users in the Financial Services and Transport & Logistics sectors. These customised workshops allowed organisations to explore potential opportunities to leverage satellite solutions, including exploring value propositions, prioritising areas most relevant to their current business needs, understanding the supplier ecosystem and developing a forward-looking delivery plan.

We've also produced a report, "The Space Advantage", co-authored by PwC and the Satellite Applications Catapult, which is designed for businesses who are at the start of their space-adoption journey and want to learn about real-life case studies from across the financial services and transport and logistics sectors. It provides accessible insights into the real business benefits experienced by household name companies who have adopted space-enabled solutions through Unlocking Space for Business funded grant projects, and crucially, the tangible benefits they've seen as a result.

Unlocking Space for Business is primarily focused on encouraging adoption of space solutions by non-space businesses, but that doesn't mean it doesn't consider the space sector, too. Through extensive Programme engagement with end-user businesses, we've produced a summary of insights for suppliers and integrators of satellite data and services. This sets out the common themes that end-user businesses perceived as limiting their business from fully capitalising on the potential use cases offered by satellite solutions. This summary of insights aims to help the space sector to better understand the needs of prospective business customers who are looking to adopt space solutions: Summary of Insights to Suppliers and Integrators of Satellite Data and Services - GOV.UK.

In what ways does the programme promote the adoption of new technologies, such as artificial intelligence and machine learning, among businesses that utilise space data?

Through our two previous funding calls, we've encouraged projects to combine satellite data and services with enabling technologies, like AI and Machine Learning, alongside existing terrestrial data, as these technologies can help to create a more comprehensive dataset, which enhances decision-making by businesses. Integration of these emerging technologies can make satellite solutions more accessible, actionable and affordable for businesses. Over two-thirds of Unlocking Space for Business-funded Contracts for Innovation projects and grant-funded projects involved AI or Machine Learning, which was integral to identifying patterns across multiple datasets and automatically producing the analysis required for business decisions, such as on investment or risk management.

Equitix Limited partnered with Sust Global to build high-resolution wind speed projections using Sust Global's innovative geospatial artificial intelligence (AI) approach and satellite data. Equitix incorporated the projections into their investment processes, developing new climate-adjusted capacity factors. The solution provided actionable insights tailored to Equitix's portfolio management processes, supporting investment decisions and long-term resilience in the wind energy sector. Looking forward, the geospatial AI approach can be applied to other asset classes to enable climate resilience across the infrastructure investment industry.

Level E Research partnered with EOLAS insight to develop an AI Risk Index (AIRI) that measures exposure of a company or investment portfolio to environmental factors. By quantifying the exposure of an investment portfolio to environmental factors, end-users can make informed decisions, reducing idiosyncratic risk. AI front-end solutions are highly scalable and offer the possibility to produce profit margins and process vast amounts of data to provide valuable insights, helping Lebel E's customer base and diversifying its revenue streams. Future use of the application has significant market potential across various sectors, including asset management and insurance.

The Unlocking Space for Business Grant Call 2, which is currently open to applications, encourages proposals which include complementary enabling technologies alongside at least one satellite domain.

What future plans or upcoming initiatives within the Unlocking Space programme aim to further stimulate innovation and investment in the space sector?

As part of the Unlocking Space Programme, Unlocking Space for Investment aims to boost the UK space sector by enhancing business readiness to gain investment, strengthening investor confidence in the space sector, and expanding financing options. The programme addresses access to finance challenges, connecting space businesses with investors to drive sustainable growth and innovation, via four pillars:

1. The **Growth Pathway**, which provides tailored investor-readiness training and supports businesses gaining access to key advisory services.

2. The **Investor Pathway**, which educates and engages deep-tech investors to build confidence in space as an investable sector.

3. The **Space Investment Network**, which facilitates structured engagement through events, roundtables, and a public information hub.

4. The **UK Innovation and Science Seed Fund**, a publicly backed venture capital fund supporting early-stage space businesses.

Announcements

The Unlocking Space for Business Grant Call 2 is currently inviting proposals from end-user business-led consortia, with a space supplier and any relevant integrator organisations, for innovative pilot projects to commercialise space solutions within the Financial Services or Transport & Logistics sectors in the UK. The call closes at 16:00 BST on 7th July 2025, with more information available here.

