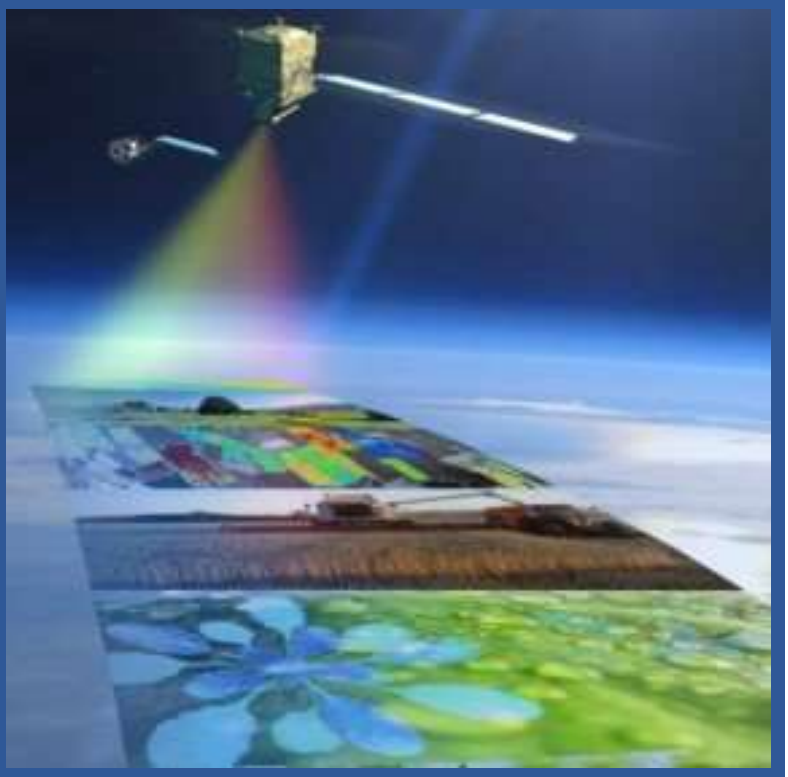
Evaluation of the Centre for Earth Observation Instrumentation (CEOI) Programme



WECD Reporting – Key Research Findings
Final

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Image on the cover: https://ceoi.ac.uk/technologies/optical-imaging/development-of-a-high-resolution-multispectral-camera-system-for-eo-applications-using-a-new-tdi-cmos-image-sensor/

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Abbreviations

3DPAMS	3D Printing for Atmospheric science- Multi-channel mm Sounder
AOCS	Attitude and Orbit Control System
ARTES	Advanced Research into Telecommunications Systems
BEIS	Department for Business, Energy, and Industrial Strategy
CSAR	Cryogenic Solar Absolute Radiometer
C4C	Capital for Colleagues
CAGE	Cold Atom Space Payload
CEOI	Centre for Earth Observation Instrumentation
CIIR	Compact Infrared Imager and Radiometer
CLARREO	Climate Absolute Radiance and Refractivity Observatory
CLASP	Challenge LED Applied Systems Programme
DASA	Defence and Security Accelerator
DSTL	Defence Science and Technology Laboratory
ECMWF	European Centre for Medium-range Weather Forecasts
EO	Earth Observation
EOEP	Earth's Observation Envelope Programme
EOI	Earth Observation Instrumentation
EPSRC	Engineering and Physical Sciences Research Council
ESA	European Space Agency
ESP-MACCS	Earth System Processes Monitored in the Atmosphere by a Constellation of CubeSats
EUMETSAT	EUropean organisation for the exploitation of METerological SATellites
FAAM	Facility for Airborne Atmospheric Measurements
FLI	Forward Looking Imager
GCOS	Global Climate Observing System
GPUs	Graphical Processing Units
HYMS	Hyper-spectral Microwave Sounder
ISR	Intelligence, Surveillance and Reconnaissance
JCR	Java Content Repository
JPL	Jet Propulsion Laboratory
LEGO	Lasers for Earth Gravity Observation
LHR	Laser Heterodyne Radiometer
LIDAR	Light Detection and Ranging
MSSL	Mullard Space Science Laboratory
MRL	Mission Readiness Level
MURMIS	Multispectral InfraRed Molecular and Ices Sensor
MWIR	Mid-wave Infrared Imager
NCEO	National Centre for Earth Observation
NERC	Natural Environment Research Council
NIMCAM	Near Infrared Multispectral Camera
NISP	National Innovation Space Programme

NOC	National Oceanography Centre
NPL	National Physical Laboratory
NSIP	National Space Innovation Programme
NSTP	National Space Technology Programme
NWP	Numerical Weather Prediction
OBDA	On-Board Data Autonomy
OSCM	Ocea Surface Current Mission
OVERPass	On-Board Video Rapid Processing
PSRE	Public Sector Research Exploitation Fund
QKD	Quantum Key Distribution
R&D	Research and Development
RAL	Rutherford Appleton Laboratory
ROKS	Responsive Operations Key Services
RSPSoc	Remote Sensing and Photogrammetry Society
SAR	Synthetic Aperture Radar
SATOC	Satellite Oceanographic Consultants Ltd
SERMON	Spectroscopic-system for environmental monitoring
SMEs	Small to Medium-sized Enterprises
SPECTRE	SPECtral Target Recognition Engine
SPIDER	Ship Position and Detection Radar
SRL	Science Readiness Level
SSTL	Surrey Satellite Technology Ltd
STFC	Science and Technology Facilities Council
TRL	Technology Readiness Level
TRLs	Technology Readiness Levels
TRUTHS	Traceable Radiometry Underpinning Terrestrial- and Helio-Studies
UKSA	UK Space Agency
WMO	World Meteorological Organisation

Executive Summary

The Centre for Earth Observation Instrumentation (CEOI) was established in 2007 as a programme initiated by the Natural Environment Research Council (NERC) to support the development of UK technical capability in innovative Earth observation instrumentation and offer a strategic source of funding for developing this capability.

With the formation of the UK Space Agency (UKSA) in 2010, UKSA took over responsibility for the CEOI programme. UKSA provides technical advice on UK government's National Space Strategy. The Agency designs and delivers programmes that implement this strategy including as a sponsor of national capabilities and an investor in space research and development.

As the latest contract for CEOI (running since 2016) is coming to an end, UKSA commissioned WECD to undertake the evaluation of the CEOI programme. The main aim of the evaluation was to provide evidence, insight and recommendations to inform the Agency's decisions on how best to continue supporting the UK Earth observation sector in the coming years, in the wake of the strategic direction set out by the National Space Strategy and resulting opportunity to develop the UK's national space programme.

To address the evaluation objectives, the methodology combined desk-based review of programme information and sector related secondary resources with primary research including interviews with CEOI-funded projects (32 of 52 technology projects involved in six calls of the programme between 2016 and 2021) and the programme's main stakeholders (31 individuals in 18 organisations). The main findings from these research tasks are summarised below under each of the main evaluation questions. Recommendations for the way forward are also included in the main report.

Evaluation Findings

1. How effectively has the programme been delivered and implemented since 2016?

The desk-based research and interviews conducted as part of this evaluation indicate that **the CEOI programme has been very effective to date** - it has delivered all its main activities as planned (contractually) and to **high levels of satisfaction and additionality** as reported by both, programme stakeholders and funded projects.

In particular**, the programme has delivered important outputs and outcomes to strengthen the UK EO sector**. These outputs and outcomes include: **identifying** technology projects aligned to EO market strengths and capabilities; **supporting** successful mission concept bids to ESA; **accelerating** the development of new UK EO instrumentation and technologies involving management, scientists and researchers in academia and larger and smaller businesses and public sector research establishments; and **making a significant contribution** to supporting maturity of technologies i.e. towards higher Technology Readiness Levels (TRLs) for the projects funded. With respect to TRLs, the **CEOI programme can be credited with contributing to 'advancing' CEOI-funded technology development projects across TRLs** - a primary indicator of technological development i.e. maturity of projects (the advancement towards higher TRLs could also be used as a proxy indicator for better chances for the projects winning commercial opportunities). Feedback received from the CEOI-funded projects indicates that projects tended to start at TRL 2 and 3, and, after CEOI funding, were raised to TRLs 4-6 (with one project even being raised to TRL 7 from 2/3).

These outputs and outcomes represent critical steps and the necessary foundation for building UK national capabilities and a stronger and globally recognised UK EO research and technology development ecosystem, ultimately leading to economic growth (e.g. jobs, productivity and income) and enhanced societal benefits.

2. What are the barriers and drivers to programme effectiveness and efficiency?

Effectiveness and efficiency of the CEOI programme is driven by:

- **The unique offer of the CEOI programme in the UK -** that provides support to fundable/investable EO instrumentation-related technology development projects (for potential use in space and non-space related sectors), de-risking their further development and successfully introducing and guiding them through to larger projects and systems and (new) commercial markets.

- **A highly regarded governance, management and delivery structure by the UK EO community (and UK space and defence sectors)** – drawing on the expertise, knowledge and credibility of the CEOI team. The team has offered a credible mechanism and platform for scientists, technologists, the commercial sector, policy makers and ESA to develop their technologies. This credibility has been built on the CEOI team's understanding of both technological and commercial aspects of what is needed to further develop technologies and assist them in participating in larger projects and opportunities.

- **An established and trusted relationship between the CEOI team and ESA –** with ESA regarding the CEOI team as a trusted and neutral partner, who is effective in consolidating and representing UK EO-related work.

3. What can be done differently/more effectively to meet CEOI and UKSA objectives?

The main areas for improvement of the programme cited by stakeholders and projects relate to **funding levels and approach for EO instrumentation related programmes and projects and the UK (national) approach for space missions**, namely:

- **Consistency of funding for EOI technology development** could be improved and this applies equally to projects as well as the programme itself including long-term commitment via ring-fenced funds for work related to the CEOI programme. For example, the UK is a leader in first generation miniaturisation but to retain this position will require long-term commitment of public funding for technology adaptation and learning from embedding technologies in larger systems or instruments, and also responding to new challenges.

- **Greater consistency of funding calls** will be welcomed by projects and stakeholders to enable the UK to maintain its leading position.

- Levels of funding will need to be reviewed to reflect technological developments and challenges in EO instrumentation for space exploration and other sectors, **with larger sums of funding required for both some lower TRL EO instrumentation technologies with market potential and proto-flight, airborne and in-orbit demonstration testing** (for example, through an additional tier of funding for projects around **£1 to £5 million)**.

- The need for **a UK national mission programme** (similar to Germany, Italy or France) and **associated funding and resourcing**, that is currently lacking. In 2020, the budget for the EO

national space and innovation programme for Germany's Space Agency, DLR (Deutsches Zentrum für Luft- und Raumfahrt), was EUR 31 million (of EUR 268 million of the German Space Agency for DLR national programmes only i.e. excluding the German ESA budget of EUR 945 million). However, it is worth noting that **DLR's structure of EO-related activities are structured in a different manner to the UK.** For example, the Earth Observation Centre (EOC) at DLR consists of the German Remote Sensing Data Centre (DFD) and the Remote Sensing Technology Institute (IMF), with both institutions being the leading national (publicly-funded) earth observation research and development institutions.

4. What benefits and impacts have been achieved amongst grant recipients? And for the skills base, space sector and economy more widely?

Desk-based review of the CEOI programme data and the interviews with stakeholders and projects indicate that a range of benefits have emerged as a result of the CEOI programme between 2016 and 2021. These include **scientific and technological benefits, and economic benefits** as follows:

- Facilitation of **collaborations and partnerships in the UK** – between industry, academia and public sector research establishments or larger and smaller businesses in space and non-space sectors, resulting to new projects for those involved. Non-space sectors where CEOI-funded projects could also have an impact include **telecommunications, security, finance, climate studies, and biomedical.**

- **Production of research and conference papers** (with the number produced tending to be between four and six papers per project).

- Contribution to **additional skills and training** (e.g. with employment of post-doctoral researchers, PhD students, MSc students and specialist technicians) and **multi-disciplinary research**.

- The CEOI programme **raises the profile of projects i.e. increases their visibility,** and provides them with credibility to **attract further funding (both public and private)** and **win new contracts.** On the basis of available information (for 18 of the 52 projects researched), it is estimated that CEOI-funded projects **leveraged approximately an additional £50 million** through follow on ESA, commercial and other public investments (excluding match funding contributions). As discussed later in the executive summary and the main report, the follow on total leverage could be higher as not all investments made during or after the completion of CEOI-funded projects have been disclosed.

- The programme has also led to the creation of **successful spin outs** through its funded projects (one is already established and two more are currently under development), and contributed to **growing turnover and employment size** for companies involved in the CEOI-funded projects. In addition, technical advances facilitated by CEOI have resulted in the UK being the world-leader in some new technologies i.e. **fully UK-sourced superconducting on-chip spectrometer technology,** previously concentrated in the US and the Netherlands), **promising potential opportunities globally for UK companies.**

The CEOI programme has also provided enhanced access to networking and knowledge exchange opportunities for the industrial and academic EO communities through its **Added Value Programme.** This part of the programme **successfully brings together academia and industry,** co-creating the way forward for EO technology development while **the CEOI team offers continuous support through to contract bidding and post-award**.

Since 2016, CEOI has **delivered 24 events**, averaging at four per year, with **over 1,850 participants representing over 60 organisations**. Event and workshop participants represent the breadth of the EO community, including: **ESA**; **government departments** (e.g. Ministry of Defence, the Defence Science and Technology Laboratory (DSTL) and Ofcom); **academia** (e.g. Universities of Birmingham, Glasgow, Imperial College London, Leeds, Reading and Southampton); independent research institutes (e.g. National Oceanography Centre, National Physical Laboratory and Fraunhofer CAP); and businesses, including both **large companies** (e.g. Airbus and Thales Alenia Space) and **SMEs** (Craft Prospect, In-Space Missions, Oxford Space Systems, Pixalytics, Surrey Nanosystems, and Twin Paradox).

The CEOI programme has been particularly beneficial for academics**,** as it has enabled them to lead bids or participate in bids where they could not bid for through other fundings grants (where the required outputs mostly relate to science and research elements). In particular**, academic researchers find it challenging to identify the opportunities, assemble and prepare the relevant resources to successfully bid for ESA missions without the necessary funding and support for progressing projects towards higher TRLs.** Funding and support offered by the CEOI programme has paid for staff time, networking with the sector including companies and technologists, brokering and building relationships with potential clients including ESA; making the linkages with other potential uses to move ideas and technologies up the Science or Technology and Mission Readiness levels (SRL, TRL, MRL); and also investing on developing relevant skills e.g. preparation of bids, risks assessment, and business or project management.

5. To what extent does the programme represent value for money?

The **CEOI programme** has achieved its contracted deliverables in spite of the pandemic and **returns a good value** against its contracted arrangements (i.e. **more deliverables produced for resources contracted**[1]).

In addition:

- The **programme's additionality is relatively high**. The majority of respondents to the project survey (70%) would not have undertaken their projects without CEOI funding.
- **Eight new UK EO technologies have won competitions and been selected for mission programmes**, representing 17% of the 46 completed projects over the period 2016 to 2021.
- The primary research undertaken as part of this evaluation did not survey all the end-users/businesses involved in CEOI-funded projects, and the survey of 32 projects provided limited information on business performance issues (e.g. value of contract won, employment size and turnover). However, on the basis of secondary data on economic benefits for the public investment that could be attributed to the CEOI programme, **the estimated return on public investment for the programme is approximately £3:£1** (drawing on an estimated public investment on the CEOI programme of approximately £17-£20 million on CEOI technology development grants and the CEOI added value programme over the period 2016 to 2021 and the resulting additional follow on leverage of approximately £50 million). The overall figure of additional leverage could represent **an underestimate** as relevant information related to investments made by various companies involved in the CEOI projects and key business

[1] https://www.nao.org.uk/successful-commissioning/general-principles/value-for-money/assessing-value-for-money/

performance indicators (e.g. employment and turnover) following their involvement with CEOI has not been disclosed.

6. How well aligned is the CEOI with other government technology development activities? Are there any synergies with other grant programmes which could be built upon? Are there any duplications which could benefit from better grant targeting?

The CEOI programme represents a relatively unique offering with few other sources of funding providing a similar focus or type of support – for technology development and testing of EO instrumentation (including both high and low level technologies).

The CEOI programme is seen as an important part of the UK research and development funding ecosystem and **is the only scheme to fund development of low-level technologies and technology development associated with EO instrumentation – for space and non-space use**. It is an important funding route to develop and test the feasibility of innovative ideas and instruments and de-risk technology development. **Low-level technology development (including as part of a larger project or system) receives limited support from other public funding sources**. Private funding is also limited for these technologies as potential returns on these investments may be hard to predict: low-level technologies may not be complex in terms of scientific or mechanical features nor require large amounts of capital investment; however, success of their application and use in larger projects or systems is unknown and needs to be tested, and testing carries significant risks of failure.

The programme already has good links with NPL (National Physical Laboratory) and ESA. In particular the **relationship between the CEOI and ESA teams** is **now very well-established and mutually beneficial**. The CEOI team provides knowledge of required processes and the content of bids to meet ESA requirements, greatly improving the ability of UK projects to compete for bids in **an impartial manner** (which is highly regarded by ESA). As a direct result of the work of the CEOI team (and UKSA) through the CEOI programme, the ESA team now has a far greater understanding of the capabilities of the UK EO sector. The fact that many CEOI-funded technology projects would not have taken place without the CEOI support is indicative of its importance in the funding landscape.

The desk-based review and interviews have also highlighted that some synergies and linkages between CEOI and other organisations and programmes will need to be explored. These include synergies with DSTL/the DASA (Defence and Security Accelerator) calls and linkages between CEOI and NCEO (National Centre for Earth Observations) and CEOI and the Engineering and Physical Sciences Research Council (EPSRC). For example, regular meetings (e.g. quarterly or biannual) with DSTL could identify issues and challenges of common interest for which joint calls and assessments can be organised. Engagement with EPSRC could also provide additional technical and engineering expertise.

7. Are there any notable gaps in the R&D funding landscape which are holding back the advancement of the EO sector?

Some of the issues raised during the interviews have been presented under question 3 of the evaluation. Additional issues highlighted during the interviews are summarised below:

- The **UK R&D funding landscape tends to focus on high-level technologies**. **Low-level technology development receives limited support from public funding sources** (see also commentary under question six).

- **Single year budgeting** poses challenges for business and resource planning for projects and the programme.

- **Funding support comparable to that for similar programmes in other countries is needed** (see also commentary under question 3) – in particular as the opportunities for the UK EO community's engagement in decision-making in major mission programmes could be negatively affected by the specific arrangements surrounding country-level participation in ESA programmes.

- **Targeted (government-funded) support for companies including SMEs** in the UK **to strengthen the UK the supply chain needed by multinational enterprises (MNEs) and original equipment manufacturers (OEMs)** operating in this sector. Support for SMEs could take the form of: tax incentives for any investments made by SMEs in the sector in R&D (including in their plants/sites and workforce development); provision of grants or free advice for issues relating to technical issues but also financial and legal matters surrounding new contracts; and grants for travel and engagement to facilitate technology demonstrations. All these incentives will support SMEs that may have the agility to be more experimental but require external funding to take these steps.

8. Overall, does the current CEOI format remain the best way to support the UK EO sector? Are there opportunities to do anything more or differently to more effectively support the aims and objectives of the National Space Strategy and the UKSA?

EO is clearly a significant sector in global markets and the UK economy in terms of catalysing public investment and generating contracts for the UK space sector, through its relationship with **the space and defence sectors but also others sectors of the economy** including addressing **climate change** and **environmental challenges**. Therefore, continuing public investment on the EO sector development is imperative.

The content of the CEOI programme with its **focus on instrumentation has worked well** and provided the **concentration and coordination** needed for the programme to achieve its goals. It has also **simplified** the UK R&D&T landscape in the domain of EO instrumentation for potential partners and stakeholders operating from outside the UK.

The successes of a programme such as the CEOI requires a large number of diverse capabilities, resources (human and capital) and networks. The CEOI programme has been **an instrumental broker and has offered highly-respected, impartial, effective and efficient leadership and management** in taking the **UK EO community from a zero position in participation in major mission programmes in 2007 to UK developed technologies winning competitions and participating in major ESA and NASA programme programmes by 2020.** A notable example of this success is the UK-led ESA's **TRUTHS mission**, where CEOI funding supported the National Physical Laboratory (NPL), working in collaboration with Airbus Defence & Space and the University of Reading, in increasing the TRL of the Cryogenic Solar Absolute Radiometer (the main solar measurement instrument) and the in-flight calibration system, both vital elements to the mission concept, from level 3 to level 5. The new TRL indicated a high enough technology maturity to be considered by ESA for delivering its programmes, resulting to TRUTHS being selected **from 35 mission proposals** and added to the list of missions to be financed under the ESA Earth Watch programme.

The **current governance, management and delivery structure** of the programme **has worked well to date** – and, in particular, it has provided to date the **impartiality** needed to build trust and a successful working relationship with ESA. The programme also tends to be oversubscribed within its available resources. The CEOI team's know-how of technology development and transfer of EO

instrumentation technologies (both low-level and high-level) into larger projects and systems sets it apart from other operational models. The future structure of the programme will need **additional permanent or longer-term resources** to address some of the issues highlighted during this evaluation and **well-defined short and long-term objectives** (clearly aligned to a strategic approach to the UK's objectives in relation to the National Space Strategy).

A programme of this scale and significance will also require **a detailed implementation plan.** This plan should include specific goals, resource allocation, financial planning, risk assessment and contingency plans relating to match-funding or contract delays, and a more concrete approach to monitoring and assessing benefits and impacts for the sector and the end-users/beneficiary organisations involved in the various projects (beyond monitoring of the contractual performance of the programme with UKSA).

1. Introduction

1.1. The UK Space Agency (UKSA) provides technical advice on UK government's National Space Strategy. The Agency designs and delivers programmes that implement this strategy including as **a sponsor of national capabilities and an investor in space-related research and development**. The Centre for Earth Observation Instrumentation (CEOI) was established in 2007 as a programme initiated by the Natural Environment Research Council (NERC) to support the development of UK technical capability in innovative Earth observation instrumentation and offer a strategic source of funding for developing this capability.

1.2. With the formation of UKSA in 2010, UKSA took over responsibility for the CEOI programme. As the latest contract for CEOI (running since 2016) is coming to an end, UKSA commissioned WECD to undertake this evaluation. The main aim of the evaluation has been to provide evidence, insight and recommendations to inform the Agency's decisions on how best to continue supporting the UK Earth observation sector in the coming years, in the wake of the strategic direction set out by the National Space Strategy and resulting opportunity to develop the UK's national space programme.

1.3. This report presents the main research findings from this evaluation. The report is structured as follows:

- The remainder of this section presents an overview of the context for this evaluation, the objectives of the evaluation and a brief description of the programme.
- Section 2 presents key findings from the evaluation research (in response to the main evaluation questions).
- Section 3 draws conclusions and makes recommendations.

The context

1.4. Earth Observation (EO) refers to remote sensing and in-situ technologies used to capture the planet's physical, chemical, and biological systems and to monitor land, water (i.e. seas, rivers, lakes) and the atmosphere. Satellite-based EO by definition relies on the use of satellite-mounted payloads to gather data about Earth's characteristics. As a result, satellite-based platforms are suitable for monitoring and identifying changes and patterns for a range of physical, economic, and environmental applications globally. Once processed, EO data can be assimilated into complex models to produce information and intelligence (e.g. forecasts, behavioural analysis, climate projections, etc.), and complemented by in-situ measurements.[2]

1.5. Beyond space, EO instrumentation technologies can also be used for measurement, optical imaging, global navigation, radar, and precision machining with applications across a much wider section of industries. These include agriculture, defence/security, maritime, medical/health, meteorology, oil and gas, rail, and water sectors. Specific market segments benefitting from EO[3]:

- Agriculture

[2] https://www.euspa.europa.eu/european-space/euspace-market/gnss-market/eo-gnss-market-report
[3] [sic.]

- Aviation and Drones
- Biodiversity, Ecosystems and Natural Capital
- Consumer Solutions, Tourism and Health
- Emergency Management and Humanitarian Aid
- Energy and Raw Materials
- Environmental Monitoring
- Fisheries and Aquaculture
- Forestry
- Infrastructure
- Insurance and Finance
- Maritime and Inland Waterways
- Rail
- Road and Automotive
- Urban Development and Cultural Heritage
- Space

1.6. In 2019, the Earth observation sector was estimated to have been worth US $58 billion globally.[4] It is estimated that EO services are supporting an estimated £100 billion (4.7%) of UK GDP.[5] The most recent report on the Size and Health of the UK Space Industry[6] estimates that **income of this sector (including meteorology) in 2019/20 amounted to be around £1.053 billion or about 6% of the UK space industry income** (compared with £475 million in 2016/17 or about 3% UK space industry income).

1.7. The European Space Agency (ESA) holds a world-leading position in EO – representing in 2022 the largest single area of investment at 22.5% of ESA's Budget (equivalent to £1.6 billion). Successfully bidding for a role in delivering **ESA EO programmes requires proven capability in the relevant technologies, and evidence that the technologies are at a sufficient Technology Readiness Level (TRL) for a mission to be selected – typically at least TRL 4, i.e. demonstration in a lab environment.**[7] An **EO instrument team also has to show that they have the required competence to take the technology to TRL 5 within 18-24 months and demonstrate the capability to then take it through TRL 6-9**.

1.8. In 2007, despite strong UK scientific involvement in ESA programmes (such as the Cryosat), UK organisations were not securing novel instrument technology contracts in ESA's Earth Observation Envelope Progammes 1 and 2 (EOEP1 and EOEP2) programmes. The CEOI programme aimed to improve this situation by supporting the development of UK capabilities in innovative EO technology and instrumentation, therefore strengthening the position of UK-led teams bidding for export opportunities and international contracts, particularly ESA EO missions.

1.9. In 2017, the UK EO Technology Strategy, prepared by CEOI on behalf of UKSA, set out clearly the UKSA vision for EO in the next 10 years: for the UK to be a world leader in new EO technologies. The ultimate aim is that over the next decade innovative new technologies developed by the UK EO space sector will make substantial contributions to economic

[4] https://geobuiz.com/geobuiz-report-2019/
[5] UK Space Agency, Size and Health of the UK Space Industry 2020 (May 2021).
[6] UK Space Agency, Size and Health of the UK Space Industry 2021 (April 2022).
[7] See: ESA Technology Readiness Levels scale.

growth, new jobs and societal benefit, with UK entities competitive in global EO commercial, institutional and science markets.

1.10. Within this context, CEOI aims to be the driving force in the UK for the development and delivery of UK expertise and capabilities in world-class instrumentation for national and international Earth observing (EO) missions **for science, operational and commercial needs.** To achieve this aim, the Centre brings together the academic community and industry through funding of EO technology development projects, horizon scanning and networking events. The end goal is for both the UK scientific community and UK businesses to be better-positioned to win leading roles in future space programmes.

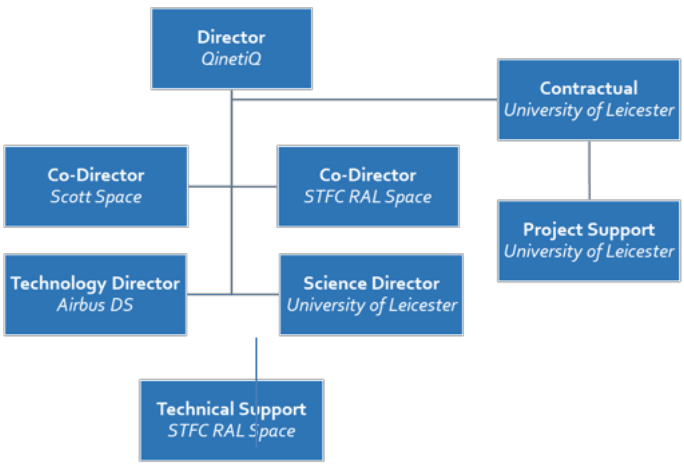
1.11. To deliver these objectives, to date, there have been two main stream of activities under which the CEOI programme has been delivered, as follows:

- **The Technology Programme:** a themed and open research and development (R&D) grant funding programme funding different size projects.

- **The Added Value Programme**: a networking and knowledge exchange programme consisting of a series of workshops and conferences – the programme seeks to engage with a wide cross section of the EO community in order to develop, forge and strengthen the links between academia and industry (including SMEs) in EO technology.

1.12. The **current contract of the CEOI programme** (signed in 2016) **has been led to the present day by an academic-industrial partnership,** consisting of QinetiQ, Airbus Defence & Space, ScottSpace Ltd, the University of Leicester, and STFC Rutherford Appleton Laboratory (RAL) Space. Part of the Added Value programme is sub-contracted and delivered in collaboration with Qi3,a company specialising in technology marketing and business development. The CEOI programme is funded by the UK Space Agency (UKSA), with parallel technology investments from industry and academia. Contractual and project administration support is provided by the University of Leicester (see Figure 1.1). The Leadership Team are responsible for the day to day operation of the CEOI, ensuring all aspects of the Centre are delivered in accordance with the UK Space Agency requirements.

Figure 1.1: CEOI Governance and Management Structure



1.13. Figure 1.2 summarises the rationale for the CEOI programme capturing its main activities and expected outputs and outcomes as described above.

Figure 2.1: CEOI Logic Chain[8]

Context and rationale: The Centre for Earth Observation Instrumentation (CEOI) was established in 2007 to support the development of UK technical capability in innovative Earth observation instrumentation and offer a strategic source of funding for developing this capability. At the time, despite strong UK scientific involvement in ESA programmes (such as the Cryosat), UK organisations were not securing novel instrument technology contracts in ESA's Earth Observation Envelope Programmes 1 and 2 (EOEP1 and EOEP2) programmes. The CEOI programme aimed to improve this situation by supporting the development of UK capabilities in innovative EO technology and instrumentation, therefore strengthening the position of UK-led teams bidding for export opportunities and international contracts, particularly ESA EO missions. In 2017, the UK EO Technology Strategy, prepared by CEOI on behalf of UKSA, set out clearly the UKSA vision for EO in the next 10 years: for the UK to be a world leader in new EO technologies, with the ultimate aim that innovative new technologies developed by the UK EO space sector make substantial contributions to economic growth, new jobs and societal benefit.

Inputs	Activities	Outputs	Outcomes	Longer-term outcomes
Government funding - £2 million per year for the technology programme and £40ok for the Added value programme **Industry and Academia collaborating** **Governance & Management -** combining industry, academic and government agencies resources and expertise (in particular sector, technical and project management) and a relatively lean organisational structure	**Technology Programme** • **'Flagship'** projects: up to £500,000 available, 24-month duration • **'Fast Track'** projects: up to £200,000 available, 15-month duration • **'Pathfinder'** projects: up to £75,000 available, 9-month duration	• Regular calls for projects – launch, assessment, project management and technical support • Distribution of annual funding through grants • Technology areas funded aligned to identified EO capabilities • Number of successful mission concept bids to ESA	• To enable the development of new UK EO instrumentation and technologies • To support the development of low-mass cost-effective EO instrumentation for institutional and commercial markets • TRL progress to higher levels for the projects funded	• To establish the UK EO technology community as recognisable capable national asset • To create strong UK EO bidding teams for national and international competitions resulting to winning commercial opportunities and investment on UK businesses and people • To leverage external follow on funding
	Added Value Programme • Challenge workshops • Industry consultation workshops • Technology showcases • (Annual) UK National Conference - in partnership with the National Centre for Earth Observation (NCEO) and remote sensing & photogrammetry society (RSPSoc) • Horizon Scanning (supporting the UK Space Agency) • Conduit and coordinator for the UK EO community in discussions with ESA • ESA bits mock interview sessions	• Number of events • Number of participants at events • Organisations participating in events	• To increase knowledge exchange between the academic and industrial EO community • To promote CEOI capabilities, technologies, and achievements of the UK EO research and industrial sector • To improve understanding within the UK EO community of opportunities presented by CEOI, UKSA and mainly ESA, the EU/Copernicus	**Impacts** UK EO technology development activities leading to: • New jobs • Increased income and GVA for the UK • Increase exports • Increased contribution to societal benefits

[8] Impacts reflect the EO Strategy and not the contractual arrangements between CEOI and the UK Space Agency.

The evaluation brief

Research questions

1.14. The evaluation was commissioned to assess CEOI activities and funding, with the focus being on the following questions:

1. How effectively has the programme been delivered and implemented since 2016?
2. What are the barriers and drivers to programme effectiveness and efficiency?
3. What can be done differently/more effectively to meet CEOI and UKSA objectives?
4. What benefits and impacts have been achieved amongst grant recipients? And for the skills base, space sector and economy more widely?
5. To what extent does the programme represent value for money?
6. How well aligned is the CEOI with other government technology development activities?
7. Are there any synergies with other grant programmes which could be built upon?
8. Are there any duplications which could benefit from better grant targeting?
9. Are there any notable gaps in the R&D funding landscape which are holding back the advancement of the EO sector?
10. Overall, does the current CEOI format remain the best way to support the UK EO sector? Are there opportunities to do anything more or differently to more effectively support the aims and objectives of the National Space Strategy and the CEOI?