Our regular Unlocking Space newsletter includes updates on all upcoming activities across the Unlocking Space programme for business end-users, space companies and investors. Sign up here.

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Ruby Packenham-Behan
Senior Project Officer
Unlocking Space for Business

Laura Bealin-Kelly
Unlocking Space for Business Lead
UK Space Agency

Data management and the orbital environment: Finding the needle in the haystack

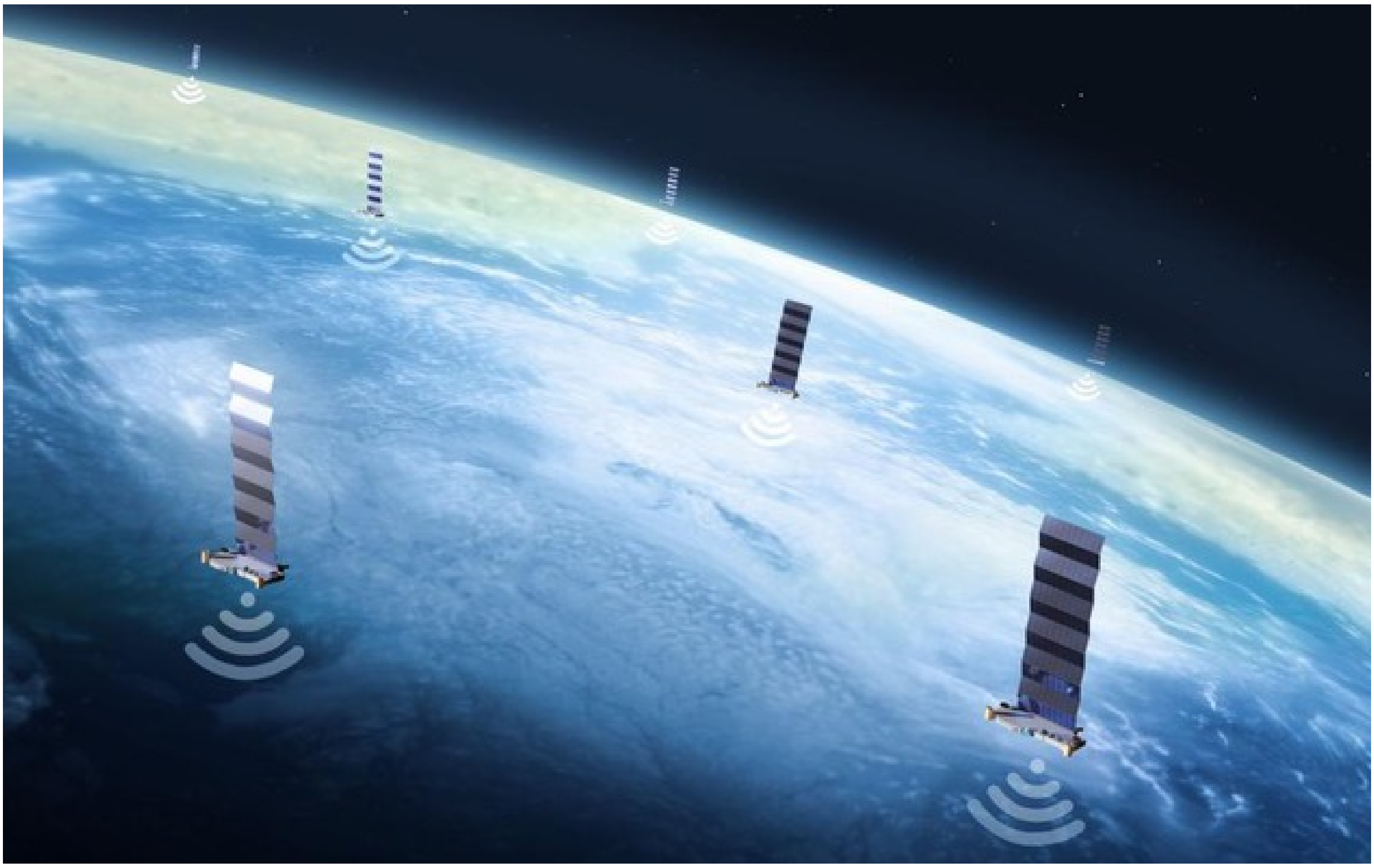
With a rapid increase in the number of objects in orbit, there is a requirement to increase available data to support safe, sustainable, and secure space operations