Overview of methods

1.15. To address the evaluation objectives, the methodology combined desk-based review of programme information and data with primary research including interviews with CEOI-funded projects and the programme's main stakeholders. The research programme was conducted in March 2022 and the main tasks included:

- **Desk-based review** of background documents and data related to the CEOI programme, e.g. annual and quarterly reports produced by CEOI, and relevant policies e.g. UK Space Agency, Size and Health of the UK Space Industry 2021 and UK Space Agency, Space Innovation and Growth Strategy, 2010-2030 (2010).
- **Interviews with stakeholders**, 31 individuals in 18 organisations – to gather feedback on the programme's rationale, design, delivery model, added value and suggestions for its future focus and approach. The list of organisations who participated in these interviews is included in Appendix A and the script used for these interviews in Appendix B.
- **An online survey and interviews** with key members of teams involved in 32 out of the 52 CEOI projects funded to date (**representing 62% of all projects funded**) – to provide feedback on their experiences from the application process, reasons for seeking funding through CEOI, benefits and added value of the porgramme support and funding,

including additional leverage and contracts generated following on from CEOI funding. The list of projects interviewed is included in Appendix C and the script used for the survey and interviews in Appendix D.

- **Review of relevant secondary data and information** to inform analysis and recommendations, including the programme's logic chain, and the development of case studies.

- **Review of approaches adopted in other countries** in funding similar programmes (i.e. EO-related) and national mission strategies.

2. Evaluation Findings

2.1. This section presents key findings from the evaluation research in response to the main evaluation questions listed in paragraph 1.14.

1) How effectively has the programme been delivered and implemented since 2016?

In summary, the desk-based research and interviews conducted as part of this evaluation indicate that **the CEOI programme has been very effective to date** - it has delivered all its main activities as planned (contractually) and to **high levels of satisfaction and additionality as reported by both, programme stakeholders and funded projects.** In particular**, the programme has delivered important outputs and outcomes to strengthen the UK EO sector**, as described in more detail in the next paragraphs. These outputs and outcomes include: **identifying** technology areas that are aligned to EO market strengths and capabilities; **supporting** successful mission concept bids to ESA; **accelerating** the development of new UK EO instrumentation and technologies involving management, scientists and researchers in academia and larger and smaller businesses and public sector research establishments; and **making a significant contribution** to TRL progress to higher levels for the projects funded and the capabilities in the EO sector..

All these outputs and outcomes represent critical steps and the necessary foundation for building UK national capabilities and a stronger and globally recognised UK EO research and technology development ecosystem, ultimately leading to economic growth (e.g. jobs, productivity and income) and enhanced societal benefits.

2.2. More detail about the programme's deliverables to date is provided below.

Programme activities

2.3. **Since 2016,** there have been six (6) open grant calls under the Technology Programme, encompassing **calls 8 to 13**.[9] These calls have **funded 52 projects**. Of the 52 funded projects:

- **Forty six projects (46) have been completed and six (6) are in progress**.
- Twenty-two (22) projects have been led by a university, 17 projects by a business (of which 5 by a small business), and 13 by a public sector research establishment (PSRE) e.g. STFC RAL Space – see Figure 2.1.
- CEOI-funded projects have involved 90 partners from across academia and industry, including 33 businesses (of which 19 were small businesses), 27 were a university, 15 were a PSRE, and one (1) was a government agency.
- In total, twenty-six (26) organisations have led the 52 projects (collaborating with an additional 40 distinct organisations) i.e. organisations involved with CEOI projects have

[9] The CEOI-2020 activities commenced in October 2016 as a continuation of the EO activities of the preceding CEOI-ST contract. This included overseeing the conclusion of 5 Flagship, 3 Fast Track and 2 Pathfinder technology projects which commenced under CEOI-ST from the CEOI 8th (that closed in September 2014) and 9th Calls. Therefore the latter two are included here given that the projects funded under these calls were delivered (and hence most CEOI support) in the period covered by this evaluation. The 14th CEOI call is being reviewed in parallel to this evaluation – it has not been included in the overall programme analysis as projects have not yet been contracted and full details are not yet available.

been involved with more than one project.

- **The majority of CEOI-funded projects (28 projects, 54%) have been led by organisations based in the South East,** followed by Scotland (7 projects, 13%) and the East of England (5 projects, 10%) (as shown in Figure 2.2).

Figure 2.1: Types of organisations involved in the 52 CEOI-funded projects

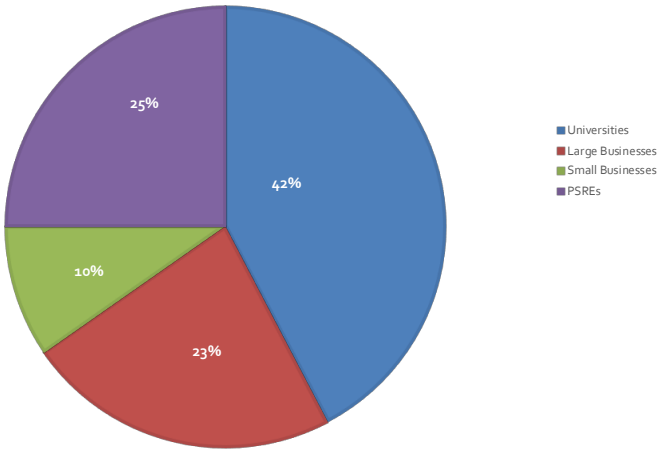


Figure 2.2: Region of CEOI project lead organisation

2.4. Alongside its technology grant funding programme, the CEOI programme provides **enhanced access to networking and knowledge exchange opportunities** for the UK industrial and academic EO communities through its Added Value programme of events. The strand has brought together **and facilitated collaboration and knowledge exchange** between the **UK EO research community, technologists, end-users, and policy makers.** Delivered in collaboration with Qi3, the knowledge exchange strand of the CEOI brings together UK scientists and engineers from academia and industry to develop UK capabilities in EO technologies and instrumentation.

2.5. Since 2016, CEOI has **delivered 24 events**, averaging at four per year, with **over 1,850 participants representing over 60 organisations**. Event and workshop participants represent the breadth of the EO community, including: **ESA**; **government departments** (Ministry of Defence, DSTL, Ofcom); **academia** (Birmingham, Glasgow, Imperial College London, Leeds, Reading, Southampton); independent research institutes (National Oceanography Centre, National Physical Laboratory, Fraunhofer CAP); and businesses, both **large defence firms** (Airbus, Thales Alenia Space) and **SMEs** (Craft Prospect, In-Space Systems, Oxford Space Systems, Pixalytics, Surrey Nanosystems, Twin Paradox).[10]

2.6. CEOI also **provides sector-related horizon scanning functions** for UKSA, for example, the UK EO Technology Strategy and the EO Missions Capability Review. The National Physical Laboratory's (NPL) **TRUTHS project (an ESA Earth Watch mission) came out of this review, highlighting the importance of CEOI's expertise and EO community convening roles.** Furthermore, the CEOI leadership represent the UK Space Agency in the EO community. See also case study on this part of the programme in Appendix E.

2.7. Table 2.1 summarises the performance of the programme against its contractual arrangements and delivery of additional supporting activities to UKSA by the CEOI team for ESA-related activities. The review indicates that **the CEOI programme** has achieved its contracted deliverables in spite of the pandemic and **returns a good value** against its contracted arrangements (deliverables produced for resources contracted).

Table 2.1: CEOI Programme Deliverables, contracted and actuals, 2016-2020/21

Deliverable	Description	Frequency		
		Contracted	Actuals	Assessment RAG rating[11]
Technology Calls	Calls for technology projects scaled to an assumed funding level of £2million per annum and aligned to the approved EO Technology Strategy	4 over five years	4 main technology calls between Dec 2016 and Nov 2021 and two support calls	

[10] This is a representative sample of the over 60 organisations participating in CEOI events from 2016-present.
[11] RAG (Red-Amber-Green) rating (known as traffic lighting rating system), where green=achieved, red=not achieved and amber=progressing steadily.

Deliverable	Description	Frequency		
		Contracted	Actuals	Assessment RAG rating[11]
	EO technology Strategy	Initial version after 6 months – version one before end of year 1	Completed	
	Independent Peer Review Panel	1 per call	As contracted	
	Technology Road mapping	4 assessments over 5 years	CEOI Co-ordination of UK Quantum Technology Expertise + CEOI Support for Mission Concept Preparation for ESA Earth Explorer 10 Proposals + Future Earth Watch Mission Studies + EO Mission Capability Review[12] including refresh	
	Call Project review	1 per call	As contracted	
Meetings with Agency	Review progress, advise the Agency, exchange information and receive the agree policy and strategic direction	4 per year	4+ per year	
Project Summary Spreadsheet	A spreadsheet summary of the contractual and technical progress of all projects	Monthly	Monthly Quarterly Annual	
Added Value Programme	CEOI Annual Conference Technology Showcase Events Consultations workshop report Challenge Workshop reports	4 over five years 2 over 5 years 10 over five years 10 over five years	An average of 4-5 event per year including over the period affected by the pandemic	
Additional support to UKSA for the ESA programme		Presumed rather than explicitly stated in contract	CEOI supports UK Space Agency in presenting UK technology capability to ESA. This takes place through invitations to ESA technology and EO experts to CEOI workshops and conferences in the UK, and	

[12] The review includes a range of activities: preparation of mission questionnaire; distribution and collation of responses; organisation of panel meetings; receiving supplementary information from mission proposers; organisation of community workshops; drafting and presenting reports; and providing feedback to proposers.

Deliverable	Description	Frequency		
		Contracted	Actuals	Assessment RAG rating[11]
			through dedicated meetings, held once or twice a year.	

Programme outputs

2.8. **CEOI funding has been distributed across a wide range of technology areas**. Table 2.2 provides an overview of how CEOI grant funding to date aligns with UK capabilities relative to international competitors in the main technology themes, together with growth trends in future markets, as set out in the 2017 EO Technology Strategy. **Projects funded by CEOI** have not focused only on areas where UK capabilities are relatively stronger or areas that only reflect strong market trends; instead, CEOI funding has aimed to capitalise on both relatively stronger areas of UK technical capabilities (e.g. Radar/SAR) and entering or capturing areas of relatively stronger market interest (e.g. IR imaging and IR spectroscopy), thus **reflecting a balanced (and realistic) approach within the resources available**.

Table 2.2: UK EO technology capability

Technology Theme	Relative UK strength	Market Trend	Comments[13]	CEOI-funded projects to (Calls 08-13)	Funding through CEOI £million
Passive microwave	✓✓✓	✓✓✓	• Excellent & established UK capability • Ongoing operational/science markets	11 projects	2.99
Optical/video imaging	✓✓✓	✓✓✓	• Excellent & established UK capability • Significant markets	11 projects	5.01
Radar/SAR	✓✓✓	✓✓✓	• Excellent & established UK capability • Significant commercial, operational/science markets	7 projects	2.66
IR imaging	✓✓	✓✓✓	• Growing UK capability • Growing markets	7 projects	0.76
Optical spectroscopy	✓✓✓	✓✓✓	• Excellent and established UK capability • Significant markets	6 projects	2.56
IR radiometry	✓✓✓	✓✓✓	• Excellent and broad UK capability • Ongoing operational/science markets	4 projects	2.14
IR spectroscopy	✓✓	✓✓✓	• Growing UK capability • Ongoing operational/science markets	3 projects	0.69
Quantum technologies	✓✓	✓✓	• Growing UK capability • Space market is long-term; non-space market more immediate	3 projects	1.11
LIDAR	✓	✓✓	• Growing UK capability • Viability of space-based LIDAR recently established (Aeolus)		
Radio altimetry	✓	✓	• Some UK capability; • Strong competition within Europe		

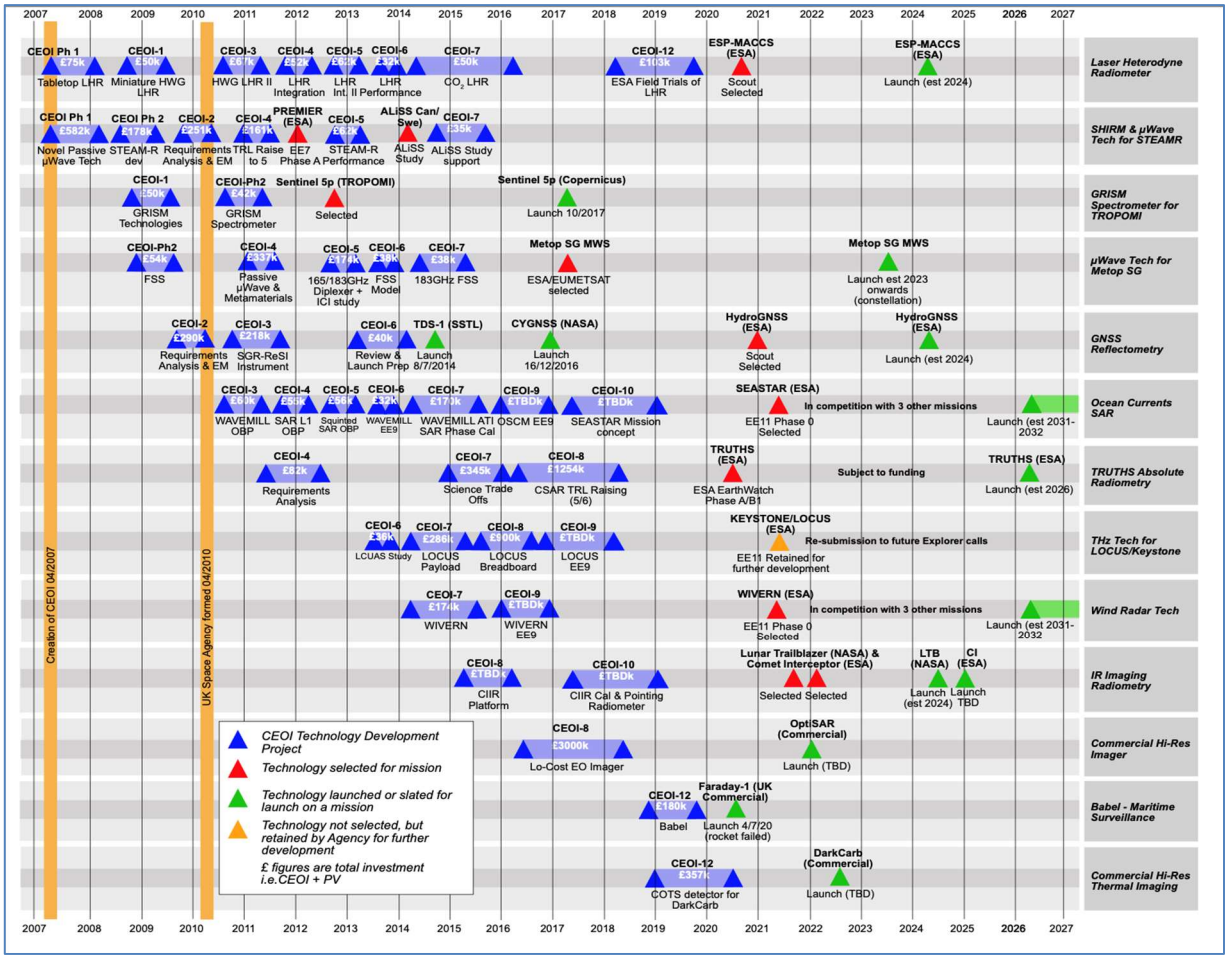
[13] The comments in the table come from a 'best efforts' panel assessment by the CEOI leadership team that aimed to inform the EO Strategy.

Technology Theme	Relative UK strength	Market Trend	Comments[13]	CEOI-funded projects to (Calls 08-13)	Funding through CEOI £million
UV spectroscopy	✓✓	✓	• Good UK capability • Limited user pull and mission opportunities		

Source: CEOI EO Technology Strategy[14] - where ✓✓✓ =strong (relative UK strength or trends) and ✓= weak

2.9. Between 2016 and 2022 **eight new UK developed technologies that were selected for mission programmes,** shown in Figure 2.3 **(see also case studies in Appendix E),** representing **17% of the 46 completed projects** within this timeframe. As also shown in Figure 2.3, only one of the projects funded by CEOI was not selected in this period, and it has been retained for further development.

Figure 2.3: Development and mission-related status of CEOI funded projects



Source: CEOI

[14] UK Space Agency, UK EO Technology Strategy (October 2019), p.7.