IT IS something of a cliche to say that the orbital environment has undergone a dramatic change both in usage and occupation over the course of the last decade, and more particularly over the last five years with the proliferation of both reusable launch vehicles and mega constellations. The ten-fold increase in human-made space objects has been matched by a consequential growth in the amount of data regarding the space environment.

Even though there has been an exponential growth of commercial space situational awareness (SSA) companies, much remains the same regarding the availability of data on operations in near-Earth space. In its simplest form, space situational awareness is the understanding of what is going into, coming out of, and happening in space, but the availability of data to support it is far from simple.

Meeting an increased need for space data

A space traffic study conducted in 2021 projected that data volumes from and about space will reach more than 500 exabytes of information over the course of the current decade. This represents a staggering 14-fold increase over ten years.[1] To promote an increase in the amount of space data, at 3S Northumbria, we



have been evangelical in our calls for increased space surveillance and tracking capability. This is needed to meet the requirements of both current and future space traffic management/space traffic coordination in enabling a safe, sustainable and secure future for near-Earth space operations – out to 36,000km (the geostationary 'belt').

With a data volume equivalent to 3.9 billion smartphones of data over the next ten years, acquiring information is only the first part of understanding, analysing and hopefully coordinating the orbital environment. This discussion will highlight some of the issues in space data management in all its forms and suggest some of the crucial steps needed to deal with the dramatic increase in space objects and ensure safe operations in space.