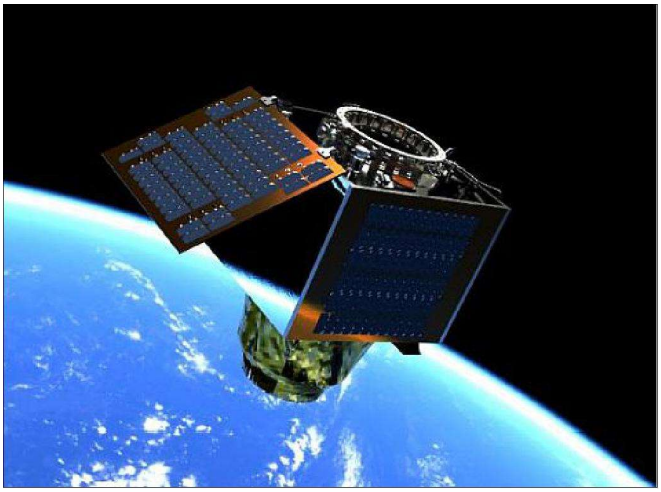
Programme outcomes to date

2.10. **CEOI** technology development projects include UK developed technologies that have won competitions **in ESA** programmes and contracts for **commercial exploitation.** Examples of ESA related projects include **TRUTHS (**Traceable Radiometry Underpinning Terrestrial- and Helio-Studies) **and SEASTAR.**

2.11. Developed by NPL, in collaboration with Airbus Defence & Space and the University of Reading, the TRUTHS mission will collect the most accurate measurements of energy coming into the Earth from the Sun, and light reflected off Earth's surface, to help understand changes in balance (global warming) and humanity's impact on the planet. TRUTHS was added to the list of missions to be financed under the ESA Earth Watch programme. This is a significant achievement, as ESA programmes are extremely competitive – **TRUTHS was selected from 35 mission proposals**. According to the interviews with stakeholders and lead members of the project, **this result would not have been achieved without the support from CEOI, both in terms of grant funding to develop the technology and concept, and technical advice received in preparing the proposal.**

2.12. Developed by the National Oceanography Centre (NOC) and Airbus Defence & Space, **SEASTAR is an innovative dual-beam interferometric synthetic-aperture radar (SAR) concept that improves SAR performance for oceanography**. The SEASTAR mission concept has recently been announced as one of four projects selected by ESA to proceed to the next stage of the Earth Explorer 11 programme. According to the interviews with the stakeholders, this **result would not have happened without the support from CEOI, both in terms of grant funding, and technical advice in preparing the mission concept proposal to ESA.**

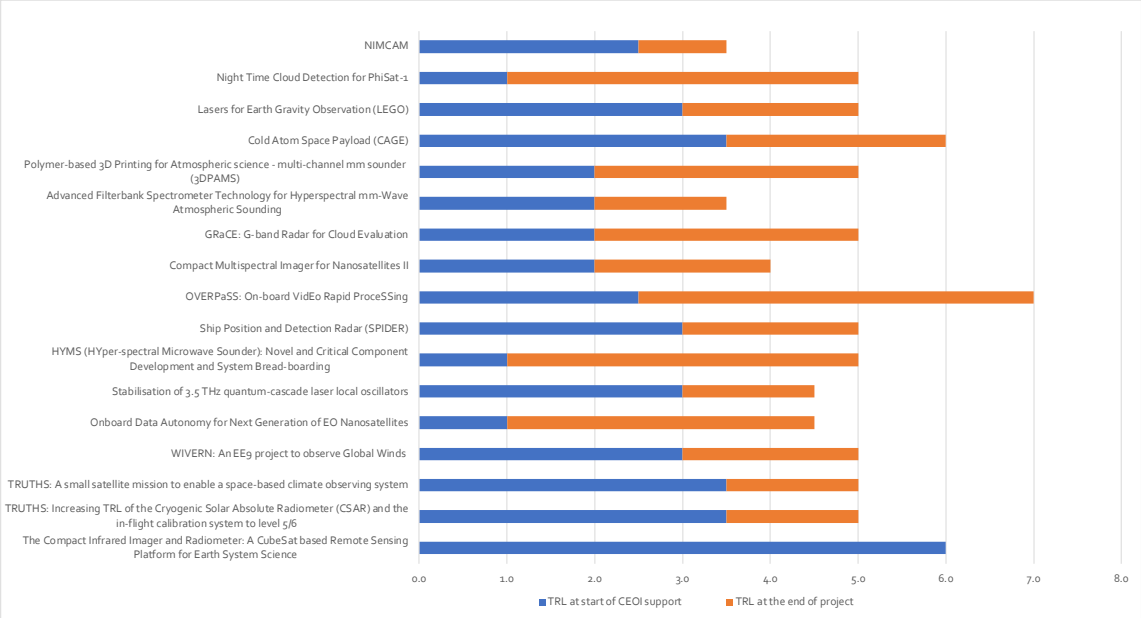
2.13. One of the technology development projects for **commercial exploitation is the** DarkCarb project. **Developed by** Leonardo UK **and** Surrey Satellite Technology Ltd **(SSTL) for Satellite Vu, the** DarkCarb project **has developed an innovative, low-cost mid-wave infrared imager (MWIR) for deployment on a small satellite platform** (see image on the right; credit SSTL). The concept overcomes current limitations by enabling imaging at both night and day under any lighting condition, providing additional temporal information by comparing temperature changes on a still target, and using temperature information to monitor items otherwise invisible to visible sensors. **DarkCarb is a highly innovative development in the commercial**



satellite imagery market, providing **affordable, high-quality and high-resolution imaging data for a range of applications,** including: building thermal efficiency monitoring; industrial asset monitoring; disaster monitoring, such as wildfires and volcanic eruptions; and monitoring aircraft and ships for defence and security (see a detailed case study for this project in Appendix E).

2.14. Furthermore, the **CEOI programme can be credited with contributing to 'advancing' CEOI-funded technology development projects towards higher TRLs** - a primary indicator of technological development among projects (the advancement towards higher TRLs could also be used as a proxy indicator for enhanced chances of accessing and winning commercial opportunities). Feedback received from the projects funded indicates that projects tended to start at TRL 2 and 3, and, after CEOI funding, were raised to TRLs of between 4-6 (with one project even being raised to TRL 7 from 2/3) – see Figure 2.4, and **with an average TRL increase of around 2.5** levels.

Figure 2.4: CEOI contribution to TRL advancement



Source: Survey of CEOI-funded projects (based on 17 CEOI-funded projects that provided relevant information – project leads interviewed).

2) What are the drivers and barriers to programme effectiveness and efficiency?

In summary, effectiveness and efficiency of the CEOI programme is driven by:

- **The unique offer of the programme in the UK** - that provides support to **fundable/investable new EOI-related technology development projects (for potential use in space and non-space related sectors) , de-risking their further development and successfully introducing and guiding them through to (new) commercial markets**.

- **A highly regarded governance, management and delivery structure by the UK EO community (and UK space and defence sectors) – drawing on the expertise, knowledge and credibility of the CEOI team.** The team has offered a credible mechanism and platform for scientists, technologists, the commercial sector, policy

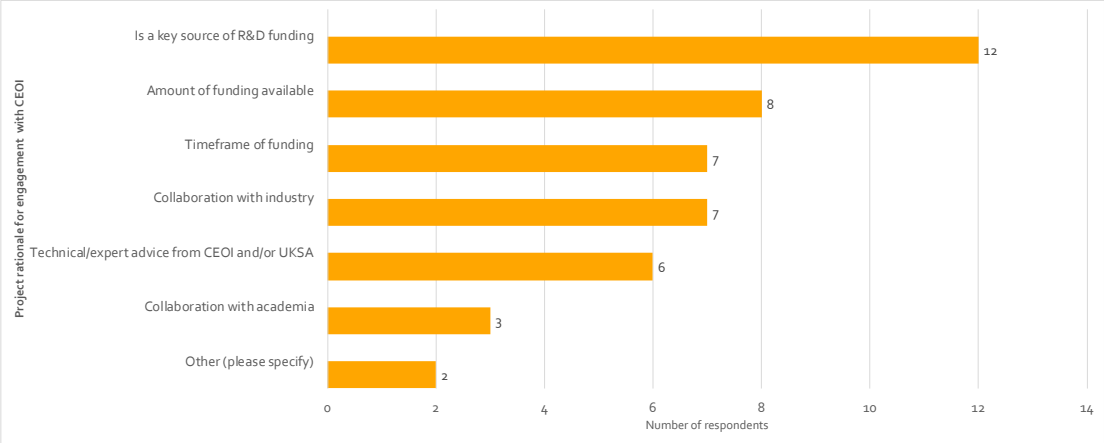
makers and ESA – **this credibility has been built on the team's understanding of both technological and commercial aspects of what is needed** including **understanding of the risks involved, embedding project management expertise in early stage scientific ideas and feasibility studies, the impartiality of the funding process**, and the **continuous support post-award including guidance for contracting arrangements.**

- **An established and trusted relationship between the CEOI team and ESA –** with ESA regarding the CEOI team as a trusted and neutral partner, who is effective in consolidating UK EO-related work.

2.15. Based on the responses received by the projects interviewed as part of this evaluation, **funding awarded by the CEOI programme is the main reason projects seek to engage with CEOI** (see Figure 2.5). Programme data also indicate that the programme tends to be oversubscribed as shown in Table 2.3.

2.16. Despite the synergies of the CEOI programme with the National Space Technology Programme (NSTP) and the National Innovation Space Programme (NISP), both UKSA programmes, the former is much broader than CEOI, and the latter focuses on a higher TRL. According to interviews with stakeholders and projects, **neither of these programmes offer the comprehensive support offered by the CEOI programme** in terms of markets' identification (with proactive support and guidance offered by CEOI that goes beyond the organisation and running of events and conferences that bring various interests together), and project management and technical oversight needed to secure shortlisting and ultimately winning business contracts.

Figure 2.5: CEOI-funded projects' rationale for engaging with CEOI



Source: Survey of CEOI-funded projects (based on 16 CEOI-funded projects that provided relevant information – project leads interviewed).

Table 2.3: Examples of subscription to CEOI Calls (8-13)

Call	Proposals received	Total grant ask £m	Projects awarded	Total grant awarded £m	Ratio Over-subscribed (£m)
8th Call	Flagship (10)	7.4	Flagship (5)	3.19	2.3
EE9 Support Call	Fast track (12)	2.25	Fast Track (6)	0.92	2.5

10th Call	IOD (2), Flagship (8), Fast Track (20), Pathfinder (22)	9.4	IOD (0), Flagship (2), Fast Track (7), Pathfinder (9)	2.43	3.9
EE10 Support Call	Pathfinder (5)	0.2	Pathfinder (4)	0.16	1.3
11th Call	Flagship (19)	12.1	Flagship (7)	4.88	2.5
12th Call	Flagship (4), Fast Track (18), Pathfinder (6)	5.5	Flagship (1), Fast Track (7), Pathfinder (2)	1.97	2.8
EE11 Support Call	Pathfinder (3)	0.14	Pathfinder (3)	0.14	1.0
13th Call	Flagship (10)	7.7	Flagship (2), Pathfinder (1)	1.92	4.0
	139	**44.69**	**56**	**£15.61**	**2.9**

Source: Programme data supplied by the CEOI team (April 2022).

2.17. The programme's delivery model has been described in paragraph 1.11-1.12. In terms of the application and selection process:

- Applications to the programme are reviewed in a transparent process by a panel of independent experts. The panel provides recommendations to the UKSA, who take the final decision on which project to fund in line with wider Governmental strategic priorities. The main criteria used for the assessment of applications are:
  - strategic importance including business/exploitation plan;
  - technological excellence;
  - project management; and
  - value for money.
- Contracts are managed via the University of Leicester.
- The CEOI team also:
  - provide technical and commercial feedback to applicants, whether successful or not;
  - oversee and monitor project progress, reporting on progress to the UKSA; and
  - provide ongoing technical and/or project management support.

2.18. There is a strong consensus, amongst both stakeholders and projects, that the **CEOI programme's application review process is fair, rigorous, and transparent,** described as the 'gold standard' by one stakeholder. According to funded projects, the application process is very useful and has been used to strengthen future bids, both to the CEOI and other funding programmes.

2.19. Key to the success of its delivery is, as one project interviewees commented, **'*...the clarity, coherence, and a degree and class of support seldom found elsewhere provided by the individual members of CEOI*'.** The CEOI role as a consistent port of call for advice around both process and the technical aspects of projects is integral to providing the feedback and flexibility to account for the specifics of each project but with the enough structure for recipients not to become overwhelmed.

2.20. In general, the CEOI team is perceived as having very impressive technical expertise according to both stakeholders and projects. Some of the comments provided are listed below.

'The technical rigour of the CEOI delivery team is impressive.'

'CEOI technical expertise is helpful for UK EO and space policy development. It costs more to have the CEOI leadership/governance set up as it is rather than in-house, but CEOI's technical expertise is very valuable.'

'CEOI's oversight of projects was good…they asked good, technical questions…they are a "critical friend".'

'CEOI is run by industry experts…they "know when they are being sold a pup". They know how to get the best value out of projects.'

'CEOI are very well managed. They have a fair, sophisticated review process and provide specific feedback, which is very useful.'

2.21. As commented by some stakeholders, UKSA lacks this level of technical expertise, so the **CEOI technical expertise is very valuable in supporting UK policy development on EO matters and in particular selection of the fundable projects and projects leading to technologies that are selected for mission programmes**. In addition the CEOI team have improved their approach to project management over the last few years, striking a welcome balance between technical oversight and project/programme monitoring. Overall, the CEOI management team are seen to run a 'very professional ship'.

2.22. As noted earlier (paragraph 2.4), the CEOI programme also provides enhanced access to networking and knowledge exchange opportunities for the industrial and academic EO communities through its **Added Value Programme.** This part of the programme **successfully brings together academia and industry,** co-creating the way forward for EO technology development while **the CEOI team offers continuous support through to contract bidding and post-award**, as required. As one stakeholder commented, the '*CEOI have done a credible job of convening the EO community'*. According to stakeholders, UKSA has not been able to fulfil this function due to technical and resource constraints – so the CEOI provides a valuable function. As another stakeholder commented, ***'the Added Value Programme makes the CEOI stand out' from other grant funding organisations.***

2.23. Respondents to the project survey **frequently praised the timescales of the funding calls**. **However,** it was often stated that **the consistency of the calls, both in terms of timing and topics, could be improved (**and this consistency would offer some predictability that would help projects – businesses and academic, with project planning). Additional recommendations for improvements focused on the application process including improving the times for responding to the calls and increasing the funding available (it is worth noting at this point that a number of projects also highlighted that increasing funding would require a corresponding increase in matched funding, which could, however, be prohibitive for many projects).

2.24. The general consensus amongst stakeholders was also that **the three funding streams have worked well to date**, providing funding for most stages of technology development. For example, it was commented that the lower value streams (Pathfinder and Fast Track) work particularly well for academia and SMEs. The funding runs over financial years, which is useful

for larger projects and provides flexibility when projects require further development or testing (highly likely on early-stage development projects of this nature).

2.25. In terms of the relationship with ESA, ESA considers the CEOI team (and the UK) a trusted and valuable partner (UK is one of the top contributors to ESA's EO programme budget). According to ESA, CEOI also consolidates and represents very well UK work and expertise in EO instrumentation capabilities, and brings relevant ideas to the table; its interactions with ESA also benefits the UK through the common infrastructure provided by ESA as the problems to be solved are complex and ambitious and no single country nor organisation has all the expertise.

2.26. The following word cloud reflects feedback provided about the CEOI programme as described above.

3) What can be done differently/more effectively to meet CEOI and UKSA objectives?

The main areas for improvement of the programme cited by stakeholders and projects relate to **funding levels and approach for EO instrumentation related programmes and projects and the UK (national) approach for space missions,** namely:

- **Reliability of funding for EO instrumentation technology development** could be improved (and this applies equally to projects as well as the programme itself including long-term commitment via ring-fenced funds for work related to the CEOI programme).
- **Consistency (i.e. regularity) of the funding calls** (as described in paragraph 2.20) will be welcomed by projects and the sector.
- Levels of funding will need to be reviewed to reflect technological developments and challenges in EO instrumentation, **with larger sums of funding required for both some low TRL EO instrumentation technologies and proto-flight, airborne and in-orbit**

demonstration testing; UK is a leader on first generation miniaturisation (small satellites) but to retain this position requires continuous public funding and technology adaptation and learning from larger instruments and responding to new challenges over a long period of time (could be 20—30 years).

- The need for **a UK national mission programme** (similar to France and Germany) and associated funding and resourcing, that is currently lacking.

2.27. More detailed feedback received from stakeholders and projects is presented below.

2.28. In addition to the issues raised in relation to the CEOI programme application process, stakeholders interviewed as part of this evaluation have highlighted that there is a need for **fourth tier of funding in the region of £1 to £5 million**. For example, this would support airborne and in-orbit demonstration testing, which would enable projects to move beyond TRL 5 – this is the point at which the majority of CEOI project funding stops. For example, supporting airborne demonstration would make CEOI-funded projects more competitive, both commercially and with ESA. Some stakeholders also commented that smaller grants of between £5,000 and £10,000 are inefficient to run due to overheads and management, and were not seen as good value.[15]

2.29. **A key challenge, particularly for industry projects, is the match-funding contributions** required to participate. Several stakeholders commented that the grant rules had recently changed and that contribution ratios were too high – industry find it challenging to provide 50% match-funding, particularly on larger projects (Flagship), where contributions could reach £250,000.[16]

2.30. The majority of the stakeholders asserted that the CEOI has been **successful in supporting the UK EO instrumentation capability and strengthening the position of UK-led teams bidding for ESA missions,** as mentioned earlier. CEOI projects have been successful with ESA Earth Explorer (SEASTAR, WIVERN), Earth Watch (TRUTHS), and Scout (HydroGNSS, LHR/CUBEMap) programmes, as well as with NASA Lunar Trailblazer (CIIR) and the ESA Comet Interceptor (CIIR). These ESA successes have also supported the winning of commercial contracts (e.g. TRUTHS).

2.31. Feedback by stakeholders highlighted that this **success is particularly significant given the relatively modest amounts of investment**, particularly compared to other European countries like France, Germany and Italy[17] with **the CEOI helping *'the UK punch above its weight'*,** as one stakeholder commented.

[15] CEOI ran the UKSA's NSTP funding from 2010-2016 which included smaller grants of this nature.

[16] The extent of financial and legal liabilities of private companies should accident happen in orbit also impact on companies' incentives to participate in projects i.e. a country's regulatory framework can be instrumental for private investment in this sector too (See Luxembourg, Germany and USA) – extensive literature; example see: https://ghum.kuleuven.be/ggs/publications/working_papers/2017/190linden

[17] In 2020, DLR's - Deutsches Zentrum für Luft- und Raumfahrt - (Germany's Space Agency) EO – National space and innovation programme was EUR 31 million (of EUR 268 million of the German Space Agency for DLR national programmes i.e. excluding the German ESA budget of EUR 945 million). See: https://www.dlr.de/EN/organisation-dlr/media-and-documents/facts/facts-and-figures.html . In 2017, Italy allocated some EUR 837 million to space activities. Key priorities of the Italian Space Agency budget includes earth observation (30%), launchers and space transportation (26%), and human spaceflight and microgravity

4) What benefits and impacts have been achieved amongst grant recipients? And for the skills base, space sector and economy more widely?

Desk-based review of the CEOI programme data and the interviews with stakeholders and projects indicate that a range of benefits has emerged as a result of the CEOI programme. These include **scientific and technological benefits, and economic benefits**. The vast majority of these benefits can be qualified. However, **quantitative information about the economic and commercial/financial benefits arising from new EO technologies and funded projects is limited at this stage, and only some estimates can be provided** drawing on secondary resources of data. Main benefits and impact of the programme include:

- Facilitation of **collaborations and partnerships in the UK** – resulting to new business for the projects involved in space and non-space sectors. Non-space sectors where CEOI-funded projects could potentially have an impact include **telecommunications, security, finance, climate studies, and biomedical.**
- **Production of research and conference papers** (with the number produced tending to be between four and six per project).
- Contribution to **additional skills and training** (e.g. with employment of post-doctoral researchers, PhD students, masters students and specialist technicians) and **multi-disciplinary research** (e.g. see the SEASTAR project).
- The **CEOI programme also raises the profile of projects** and provides them with credibility to **attract further funding (both public and private)** and **win new contracts.** It is estimated that projects-funded by the CEOI programme between 2016/17-2021 have **leveraged approximately £50 million** through follow on ESA, commercial and public investments.
- In terms of other economic benefits resulting from the CEOI-projects (e.g. jobs or Gross Value Added and exports), relevant information is not collected by projects. However, drawing on the survey feedback and secondary research (e.g. business data recorded by the Bureau Van Dijk database FAME[18]), some significant benefits for business that have participated in the programme have been identified. For example, **one** of the projects has already **established a successful spin out** operating in **space and non-space sectors** (see paragraph 2.37 and case study) and **two more** projects are currently considering establishing spin outs in the future (see case study in Appendix E).
- In addition, technical advances facilitated by CEOI have resulted in the development of **fully UK-sourced superconducting on-chip spectrometer technology (**CEOI12-FT001 – see Figure 2.3 and Appendix C**), which was previously concentrated in the US and the Netherlands,** promising potential benefits for UK companies.

2.32. More detail about these points is provided below.

Capabilities development

(20%) – see: https://www.oecd-ilibrary.org/sites/d143ef90-en/index.html?itemId=/content/component/d143ef90-en.

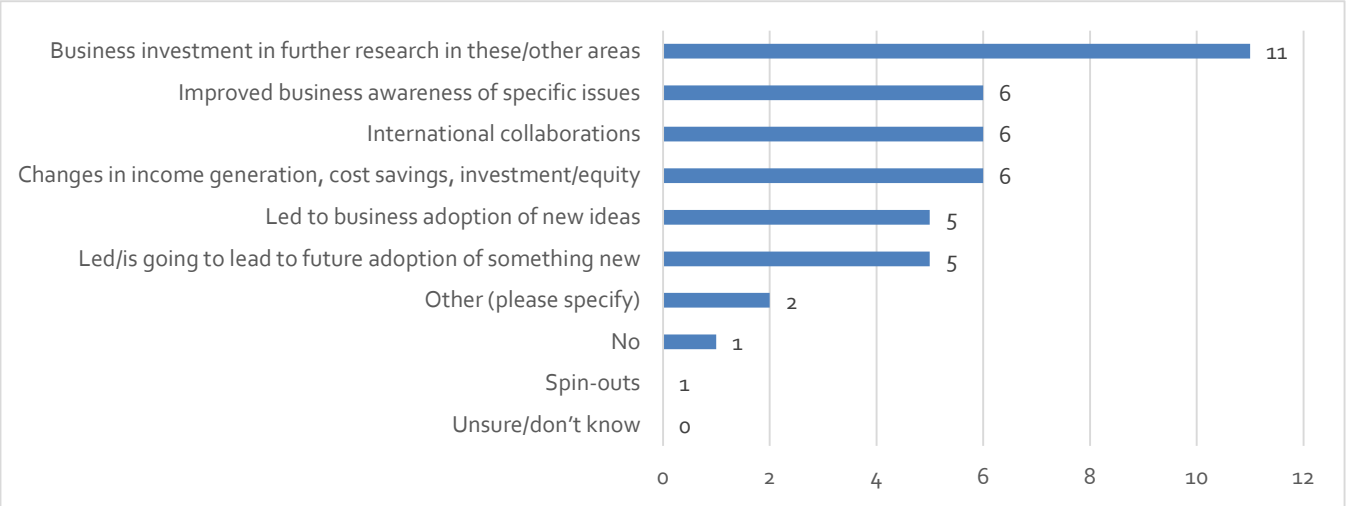
[18] https://www.bvdinfo.com/en-gb/our-products/data/national/fame

2.33. Direct benefits of CEOI support cited by the respondents to the project survey include the **facilitation of further business investment in research** – see Figure 2.6. According to the project respondents, the CEOI programme raises the profile of projects and affords them credibility making them more attractive for further investment.

2.34. In addition, as shown in Figure 2.6, the CEOI support has helped projects **improve their business awareness, increase income generation, facilitate international collaboration and lead to the adoption of new business ideas and practices.**

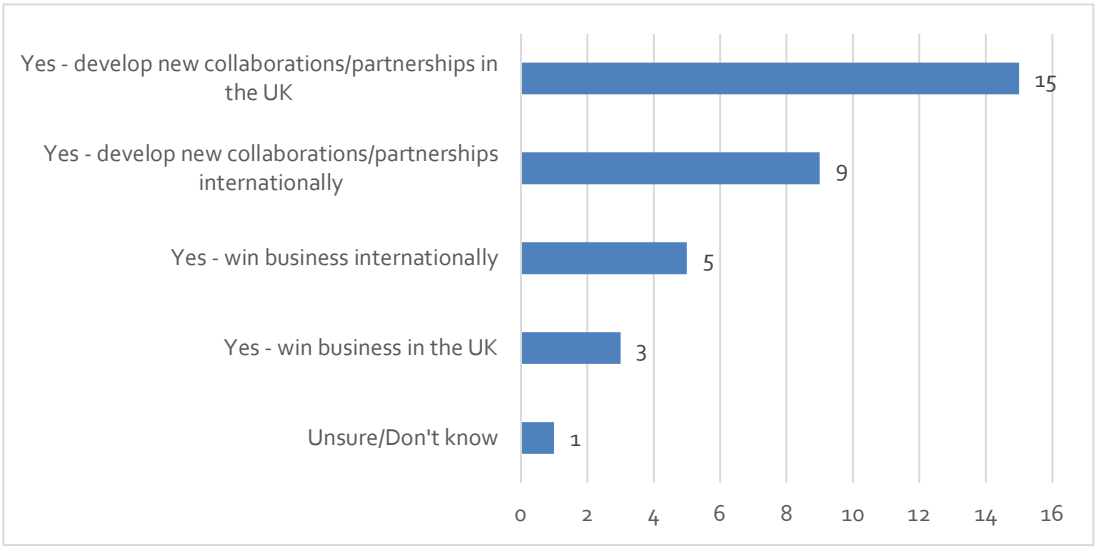
2.35. The majority of surveyed projects (15 of the 19 responding to this question) have stated that **CEOI support had facilitated collaborations and partnerships in the UK.** A smaller but still notable number of respondents stated that new business had been won either as a direct or indirect result of CEOI support – see Figure 2.7, with these benefits being the result of networking facilitated and 'doors opened' by the CEOI.

Figure 2.6: Ways the CEOI funding has helped projects



Source: Survey of CEOI-funded projects (based on 18 respondents – project leads).

Figure 2.7: How the CEOI support through project funding has helped (multiple selection possible)



Source: Survey of CEOI-funded projects (based on 19 respondents – project leads).

2.36. Additional benefits arising from the CEOI support cited by stakeholders and project respondents include:

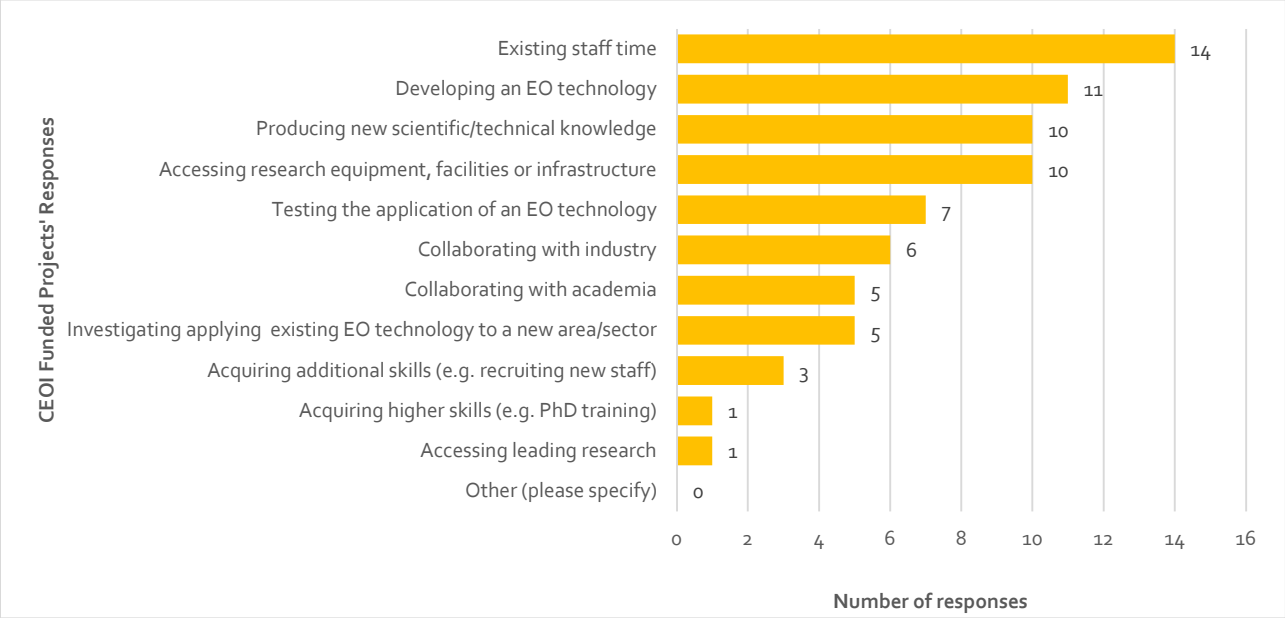
- **Contribution to additional skills/training** (mentioned by 12 respondents). This included post-doctoral researchers, PhD students, masters students and specialist technicians. One respondent noted that whilst their project received no formal educational support it did benefit from informal knowledge transfer which may apply to other projects.

- **Opportunities and support for multi-disciplinary research** – for example, the SEASTAR project represents a major step in addressing the multidisciplinary needs of the ocean, air- sea interactions, coastal processes, cryosphere, forecasting and climate communities. The National Oceanography Centre (NOC) **is leading a team of 70 international scientists to work on this project.** If successful through Phase 0 and Phase A studies (it has to compete with three other mission concepts), SEASTAR would be launched in 2031/32. If SEASTAR is launched, it could support improved climate models and forecasting, deliver increased observation capabilities in coastal and polar regions, support coastal management including shipping, fishing and off-shore renewables, and support environmental monitoring, for example, tracking oil spills and plastic pollution.

- **Contribution to producing research and conference papers** (mentioned by 12 respondents) with the number produced tending to be between four and six. One respondent stated the CEOI had contributed to his team producing 25 papers.

2.37. The CEOI programme has been **particularly beneficial for academics,** as it has enabled them to lead bids or participate in bids where they could not bid for through other fundings grants (where the required outputs mostly relate to science and research elements). In particular, **it is not possible for academic researchers to identify the opportunities, assemble and prepare the relevant resources to successfully bid for ESA missions without the necessary funding.** Funding and support offered by the CEOI programme is needed to 'pay' for staff time, networking with the sector including companies and technologists, brokering and building relationships with potential clients including ESA; making the linkages with other potential uses to move ideas and technologies up the Science or Technology and Mission Readiness levels (SRL, TRL, MRL); and also investing on developing relevant skills e.g. preparation of bids, risks assessment, and business or project management. A shown in Figure 2.8, the CEOI funding has been used on existing staff time.

Figure 2.8: Use of CEOI funding by CEOI-funded projects



Source: Survey of CEOI-funded projects (based on 16 respondents – project leads).

Economic benefits – business, sector and wider economy

2.38. Drawing on a number of secondary resources and through the project interviews, it is estimated that that projects funded by the CEOI programme between 2016/17-2021 have **leveraged approximately £50 million** through follow on ESA, commercial and other public investments – based on 18 of the funded projects for which information is available.

2.39. For example, see case study on the **HYMS** (Hyper-spectral Microwave Sounder) project in Appendix E. This project has been developed by RAL Space**, in partnership with** JCR Systems **and** STAR Dundee**.** Climate change is increasing the frequency and severity of extreme weather events, such as floods, hurricanes and cyclones. Damages from extreme weather cost the global economy approximately $2.5 trillion between 2011 and 2020. Improved observations of our weather systems and more accurate forecasts are essential for understanding, planning, and mitigating extreme events. HYMS is **a new, innovative atmospheric sounding instrument,** which will measure the levels of oxygen and water vapour in the Earth's atmosphere, essential for weather forecasting. A range of outcomes and impacts have emerged from CEOI funding for the HYMS concept. Notably:

- The **project has leveraged approximately £1.9 million in further funding. HYMS has secured two funding grants from the National Space Innovation Programme (NSIP) in 2020 and 2021, worth** £600,000 **and** £814,000 **respectively** to accelerate the development of the instrument as a small satellite payload. This project, in partnership with JCR Systems, STAR Dundee, and NanoAvionics, will support an in-orbit demonstration of HYMS, which is planned for 2022. The eventual goal is to deploy a constellation of small/nano satellites with HYMS sounders. This highlights how the **CEOI supports the delivery of space-based infrastructure that enables world-class science, and drives UK space sector growth**.

- The **HYMS instrument also has potential defence applications,** and RAL Space has secured £93,000 from DSTL's DASA programme under the Invisible Battlespace call. The SPECTRE project (SPECtral Target Recognition Engine) will explore the applications of the HYMS instrument for signal jamming for front-line military capabilities.

- RAL Space are also exploring potential commercial avenues for the HYMS instrument, including a spin-out company. The HYMS team **secured £450,000 from STFC's Challenge Led Applied Systems Programme (CLASP), which supports the application and commercialisation of STFC research**. To date, one patent has been filed, which is jointly attributable to CEOI and NSIP funding.

2.40. Available information about funds leveraged by CEOI-funded projects is presented in Table 2.4. Information about match funding is also provided. The overall figure could **represent an underestimate** as relevant information related to investments made by various companies involved in the projects often has not been or cannot be disclosed.