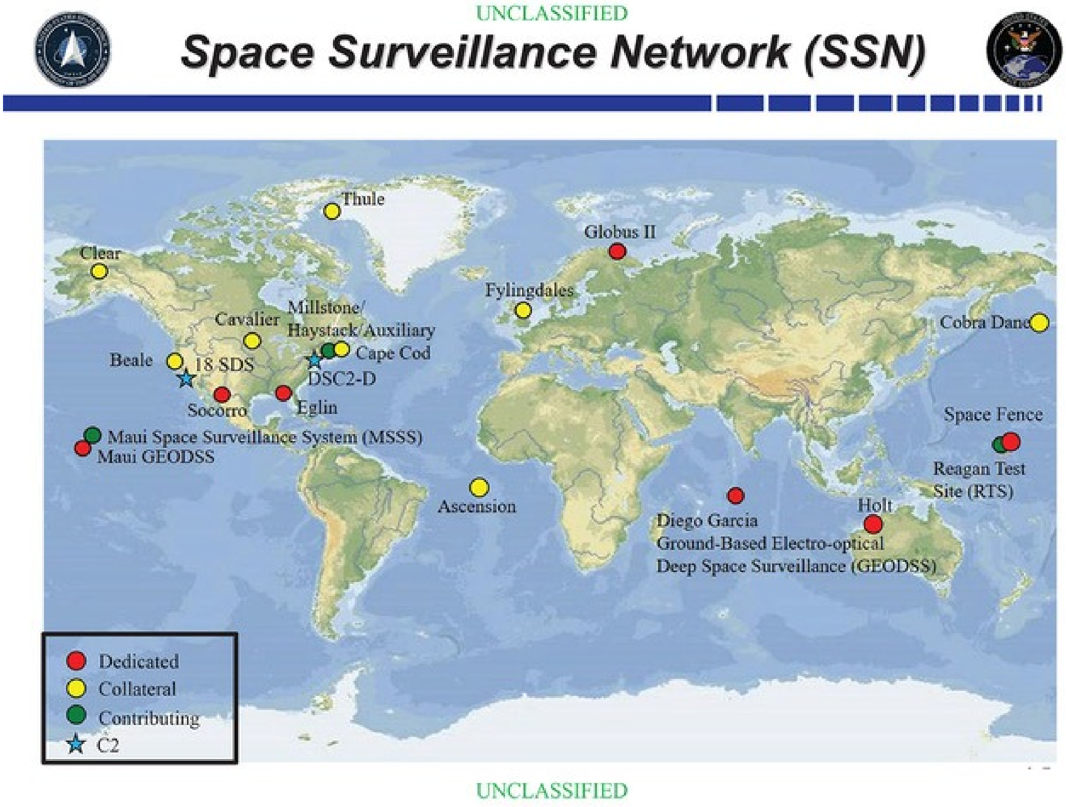
Understanding low-Earth orbit

Any discussion on data from and about space needs to start by acknowledging the emergence of large constellations and the dramatic increase in the number of space objects in low-Earth orbit (LEO). At the time of writing, there are over 13,000 active satellites in orbit, with more than 60% of them belonging to one owner/operator, the Starlink constellation. These large-scale deployments of smaller satellites create a significant increase in data generation rates. To provide a full picture for space situational awareness, each satellite requires continuous tracking, collision avoidance assessment, and subsequent coordination with objects and phenomena in the wider orbital environment.

The Starlink constellation publishes bi-annual manoeuvre reports[2] and employs an autonomous collision avoidance algorithm that ensures each satellite can manoeuvre to maintain safety from other satellites in its path. However, each manoeuvre reduces the orbital life span of the satellite, which carries a finite 'fuel' supply, and the accuracy of conjunction prediction is questionable at best.

The implications of the sheer amount of data required/generated move us beyond simple object tracking. There is data generated in respect of orbital propagation calculations, manoeuvre planning coordination, and real-time collision probability assessments. Despite the Starlink constellation benefiting from autonomous collision avoidance, other satellite users still need to consider planned orbital manoeuvres, station-keeping activities and end-of-life disposal procedures. This type of sophisticated data management needs systems that can deal with a high number of updates, manage multi-dimensional orbital data, and model complex, inter-constellation satellite relationships. This is just considering the data generated by active, operational satellites. Adding in lethal, non-trackable pieces of space debris, we then quickly run into differing requirements of object categorisation, the need for alternate detection methodologies, storage protocols and processing capabilities.

Currently, the management and sharing of data and safety of flight warnings is carried out by the US Space Force, 18th Space Defense Squadron (18SDS). This is



achieved through the daily updating of SpaceTrack.org[3] – a service that long predates the increase in space traffic – and providing a direct warning to operators if a conjunction is detected within a specific range of probability. Although there has been a proliferation of commercial SSA companies in the last ten years, the US Space Force still primarily relies upon the US Space Surveillance Network (SSN) as its source of data and information.

Space Surveillance Network

The SSN is a network of radar, electro-optical and passive radio frequency (RF) sensors used for missile warning, space object cataloguing and identification alongside safety and compliance monitoring. Only a few are dedicated to space tracking, with many of the ground-based radars optimised to support missile warning and defence.

The work that we undertake at 3S Northumbria, and with our American partners at Exo-Analytic Solutions, illustrates that analysing space traffic data is not just a question of managing the volume of information. It encompasses diversity and complexity in data types. To have complete space situational awareness, systems must process observational data from ground-based radar systems, optical telescopes and space-based sensors. Each one of these will generate data in different formats, have differing accuracy levels, update at different times and ultimately come from different sources.

Additionally, there are differing requirements for the different orbital regimes. Objects in LEO often require faster response times than those in geostationary orbits due to the operational dynamics of the regime. They are travelling at speeds akin to 7 km per second, orbiting the Earth in as little as 90 minutes. Therefore, warnings of any changes or dangers are short and need to be processed and executed rapidly. We haven't even touched on the effects of the environment outside Earth's atmosphere, which can have a significant effect on the propagation of orbits.

Utilising new technologies

Adding artificial intelligence (AI) and machine learning algorithms into the mix brings another layer of complexity. Such systems require extensive training datasets, as well as access to active sensor feeds. Often, the wealth of data needed to support effective AI is not available due to government and military classification restrictions. This is all combined with historical trend data to try to accurately predict orbital trajectories, as well as collision probabilities. As a result of all of this, any data infrastructure must accommodate not only the raw observational data but also the processed outputs from these various algorithms. Whilst these difficulties are not insurmountable, they do point to some of the difficulties encountered by policymakers and regulators when trying to manage satellite operations in Earth orbit.