Table 2.4: Estimated match funding and follow on leverage for CEOI-funded projects

CEOI Project	Funder	Programme/ Project	Follow on leverage	Source/reference
All (calls 8-13)	**Match-funding contributions**	Calls 8-13	£8,158,949	CEOI administrative data
Earth-i	ESA	VANTAGE	Not available	
	UKSA	International Partnerships Programme (ACCORD)	Not publicly available	
	Sales		Not available	
LHR (RAL Space)	ESA	Scout	£14,000,000	Project interview
	ESA	FRM4GHG campaign	£209,000	Project interview
	Mirico (spin out)	Investment	£4,500,000	https://www.crunchbase.com/organization/mirico/company_financials
CIIR (Oxford)	NASA	Lunar Trailblazer	Not available	
	ESA	Comet Interceptor	Not available	
HYMS (RAL Space)	DSTL	Project: SPECTRE	£93,000	https://www.gov.uk/government/publications/accelerator-funded-contracts/accelerator-funded-contracts-1-april-2018-to-31-march-2019
	UKSA	NSIP	£600,000	https://www.ukri.org/news/stfc-to-build-a-new-sensor-for-

CEOI Project	Funder	Programme/ Project	Follow on leverage	Source/reference
				tracking-extreme-weather/
	STFC	STFC Innovations Ltd	£450,000	Project interview
	UKSA	NSIP	£814,000	https://www.gov.uk/government/news/government-backs-ground-breaking-space-technology-to-tackle-climate-change
WIVERN (Reading)	ESA	Earth Explorer 11	£837,000	Project interview
SEASTAR (NOC)	ESA	Earth Explorer 11	1,100, 000	Project Interview
TRUTHS (NPL)	ESA	Earth Watch	Not available	
GNSS Reflectometry	NASA	CYGNSS	£5,000,000	
	ESA	HydroGNSS (Scout)	Not available	
Craft Prospect	Sales of FLI		Not available	
	UKSA	NSIP	£870,000	https://www.gov.uk/government/news/government-backs-ground-breaking-space-technology-to-tackle-climate-change
	University of Strathclyde		£300,000	https://craftprospect.com/glasgow-based-space-company-craft-prospect-limited-secures-follow-on-investment-and-funding-for-quantum-communications-mission/
	Capital4Colleagues	Shares	£800,000	https://craftprospect.com/craft-prospect-ltd-announces-major-investment-from-c4c-plc/
	Scottish Enterprise	Shares	£200,000	https://craftprospect.com/craft-prospect-ltd-announces-major-investment-from-c4c-plc/
DarkCarb (SSTL)	Commercial contract	With Satellite Vu	Not available	

CEOI Project	Funder	Programme/ Project	Follow on leverage	Source/reference
	Commercial investment	Into Satellite Vu	£15,000,000	https://seraphim.vc/british-satellite-scale-up-raises-15m-in-oversubscribed-series-a-funding/
	Commercial investment	Into Satellite Vu	£3,600,000	https://www.satellitevu.com/press/satellite-vu-raises-36m-us5m-for-high-resolution-thermal-satellite-insights-to-support-the-green-industrial-revolution
	UKSA	NSIP	£1,000,000	https://www.gov.uk/government/news/government-backs-ground-breaking-space-technology-to-tackle-climate-change
Total match funding and leverage			**£57,531,949**[19]	
Total excluding match funding contributions			**£49,373,000**	
Total excluding ESA contributions			**£33,227,000**	

2.41. In terms of other economic benefits resulting from the CEOI-projects (e.g. jobs or Gross Value Added and exports), relevant information is not collected by projects. However, drawing on

[19] In-Space Missions (based in Hampshire and acquired in September 2021 by BAE Systems) that received a relatively small grant through CEOI Call 12 in 2019 for a project that ended in November 2020 (Babel for testing in Faraday 1, a 6U CubeSat – see https://ceoi.ac.uk/wp-content/uploads/CEOI_2020_Workshops/Emerging_Technologies_for_EO_May_2019/6.Faraday-IOD-ES-Service-Liddle-In-Space-CEOI-v2.pdf), also received in June 2021 **£4.9 million** of funding from UKSA through ESA's Pioneer Partnership Programme, to develop one of three satellites due to lift off from NASA's Kennedy Space Center in Florida in 2022/23. The satellite aims to monitor and tackle climate change and track endangered wildlife. (The other two satellites funded through the same programme by UKSA will be built by Spire. The Glasgow-based company will develop optical intersatellite links (ISL) which will provide a step change in how we get large amounts of data from space down to Earth). See: https://www.gov.uk/government/news/british-built-satellites-will-help-fight-climate-change-and-save-wildlife. In January 2020, In-Space Missions had also signed a Public Private Partnership (PPP) programme with ESA worth **€10M (£8.5 million)** to develop the Faraday Second Generation capabilities to become a Service Mission Provider (SMP) and fly two microsatellite validation missions in low Earth orbit. The PPP programme was co-funded under the ESA advanced research into telecommunications (ARTES) Pioneer programme – see https://in-space.co.uk/e10m-esa-programme-unleashes-next-generation-space-as-a-service-from-in-space-missions-2/. None of these contracts for In-Space Missions have been included in Table 2.4 as they are not following on from the CEOI funding.

the survey feedback and secondary research (e.g. business data recorded by the Bureau Van Dijk database FAME[20]), some significant direct and indirect benefits for business that have participated in the programme have been identified. These are summarised below.

- RAL Space have established a spin out company**,** Mirico Ltd, to exploit the LHR technology in terrestrial applications. The SME provides gas sensing products for medical, industrial and agricultural industries. Review of secondary data about the company indicates that its employment increased gradually **from 6 employees in 2017 to 18 employees in 2020.**[21] Gross Value Added to the economy per job created in this sector[22] is estimated to be £103,100 (2020)[23] **– therefore, the added value of these 12 jobs to the sector and the economy is equivalent to £1,237,200 per annum** (approximately £3.6 million over a three-year period).

- Number of employees at Satellite Vu (involved in the DarkCarb project) have also increased from 3 to an estimated 22-24 within the last five years.

- Craft Prospect a space engineering company first supported by CEOI in 2017 reports that it has increased both **its turnover and size**. The project has also **supported the development of a new product,** the Forwards Looking Imager (FLI) and the company are currently gearing up for **their first international sale of the hardware product,** and have received interest from others – see case study.

- Information about Leonardo MW UK (Leonardo has led or partnered on five CEOI-funded projects between 2016 and 2021 and is one of the UK's leading aerospace companies and one of biggest suppliers of defence and security equipment to the Ministry of Defence), indicates that the company's workforce has increased from **4,400 in 2016 to 7,400 in 2020**; turnover has also increased **from £990 million in 2016 to £2.01 billion in 2020** (of which 50% are related to exporting activities).

2.42. Some survey respondents (10 of the 32 – i.e. 1 in 3) also noted that **their CEOI-funded projects have contributed to them targeting opportunities in different sectors, and impacting on these sectors** – see case study on CEOI funding supported Earth-i's OVERPaSS (On-board VidEo Rapid ProceSSing and) in Appendix E. Some of the more commonly cited impacted sectors include **telecommunications, security, finance, climate studies, and biomedical.**

2.43. In addition, technical advances facilitated by CEOI have resulted in the development of **fully UK-sourced superconducting on-chip spectrometer technology (**CEOI12-FT001 – see Figure 2.3 and Appendix C**), which was previously concentrated in the US and the Netherlands,** promising potential opportunities globally for UK companies.

[20] https://www.bvdinfo.com/en-gb/our-products/data/national/fame
[21] FAME database.
[22] UK Standard Industrial Classification (SIC) 2007 Sector 26 as this company report results under SIC 2651 - Manufacture of instruments and appliances for measuring, testing and navigation. To note: companies vary in terms of the SIC codes. For example, some companies (e.g. Leonardo) report their results under telecommunications, others (e.g. SSTL) under industrial, electric & electronic machinery.
[23] See: https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/datasets/compendiumofdatarelatedtolabourproductivitybylowlevelindustry (January 2022).

5) To what extent does the programme represent value for money?

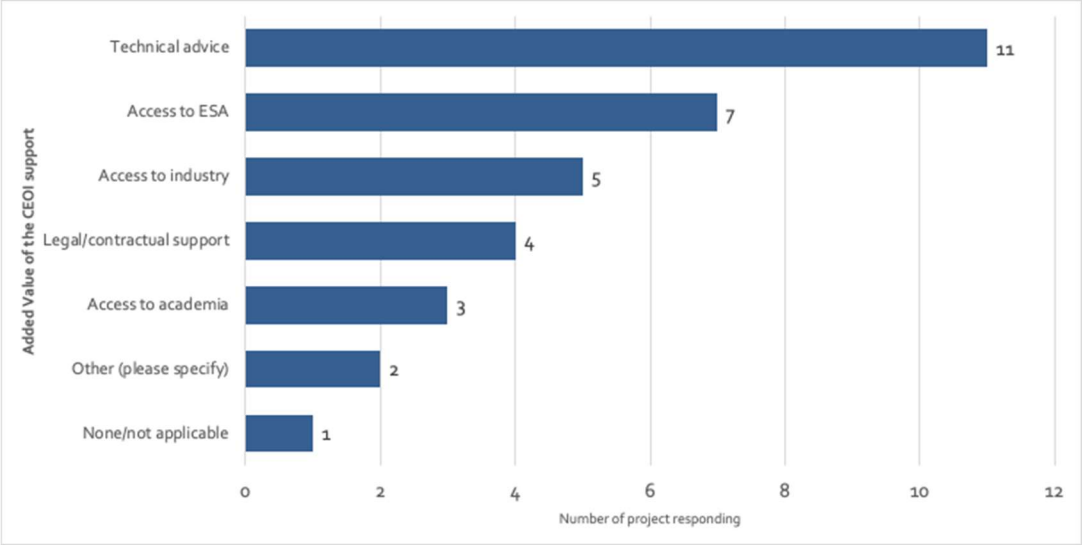
The desk-based research of available data and responses to the survey indicate that:

- The **programme's additionality is relatively high.** The majority of respondents to the project survey (70%) would not have undertaken their projects without CEOI funding**.**
- **Eight new EO technologies have been selected for mission programmes,** representing **17% of the 46 completed projects** over the period 2016 to 2021.
- On the basis of the limited available information on economic benefits for the public investment that could be attributed to the CEOI programme, the **estimated return on public investment is approximately £3:£1** (drawing on an estimated public investment on the CEOI programme of approximately £17-£20 million on CEOI grants and the added value programme over the period 2016 to 2021 and the resulting additional leverage of approximately £50 million).

2.44. As discussed in the earlier paragraphs, a **number of CEOI-funded projects have secured follow on funding and leverage.** Furthermore, only 4 of the 16 projects responding to the evaluation survey stated that they would have gone ahead with the project (representing an estimated 25% deadweight). The reasons for those who would not have gone ahead without the CEOI support (11 of the 16 projects) revolved around there being no appropriate funding sources elsewhere and the collaboration facilitated by the CEOI.

2.45. For respondents to the project survey, the **added value** that CEOI brought to them/their organisation have also included technical advice; access to ESA; and legal and contractual support – see Figure 2.9.

Figure 2.9: Added Value of CEOI support brough to the CEOI-funded projects



Source: Survey of CEOI-funded projects (based on 16 respondents – project leads)

2.46. The value for money of the programme also depends on the success of the projects it funds. Projects funded under the CEOI have been broadly successful. TRLs among projects have made relatively consistent progress and, despite some barriers, the future plans of projects

beyond CEOI support are promising, with several projects even soon to move into the commercialisation and exploitation phases.

2.47. As noted in paragraph 2.7 (and Table 2.1), the **CEOI programme** has achieved its contracted deliverables in spite of the pandemic and **returns a good value** against its contracted arrangements (i.e. **more deliverables produced for resources contracted**[24]).

2.48. The CEOI programme is also widely regarded by stakeholders as providing good value for money. According to interviews, the programme has provided a very high return on investment for its operating expenditures, and when seen from an industry viewpoint, CEOI was judged valuable and accomplished a lot with few resources.

6) How well aligned is the CEOI with other government technology development activities?
7) Are there any synergies with other grant programmes which could be built upon?
8) Are there any duplications which could benefit from better grant targeting?

According to both, stakeholders and projects, **the CEOI programme represents a relatively unique offering with few other sources of funding providing a similar focus or type of support – for early technology development and testing of EO instrumentation**. There was a strong consensus that the CEOI is well targeted, unique, and delivers something different for EO technology at national level.

2.49. The CEOI is regarded as an important part of the UK research and development funding ecosystem and **is the only scheme to fund development of low-level technologies and early stage technology development associated with EO instrumentation – for space and non-space use**. It is an important funding route to develop and test the feasibility of innovative ideas and instruments and de-risk technology development. **Low-level technology development receives limited support from other public funding sources**, and private funding is limited as potential returns on these investments may be hard to predict (low-level technologies may not be complex in terms of scientific or mechanical features nor require large amounts of capital investment but their application and use in larger projects and systems or high-level technologies needs to be 'proved').

2.50. Therefore, unsurprisingly, CEOI is seen by stakeholders as a good complement to the UK's innovative grant programmes. One point raised by stakeholders was the inadequacy of research councils for space technology funding. As a few stakeholders commented '*Research councils tend to be dominated by scientists and therefore technology can be pushed out. For instance, if you want to develop a technology you must produce a correlating science output*.'

2.51. According to stakeholders, running the programme outside of UKRI also gives it more flexibility and allows CEOI to 'spacify' technology from UKRI (e.g. quantum cascade lasers and quantum gravity meters have space applications).

2.52. The programme already has good links with NPL (National Physical Laboratory) and ESA. The **relationship between the CEOI and ESA teams**, and in particular understanding and trust, is **now very well-established and mutually beneficial**. As discussed in previous paragraphs (see 2.8 and 2.16), the CEOI team provides knowledge of required processes and

[24] https://www.nao.org.uk/successful-commissioning/general-principles/value-for-money/assessing-value-for-money/

content of bids for the ESA submissions, greatly improving the ability of UK projects to compete for bids in **an impartial manner** (which is highly regarded by ESA). As a direct result of the work of the CEOI team (and UKSA) through the CEOI programme, the ESA team now has a far greater understanding of the capabilities of the UK EO sector. The fact that many CEOI-funded technology projects would not have taken place without the CEOI support is indicative of its importance in the funding landscape.

2.53. The desk-based review and interviews have highlighted that there a few synergies with other calls for funding that can be explored. For example, although it is important to recognise the different needs and contexts within which civil and defence sectors operate, synergies between the work of CEOI and DSTL/DASA should be explored. These synergies can be identified through regular discussions (e.g. quarterly or biannual) between UKSA/CEOI and DSTL and DASA teams and could include identification of issues and challenges of common interest for which joint calls and assessments can be organised. This approach will enable the UK to improve on dual use (i.e. civil and defence) applications of EO technologies.

2.54. Feedback from the stakeholder interviews also suggested that linkages between CEOI and NCEO and CEOI and EPSRC could be improved. A similar approach could be followed here i.e. regular discussions (e.g. through biannual meetings).

9) Are there any notable gaps in the R&D funding landscape which are holding back the advancement of the EO sector?

The R&D funding landscape tends to focus on high-level technologies. Low-level technology further development receives limited support from public funding sources, as noted in the previous paragraphs.

A number of other issues have been highlighted by stakeholders and projects (some discussed under question 3 and others under questions 6-8). Other issues highlighted here include:

- challenges associated with **single year budgeting**;
- **funding support comparable to that of other activities for similar programmes in other countries** (see paragraph 2.31 and footnote 17) – in particular as the opportunities for the UK EO community's engagement in decision-making in major mission programmes could be negatively affected by the specific arrangements surrounding country-level participation in ESA programmes;
- **funding support to maintain the capabilities and infrastructure already built by the CEOI programme** (that could be weakened if engagement in major programmes is reduced); and
- **targeted support for companies including SMEs** in the UK **to establish in the UK the supply chain that multinational enterprises (MNEs) and original equipment manufacturers (OEMs)** operating in this sector need.

2.55. Overall, stakeholders commented that that UK performs relatively well in EO capabilities compared to other countries given the much lower levels of government investment – countries like France and Germany invest significantly more difference (see WECD research

findings in footnote 17). Particular strengths of UK capabilities mentioned by the stakeholders include:

- UK strength in small sensors – so makes sense to bid into Scout missions (small, more agile missions);
- UK is world-leading/world competitive in quantum gravity measurements (partly due to CEOI support); and
- UK world-leading in weather modelling (NWP capability, strong industry and SME capability).

2.56. However, during the interviews it was pointed out that the **UK's EO capabilities will worsen as the UK becomes less involved in major programmes.**

2.57. A theme noted by most stakeholders was that **single year budgets are challenging** for planning and delivering ambitious technology developments – these take place over a long period of time; therefore, long-term consistent funding and multi-year funding settlements are needed.

2.58. In general, **further funding was identified as required in the future to support the development of UK EO technologies capabilities**. Larger amounts of funding (e.g. a 'fourth tier' as described in paragraph 2.28) could support airborne demonstration of instruments/technologies – this would enable further development of EO technologies and make them more competitive commercially and with ESA. With further resources, CEOI could also provide more horizon scanning activities and workshops, supporting UK EO policy development and mission pipeline.

2.59. A specific issue raised during the interviews as a gap in funding was around **the relative narrow focus of the CEOI on maturing technology for the ESA bids.** Widening the support the CEOI offers could be beneficial for the wider sector. This might include "taking academic ideas and transitioning into practical systems" as well as continuing non-monetary support to EO technology that moves beyond the scope of CEOI funding to prevent a "cliff edge". Beyond this, some important technological focuses for consideration include AI and intelligent sensors, as well as, cloud radar. Stakeholders also noted that research and development funding is narrowed to only 'instrumentation' that may limit potential projects only to hardware (unless synergies with other programmes-related to software and data and imaging analytics capabilities are strengthened) .

2.60. As noted in earlier questions (question 3), the perception among stakeholders is that the UK is weaker since the UK has no national strategy for space missions and what the UK should major in the future. It was also highlighted by stakeholders, that, in similar vein, as large companies such as Airbus in Spain have the backing of powerful and national agencies, SMEs need this backing from national agencies in the UK. Such a backing and targeted support will need to enable in order to build up their capabilities and engagement with OEMs in the sector and demonstrate that they can meet the supply chain requirements needed compete with other countries.

10) Overall, does the current CEOI format remain the best way to support the UK EO sector? Are there opportunities to do anything more or differently to more

effectively support the aims and objectives of the National Space Strategy and the CEOI?

The evaluation findings indicate that projects funded under the CEOI generally carry a degree of uncertainty involved in their development and commercialisation. As noted earlier in this report (paragraph 2.49), low-level technologies may not be complex in terms of scientific or mechanical features nor require large amounts of capital investment, but their application/use in larger projects or high-level technologies needs to be identified and 'proved'. In addition, understanding both, high-level and low-level technologies and their interface for specific technologies is essential.

All these elements require a large number of diverse capabilities, resources (human and capital) and networks, often based in different countries, (and hence operating in different innovation ecosystems and regulatory frameworks) to find each other and effectively work together towards a common goal in a systematic and coherent way (and within critical timelines and budgets). The **CEOI programme has been an instrumental broker and has offered highly-respected, impartial, effective and efficient leadership and management in taking the UK EO community from a zero position in participation in major mission programmes in 2007 to eight technologies participating in major ESA programmes in 2020.**

The programme tends to be oversubscribed within its available resources. The 'level of non-risk aversion' of the CEOI coupled, however, by practical experience of risks involved in technology development and transfer and support for the further technological development of EOI technologies (both low-level and high-level) sets it apart from other operational models.

2.61. The above WECD assessment is supported by the feedback received from projects funded under CEOI and feedback provided by stakeholders. For example, most stakeholders commented that the **current approach and governance structure worked well for the current investment and policy situation** i.e. it works for the current level of funding (approximately £2 million per year) and UK government ambition. This was seen by the majority of stakeholders as the minimum level required to run an EO technology development funding programme.

2.62. Most recommendations for the CEOI programme operations revolved around expansion of its scope. According to stakeholders, an expanded budget (i.e. to £20 million per year) would need replication of similar expertise and further resources to support a larger technical and management/leadership team - operating impartially and independently (i.e. retaining similar governance and management structures). Additional funding could be used for introducing funding for feasibility studies at lower TRL and disruptive innovative ideas (see LHR), supporting in-orbit missions, and follow-on funding for system and field deployment. The CEOI programme may also include 'travel and engagement grants' to facilitate technology demonstrations and more ways to support SMEs, which may have the agility to be more experimental but require external funding to take these steps.

2.63. Suggestions made by project survey respondents for additional activities that might benefit the EO sector in the UK included the CEOI programme, bringing in other technology sectors who might not have of EO previously, short online webinars covering key and emerging technologies and international conferences for EO partners abroad.

2.64. Desk-based review of the programme and interviews with stakeholders and projects also lead to a number of recommendations for the way forward by the WECD team. These are summarised in the next section of this report.

3. Conclusions and Recommendations

3.1. The main aim of the evaluation has been to provide evidence, insight and recommendations to inform the Agency's decisions on how best to continue supporting the UK Earth observation sector in the coming years, in the wake of the strategic direction set out by the National Space Strategy and resulting opportunity to develop the UK's national space programme.

3.2. The evaluation research has drawn on a combination of resources to address the main evaluation questions and its conclusions can be summarised as follows:

- The CEOI programme has been **a very successful programme in terms of achieving its main objectives and delivering its contractual outputs**. The programmes has delivered all its main activities as planned (contractually) and to **high levels of satisfaction and additionality.**

- In particular**, the programme has delivered significant outputs and outcomes to strengthen the UK EO sector**. These outputs and outcomes include technology areas that are aligned to EO market strengths and capabilities; successful mission concept bids to ESA; the development of new UK EO instrumentation and technologies involving management, scientists and researchers in academia and larger and smaller businesses and public sector research establishments; and contribution to TRL progress to higher levels for the projects funded.

- With respect to TRLs, the **CEOI programme can be credited with contributing to 'advancing' CEOI-funded technology development projects towards higher TRLs** - a primary indicator of technological development and maturity of projects (the advancement towards higher levels of TRL could also be used as a proxy indicator for enhanced chances of accessing and winning commercial opportunities). Feedback received from the projects funded indicates that projects tended to start at TRL 2 and 3, and, after CEOI funding, were raised to TRLs of between 4-6 (with one project even being raised to TRL 7 from 2/3).

- Desk-based review of the CEOI programme data and the interviews with stakeholders and projects indicate that a range of other benefits have emerged as a result of the CEOI programme. These include **scientific and technological benefits, and economic benefits**. These include:

  - Facilitation of **collaborations and partnerships in the UK** – resulting to new business for the projects involved in space and non-space sectors including **telecommunications, security, finance, climate studies, and biomedical.**

  - **Production of research and conference papers**.

  - Contribution to **additional skills and training** (e.g. with employment of post-doctoral researchers, PhD students, masters students and specialist technicians) and **multi-disciplinary research activities**.

- The CEOI programme also provides enhanced access to networking and knowledge exchange opportunities for the industrial and academic EO communities through its

Added Value Programme. This part of the programme **successfully brings together academia and industry,** co-creating the way forward for EO technology development while **the CEOI team offers continuous support through to contract bidding and post-award**.

- The CEOI programme has been **particularly beneficial for academics,** as it has enabled them to lead bids or participate in bids where they could not bid for through other fundings grants (where the required outputs mostly relate to science and research elements). In particular, **academic researchers find it challenging to identify the opportunities, assemble and prepare the relevant resources to successfully bid for ESA missions without the necessary funding.** Funding and support offered by the CEOI programme has paid for staff time, networking with the sector including companies and technologists, brokering and building relationships with potential clients including ESA; making the linkages with other potential uses to move ideas and technologies up the Science or Technology and Mission Readiness levels (SRLs, TRLs, MRLs); and also investing on developing relevant skills e.g. preparation of bids, risks assessment, and business or project management.

- Drawing on a number of secondary resources and through the project interviews, it is also estimated that projects funded by the CEOI programme between 2016/17-2021 have **leveraged approximately £50 million** through follow on ESA, commercial and public investments. On the basis of this information, the **estimated return on public investment is approximately £3:£1** (drawing on an estimated public investment on the CEOI programme of approximately £17-£20 million on CEOI grants and the added value programme over the period 2016 to 2021). As discussed in the main report, this figure could represent **an underestimate** as relevant information related to investments made in all CEOI-funded projects has not or cannot be disclosed.

- The programme has also led to the creation of **successful spin outs** through its funded projects (one is already established and two more are currently under development), and contributed to **growing turnover and employment size** for companies involved in the CEOI-funded projects.

- In addition, technical advances facilitated by CEOI have resulted in the UK on a world-leading position in new technologies (**fully UK-sourced superconducting on-chip spectrometer technology,** previously concentrated in the US and the Netherlands), **promising potential opportunities globally for UK companies.**

3.3. All these outputs and outcomes **represent critical steps and the necessary foundation for building UK national capabilities and a stronger and globally recognised UK EO research and technology development ecosystem, ultimately leading to economic growth (e.g. jobs, productivity and income) and enhanced societal benefits.**

3.4. The **CEOI programme** is ran **efficiently** and **returns a good value** against its contracted arrangements (i.e. more deliverables produced for resources contracted[25]).The evaluation findings indicate that projects funded under the CEOI generally carry a degree of uncertainty involved in their further development and commercialisation or scalability. In particular, **low-**

[25] https://www.nao.org.uk/successful-commissioning/general-principles/value-for-money/assessing-value-for-money/

level technologies involved in a number of CEOI-funded projects may not be complex in terms of scientific or mechanical features nor require large amounts of capital investment, but their application/use in larger systems or projects needs to be identified and 'proved'.

3.5. These elements require a large number of diverse capabilities, resources (human and capital) and networks, often based in different countries, (and hence operating in different innovation ecosystems and regulatory frameworks) to find each other and effectively work together towards a common goal in a systematic and coherent way (and within critical timelines and budgets). The **CEOI programme has been an efficient broker and has offered highly-respected and impartial leadership and management** in taking the UK EO community **from a zero position in participation in major mission programmes in 2007 to eight technologies participating in major ESA programmes in 2020.**

3.6. The programme **tends to be oversubscribed within its available resources**. The 'level of non-risk aversion' of the CEOI coupled by 'know-how' and practical experience of the risks involved in technology development and transfer and support for the further technological development of EO instrumentation technologies (both low-level and high-level) sets it apart from other operational models.

Recommendations

3.7. The main issues raised for improvement of the programme design relate to **funding levels and approach for EO instrumentation related programmes and projects and the UK (national) approach for space missions**, namely:

- The UK R&D funding landscape tends to focus on high-level technologies **and low-level technology development receives limited support from public funding sources**.
- Operational and planning challenges associated with **single year budgeting**.
- **Funding support comparable to that of other activities for similar programmes in other countries** – in particular as the opportunities for the UK EO community's engagement in decision-making in major mission programmes could be negatively affected by the specific arrangements surrounding country-level participation in ESA programmes.
- **Funding support to maintain the capabilities and infrastructure already built by the CEOI programme** – among the academic and business community, UKSA and UK central government (that could be weakened if engagement in major programmes is reduced).

3.8. Therefore, the issues to be considered going forward include:

- **Better reliability of funding for EO instrumentation technology development** for early ideas' development, low-level technologies and testing of success of earth observation instrumentation in major programmes or high-level technologies (and this applies equally to projects as well as the programme itself including long-term commitment via ring-fenced funds for work related to the CEOI programme).
- Associated with the above**, consistency (i.e. regularity) of the funding calls**.

- Also associated with the first point, levels of funding will need to be reviewed to reflect technological developments and challenges in EO instrumentation, **with larger sums of funding** required for both **the further development of lower TRL EO instrumentation technologies with market potential and proto-flight**, airborne and in-orbit demonstration testing of technologies (for example, through an additional tier of funding for projects around **£1 to £5 million)**.

- **Targeted support for companies including SMEs** in the UK **to establish in the UK the supply chain needed by multinational enterprises (MNEs) and original equipment manufacturers (OEMs)** operating in this sector. Support could take the form of tax incentives for any investments made by SMEs in related R&D and advice on issues relating to financial and legal matters surrounding space-related contracts (see footnote 16).

- The need for **a UK national mission programme** (similar to Germany or Italy and France) and **associated funding and resourcing,** that is currently lacking. In 2020, DLR's - Deutsches Zentrum für Luft- und Raumfahrt - (Germany's Space Agency) EO – National space and innovation programme was EUR 31 million (of EUR 268 million of the German Space Agency for DLR national programmes i.e. excluding the German ESA budget of EUR 945 million).[26] In 2017, Italy allocated some EUR 837 million to space activities. Key priorities of the Italian Space Agency budget included earth observation (30%), launchers and space transportation (26%), and human spaceflight and microgravity (20%).[27]

3.9. The importance of the EO sector and the rationale for investment on this sector has been recognised in the National Space Strategy where ambitious plans have been set out to build new leadership in high growth areas including EO (as well as navigation applications and services, and satellite broadband). As set out in the strategy '*The UK will not reach its goal of net zero emissions by 2050 without a clear understanding of how climate change is impacting the Earth, to guide crucial decision-making and investments. We will strive to remain at the forefront of earth observation technology and know-how, including by participating in Copernicus, the world's leading global earth observation programme and working with partners in ESA on the TRUTHS mission to deliver a tenfold improvement in accuracy.'*[28]

3.10. The strategy also identifies EO and Intelligence, Surveillance and Reconnaissance (ISR) as one of the **eight key civil and defence capability priorities for the UK,** with the main activity being for '*….. The UK also intends to develop and benefit from the Copernicus Earth Observation programme under the terms of the UK-EU Trade and Co-operation Agreement.'*[29]

[26] See: https://www.dlr.de/EN/organisation-dlr/media-and-documents/facts/facts-and-figures.html. For any comparisons with Germany, it is also worth noting that DLR's structure of EO-related activities are structured in a different manner to the UK. For example, the Earth Observation Center (EOC) at DLR consists of the German Remote Sensing Data Center (DFD) and the Remote Sensing Technology Institute (IMF) and is the centre of competence for earth observation in Germany. IMF and DFD are the leading national earth observation research and development institutions with public funding. For more information see: https://www.dlr.de/eoc/en/desktopdefault.aspx/tabid-5277/8858_read-15912/

[27] See: https://www.oecd-ilibrary.org/sites/d143ef90-en/index.html?itemId=/content/component/d143ef90-en

[28] National Space Strategy, page 41.

[29] National Space Strategy, page 39.

3.11. EO is clearly a significant sector in global markets and the UK economy in terms of creation of national wealth on its own accord and in relationship with **mainly the space and defence sectors but also others sectors of the economy** (as listed in paragraph 1.5) including making contribution to **climate change** and **environmental challenges** (see: HYMS - increasing the accuracy weather forecasting by enhancing and miniaturising measurement instruments), and the global **Sustainable Development Goals** (SDGs). Therefore, continuing public investment on the EO sector development is imperative.

3.12. The content of the CEOI programme with its **focus on instrumentation has worked all** and provided the **concentration and coordination** needed for the programme to achieve its goals. It has also **simplified** the UK R&D&T landscape in the domain of EO instrumentation for potential partners and stakeholders operating from outside the UK.

3.13. **Synergies** with other programmes will need to be **explored cautiously and in detail** to ensure that the programme is not operating in silo while benefits arising from the successes of the programme (as well as knowledge and networks) are **purposefully distributed across a wider academic and business community**.

3.14. The programme already works with the most important organisations in the EO(I) sector; however, the (potential) **value and supply chains** of the sector and its relationship with other sectors and technologies need to be further explored through a comprehensive (and regularly updated) mapping exercise of UK-based **companies with capabilities in development, testing and manufacturing of related technologies and instruments**. Research undertaken as part of this evaluation indicates that companies operating in this sector span across various industrial sectors and there may be scope **for establishing a range of time-bound working groups in the delivery model or built in additional workshops in the programme** - to ensure that future partners are carefully selected.

3.15. The **current governance, management and delivery structure** of the programme **has worked well to date** – and, in particular, it has provided to date the **impartiality** needed to build trust and a successful working relationship with ESA. The future structure of the programme – including a scaled-up operation, could replicate the same approach, but **with additional permanent resources**, and clearly aligned to a strategic approach to the UK's objectives in relation to the National Space Strategy. In the future, **a more strategic and focused approach is needed** (by UKSA and the UK government) in relation to the UK's position to space missions and relationships with other countries' national space agencies (including ESA, which holds a world-leading position in EO and cannot be ignored - and specific European programmes for which strong capabilities have been built in the UK).

3.16. In the light of changes in the position of the UK with the EU and European programmes, the **EO strategy will need to be refreshed**.

3.17. A programme of this scale and significance will also require **a detailed implementation plan.** This plan should include specific goals, resource allocation, financial planning, risk assessment and contingency plans relating to match-funding or contract delays, and a more **concrete approach to monitoring and assessing benefits and impacts for the sector and the organisations involved** (beyond monitoring of the contractual performance of the programme with UKSA).

Appendix A: Stakeholder organisations interviewed

Organisation
1) UK Space Agency
2) CEOI
QinetiQ
Scott Space
STFC RAL Space
Airbus DS
STFC RAL Space
University of Leicester
Ex-CEOI
3) ESA
4) NCEO
5) BEIS
6) STFC RAL Space
7) DSTL
8) Qi3
9) UK Space Agency
10) Met Office
11) Airbus DS
12) SSTL
13) In-Space Missions
14) JCR Systems
15) National Physical Laboratory
16) University of Reading
17) University of Leicester
18) University of Oxford
18 organisations; 31 individuals

Appendix B: Stakeholder interviews – script

General info

1. What has been your involvement so far in the CEOI?

Programme rationale and design

2. What are the key strengths of the programme? Have these changed over time?
3. What was the rationale and the expectations from the specific design of the programme, namely:
    a. Three Technology Programme funding streams (Flagship, Fast Track and Pathfinder)
    b. Added Value Programme (Challenge Workshops, Industry Consultation Workshops, Technology Showcases, Conferences)
4. Would you recommend the same approach in the future?