Safe space operations depend upon near-real-time sharing and dissemination of information to provide collision warnings and recommend collision avoidance manoeuvres. Although the current support to operators appears adequate, it begs the question of whether it can handle any further increases in space traffic. Any hope for space traffic management in the future will rest upon the ability of data providers to furnish near-real-time data processing capabilities. Standardising information and ensuring information sharing across international borders presents not only technical challenges with respect to the format of the data. There are also procedural and institutional obstacles, with no obvious formalised lines of communication between trackers, regulators, operators, and holders of data.

Establishing procedures and policies

In addition to these procedures and processes, which need locating within the proper institutions (and these may vary depending upon the jurisdiction), there is the

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challenge of establishing and maintaining the quality of the data produced whilst ensuring safe, sustainable, and secure space. Currently, the contours for liability for damage caused by one space object to another are uncertain, untested and cumbersome. The Liability Convention of 1972, Article III provides that a State will be liable for damage caused by their space object if it can be shown that the space object of that State (or the persons for whom they are responsible) caused that damage. The 1972 Convention goes on to set out a quasi-diplomatic mechanism by which damages for liability can be recovered.

If, as would appear likely, the liability for damage caused on-orbit rests with the party at fault, then an operator, deciding on whether to execute a collision avoidance manoeuvre, needs to be assured that the data they are relying on is of the best possible quality. There are numerous opportunities for imaginative legal advisors to challenge the integrity of data that has been integrated from ground-based sensors and then processed by algorithms. The mechanisms for managing and sharing the data need to be as certain as those for processing and analysing that data. Operators relying on data for safe operations will be quick to question the probity of data should a collision result in expensive claims for damages for damage caused while acting upon that data.

The reliance upon this vast amount of data clearly presents several difficulties. Primary amongst these is the requirement that the data is processed, stored, and shared in a format that is widely understood. Work has been ongoing with both the Consultative Committee for Space Data Systems (CCSDS) conjunction data message standard and the emerging ISO/TC20/SC14 standard for space traffic coordination, addressing the need for recognised international standards in data collection, storage and exchange with interoperable messaging formats. Establishing standardised international data sharing protocol can be achieved but requires dialogue between all uses of space, including satellite operators, national regulators, and commercial providers of SSA information, and also requires a change in how this is provided. There is a clear argument that the safety and sustainability of space should become a civil 'agenda', releasing the military organisations that currently provide the support to focus on security.

Further support needed for space operators

Looking to the future, the work being undertaken by the U.S. Department of Commerce should help alleviate the problem and provide greater safety support to operators. The Office of Space Commerce in the National Oceanic and Atmospheric Administration (NOAA) is developing the Traffic Coordination System for Space (TraCSS) to provide basic SSA data and services to civil and commercial operators in support of spaceflight safety. This will mean that the future of coordinating the orbital environment will involve integrating data from an ever-increasing array of sensor technologies. It is important, however, that the industry does not lose sight of the need for increasing this capacity alongside other more glamorous ways of spending money. Increasing the data sources will inevitably lead to the provision of better, more reliable data about the orbital environment. The resulting data management infrastructure will need to be flexible enough to accommodate these new types of sensors whilst being compatible with the existing legacy systems. And it will need to be international.

This discussion has sought to highlight some of the issues regarding data management as the number of objects in orbit continues to grow at a dramatic rate. These issues do not exist in isolation – the technical, operational, and governance obstacles must be addressed together. Increasing the number and variety of sensors gathering information about the orbital environment will inevitably lead to better data for operators. Managing that data and disseminating that data effectively will reap the benefits and represent low-hanging fruit for those concerned about the safety of operations in an ever-more congested orbital environment.

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Ralph Dinsley
Managing Director
3S Northumbria Ltd
+44 (0) 1665 517537

Professor Christopher Newman
Northumbria Law School
Northumbria University, UK
Space Law Consultant, 3S Northumbria


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