Achievements and lessons learned

5. What are the main successes of the overall programme?
6. How successful (or otherwise) has CEOI been in supporting UK EO instrumentation capability and strengthening the position of UK-led teams bidding for ESA missions (and other international contracts) and export opportunities?

    Prompt, if required:

    - Very successful
    - Successful
    - Moderately
    - Unsuccessful
    - Very unsuccessful
7. What do you consider that the has worked less well with the CEOI? What could be improved?
8. Are there any synergies with other grant programmes which could be built upon?
9. Are there any duplications which could benefit from better grant targeting? (i.e. other grant schemes that offer the same/similar support)

Future

10. How well aligned is the CEOI with other government technology development activities?

11. What other/more needs to be done in this area?

12. Which EO technology areas most important for UK instrumentation capability? Where should the UK Government target funding support through UKSA/CEOI? (e.g. certain EO technologies, business models)

13. How does the UK compare to other countries in terms of EO capability and capacity? Who are the main competitors in bidding into ESA missions?

14. To what extent does the CEOI programme represent value for money?

    Prompt, if required: value for money for taxpayers, UKSA, industry?

    - A great deal
    - Considerably
    - Moderately
    - Slightly
    - Not at all

15. Are there any notable gaps or 'market failures' in the R&D funding landscape which are holding back the advancement of the EO sector?

16. Does the current CEOI format remain the best way to support the UK EO sector using taxpayers money?

17. Any suggestions or views on any other models or approaches that could be used in the future to support EO technology development and commercialisation?

Evaluation work – to ask if enough time

18. What key points would you suggest would be useful for us to raise with the projects when we talk to them?

19. Can you suggest any particular projects for us to follow up with to use as case studies? Why these particular projects?

Appendix C: Projects interviewed and surveyed

Project No.	Project Name	Lead Organisation	Partners
1) EO8-FS-005	The Compact Infrared Imager and Radiometer: A CubeSat based Remote Sensing Platform for Earth System Science	University of Oxford	STFC RAL Space Clyde Space Ltd Satellite Applications Catapult
2) EO8-FS-009	TRUTHS: Increasing TRL of the Cryogenic Solar Absolute Radiometer (CSAR) and the in-flight calibration system to level 5/6	National Physical Laboratory	Airbus DS
3) EO8-FS-003	Critical Technology Advancement of the LOCUS Mission	University College London	STFC RAL Space STAR-Dundee Ltd University of Leeds Glyndwr University JCR Systems
4) EO9-EE9-011	Technology Development of Extended Spectral Response for SWIR Detectors	Leonardo MW Ltd	UK Astronomy Technology Centre
5) EO9-EE9-002	Mission preparation and technology development of the Tropical Carbon Mission concept	University of Edinburgh	University of Leicester UK Astronomy Technology Centre External contractors (Airbus DS, Leonardo MW)
6) EO9-EE9-008	TRUTHS: A small satellite mission to enable a space-based climate observing system	National Physical Laboratory	Airbus DS University of Reading
7) EO9-EE9-003	Developing a successful Ocean Surface Current Mission (OSCM) proposal for ESA Earth Explorer 9	National Oceanography Centre	Airbus DS Satellite Oceanographic Consultants Ltd (SATOC)
8) EO9-EE9-005	WIVERN: An EE9 project to observe Global Winds	University or Reading	University of Leicester STFC RAL Space
9) CEOI10-FT019	Proton radiation testing of Leonardo large format MCT arrays	Leonardo MW Ltd	None

Project No.	Project Name	Lead Organisation	Partners
10) CEOI10-PF014	High Performance Pyroelectric Detectors for Space-Based Instruments	Leonardo MW Ltd	None
11) CEOI10-PF010	Onboard Data Autonomy for Next Generation of EO Nanosatellites	Craft Prospect	UCL University of Manchester Bright Ascension Ltd
12) CEOI10-PF003	MEMS-based spectrometers for ultra-miniature space-borne hyperspectral remote sounders	STFC RAL Space	None
13) CEOI10-FT003	Stabilisation of 3.5 THz quantum-cascade laser local oscillators	University of Leeds	STFC RAL Space
14) CEOI10-FT005	HYMS (HYper-spectral Microwave Sounder): Novel and Critical Component Development and System Bread-boarding	STFC RAL Space	STAR-Dundee Ltd JCR Systems Ltd
15) CEOI10-FS001	Ship Position and Detection Radar (SPIDER)	Airbus DS	None
16) CEOI10-FT002	SEASTAR+: enhancing the mission concept	National Oceanography Centre	Airbus DS Satellite Oceanographic Consultants Ltd (SATOC)
17) CEOI11-FS009	High-resolution multispectral camera system with TDI CMOS image sensor	Teledyne e2v	SSTL Open University
18) CEOI11-FS011	Fast Slew Gimbaled Optics for Real-time EO	University of Surrey	In-Space Missions
19) CEOI11-FS012	OVERPaSS: On-board VidEo Rapid ProceSSing	Earth-i Limited	MSSL Cortexica
20) CEOI11-FS014	Compact Multispectral Imager for Nanosatellites II	University of Strathclyde	None
21) CEOI11-FS013	GRaCE: G-band Radar for Cloud Evaluation	STFC RAL Space	Thomas Keating Ltd University of St Andrews University of Leicester
22) CEOI12-FT014	Validation of high performance COTS infrared detectors for high spatial resolution imagery	Leonardo MW Ltd	SSTL

Project No.	Project Name	Lead Organisation	Partners
23) CEOI12-FT015	Autonomy Assurance for Small Earth Observation Missions	Craft Prospect	Bright Ascension Ltd University of Manchester
24) CEOI12-FS001	Spectroscopic-system for EnviRonmental MONitoring (SERMON)	STFC RAL Space	STAR-Dundee JCR Systems Ltd UK Met Office ECMWF
25) CEOI12-FT001	Advanced Filterbank Spectrometer Technology for Hyperspectral mm-Wave Atmospheric Sounding	University Cambridge	University of Cardiff
26) CEOI12-FT004	Polymer-based 3D Printing for Atmospheric science - multi-channel mm sounder (3DPAMS)	National Physical Laboratory	Imperial College London
27) CEOI12-FT011	Cold Atom Space Payload (CAGE)	Teledyne e2v	STFC RAL Space BGS Universities of Bristol, Newcastle, Nottingham, Reading, and Birmingham
28) CEOI12-FT018	Lasers for Earth Gravity Observation (LEGO)	Surrey Space Centre, University of Surrey	TwinParadox Ltd
29) CEOI12+SP001	LHR in Finland	STFC RAL Space	None
30) CEOI12+SP002	Night Time Cloud Detection for PhiSat-1	Craft Prospect	None
31) CEOI13-PF001	NIMCAM	University of Edinburgh	UK Astronomy Technology Centre
32) CEOI13-FS006	CASPA Accelerometer: Development of a Cold Atom Accelerometer for Atmospheric Drag Measurement	Teledyne e2v	STFC RAL Space University of Birmingham

Appendix D: Project online and interviews script

Engagement and rationale

This section provides an opportunity for you to describe your rationale for engaging with CEOI funding, and provide feedback on the funding process.

1. What is the name of your organisation?
2. Rationale for engagement – why did you apply to the CEOI to fund this project over other sources of funding?
    a. Amount of funding available
    b. Timeframe of funding
    c. Is a key source of R&D funding
    d. Technical/expert advice from CEOI and/or UK Space Agency
    e. Collaboration with industry
    f. Collaboration with academia
    g. Other **(please specify)**
3. How would you rate the overall quality of the application process?
    a. Very good
    b. Good
    c. Average
    d. Poor
    e. Very poor
4. How might the application process be improved? (e.g. changes to the timing, amount of funding, or structure of CEOI funding calls)

a. Would you prefer more or less funding for your project?
    a. More funding
    b. Less funding
    c. The same
    d. Unsure/Don't know

Your project

This section provides an opportunity for you to describe your CEOI-funded project and how the funding was used.

5. How did you use the funding?
    a. Existing staff time
    b. Accessing research equipment, facilities or infrastructure (e.g. airborne demonstration – **please specify)**
    c. Producing new scientific/technical knowledge
    d. Developing an EO technology
    e. Testing the application of an EO technology

f. Investigating the feasibility of applying an existing EO technology to a new area/sector
g. Collaborating with industry
h. Collaborating with academia
i. Accessing leading research
j. Acquiring additional skills (e.g. recruiting new staff)
k. Acquiring higher skills (e.g. PhD training)
l. Other **(please specify)**

6. Did you have to match the CEOI funding with other funds?
   a. Yes – Cash Funding
   b. Yes – In-kind support
   c. No
   d. Unsure/don't know

6b - i. What proportion of your match funding was in the form of in-kind support (approximately)?

6b - ii. What did the in-kind support involve?
   a. Staff time (internal)
   b. External Advice
   c. Access to equipment/facilities
   d. Other (please specify)

6b - iii. Could you estimate the hours/days of support you received (approximately)?

7. What challenges, if any, did you face during project development and implementation?

Benefits, outcomes and impacts

This section provides an opportunity for you to describe the benefits to your project as a result of the funding and support received by CEOI.

8. Has CEOI support through this funding grant/project helped you win business or develop new collaborations/partnerships – in the UK and/or internationally?
   a. Yes – win business in the UK
   b. Yes – win business internationally
   c. Yes – develop new collaborations/partnerships in the UK
   d. Yes – develop new collaborations/partnerships internationally
   e. No
   f. Unsure/don't know

   a. To what extent has CEOI funding helped you to win business in the UK?
      a. A great deal
      b. A lot
      c. A moderate amount

d. A little
e. None at all

b. To what extent has CEOI funding helped you to win business internationally?
    a. A great deal
    b. A lot
    c. A moderate amount
    d. A little
    e. None at all

c. To what extent has CEOI funding helped you to develop new collaborations/partnerships in the UK?
    a. A great deal
    b. A lot
    c. A moderate amount
    d. A little
    e. None at all

d. To what extent has CEOI funding helped you to develop new collaborations/partnerships internationally?
    a. A great deal
    b. A lot
    c. A moderate amount
    d. A little
    e. None at all

9. Has CEOI support (through this funding grant/project) helped you to target opportunities in other sectors? (such as remote sensing technologies with both civil and defence applications, or instrumentation technologies with spin-out applications in sectors such as agriculture and healthcare)
    a. Yes (which sectors?)
    b. No
    c. Unsure/don't know

a. And, to what extent has CEOI funding grant/project helped you to target opportunities in other sectors?
    a. A great deal
    b. A lot
    c. A moderate amount
    d. A little
    e. None at all

10. Please describe the technical and scientific achievements and advances the CEOI funding may have enabled?

11. If possible, please could you estimate the project/technology TRL before and after funding? (see: ESA Technology Readiness Levels)

Before	
After	

12. Are there any patents resulting from this CEOI-funded project?
    a. Yes **(please specify** e.g. how many? What patents?)
    b. No
    c. Unsure/don't know
13. Has the CEOI funding helped in any way to:
    a. Changes in turnover/income generation (actual/planned), cost savings, employees, trade/exports (current and potential), investment/equity – please specify
    b. Spin-outs – please specify
    c. Improved business awareness of specific issues
    d. Led to business adoption of new ideas/processes/products (now or in the future)
    e. Led or is going to lead to future adoption of something new
    f. Business investment in further research in these/other areas
    g. Other **(please specify)**
    h. No
    i. Unsure/don't know
14. Has you project had any impact on any sectors/industries in the UK or internationally? (e.g. . space, medical, food, defence and security, other).
    a. Yes **(please specify** which sectors**)**
    b. No
    c. Unsure

a. To what extent has your project had an impact on the above sectors?
    a. A great deal
    b. A lot
    c. A moderate amount
    d. A little
    e. None at all
    f. Unsure/Don't know

15. Will your project have an impact on any sectors/industries in the future?
    a. Yes **(please specify** which sectors**)**
    b. No
    c. Unsure

a. To what extent do you predict your project will have an impact on the above sectors?

a. A great deal
b. A lot
c. A moderate amount
d. A little
e. Not at all
f. Unsure/Don't know

16. Has the CEOI funding contributed to additional skills training/impacts (e.g. student placements, PhD students)?
    a. Yes (how many?)
    b. No
    c. Unsure/Don't know
17. Has the CEOI funding contributed to the production of research papers?
    a. Yes (how many?)
    b. No
    c. Unsure/Don't know

Added value of the support and next steps

18. Would you have undertaken this project **without** the CEOI grant?
    a. Yes
    b. No
    c. Unsure/Don't know

18a - i. Why?

18a - ii. How would the project have differed without funding?

a. It would have taken longer to start
b. It would have taken longer to complete
c. We would not have had access to the same resources or facilities
d. It would not have been possible to collaborate with the same industrial partners
e. It would not have been possible to engage with ESA (or other partners – please specify what partners)
f. Other (please specify)

18b. Why not?

19. Beyond project funding, what value has CEOI brought to supporting your EO technology development project?
    a. Legal/contractual support
    b. Technical advice
    c. Access to ESA
    d. Access to academia
    e. Access to industry

f. Other (please specify)
g. Unsure/Don't know
h. None/Not applicable

20. How would you rate CEOI support (including funding, events and other support) vs other grant funding?
    a. More useful
    b. The same
    c. Less useful
    d. Unsure/Don't know
21. What are this specific project's next steps/long-term plans in this area of technology, sector or other sectors?
22. Do you face any specific opportunities and threats/barriers to these future plans?

Added Value programme

23. Have you participated in any of the following events/workshops organised by the CEOI? (in each case, please state when)
    a. Science Challenge Workshops
    b. Technology Challenge Workshops
    c. Industry Consultation Workshops
    d. National EO Conference/EO Week
    e. Technology Showcase events
    f. ESA bid mock interview sessions
    g. Training Workshops
    h. Other **(please specify)**
    i. None
24. What are the benefits from attending these activities?
    a. Networking with industry
    b. Networking with academia
    c. Technical/expert advice from CEOI/UKSA
    d. Horizon scanning/keeping track of latest EO developments
    e. Identifying priority technological developments
    f. Knowledge exchange
    g. Continued professional development/training
    h. Other **(please specify)**
25. How do CEOI networking activities benefit the EO sector?
26. Would you suggest any additional activities which might benefit the UK EO sector?

Recommendations and future steps

27. Where should the UK Government target funding support through UKSA/CEOI? (e.g. certain EO technologies, business models). Please specify.
28. Are there any notable gaps in the R&D funding landscape which are holding back the advancement of the EO sector?
29. Does the current CEOI format remain the best way to support the UK EO sector?
30. Any suggestions or views on any other models or approaches that could be used in the future to support EO technology development and commercialisation?

Final questions

31. To help the UKSA make the strongest possible case for future support, should we speak to any of your project partners (if relevant) about their role in the project? If so, who? Please provide details.
32. Would you be willing for your project and the information you provided here to be included as a case study in either of the following? (please tick options if you are happy)?
    a. In this report?
    b. UKSA business case/policy development for EO instrumentation support?
33. Are you happy to be re-contacted in relation to this project? (e.g. follow-up interview, case study)
    a. Yes
    b. No

Thank you.

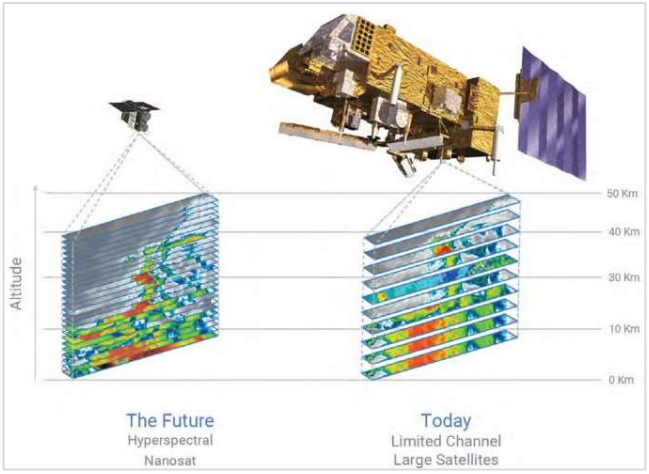
Appendix E: Case Studies

1) HYMS – RAL Space

Increasing the accuracy weather forecasting by enhancing and miniaturising measurement instruments

Climate change is increasing the frequency and severity of extreme weather events, such as floods, hurricanes and cyclones. Damages from extreme weather cost the global economy approximately $2.5 trillion between 2011 and 2020. Improved observations of our weather systems and more accurate forecasts are essential for understanding, planning, and mitigating extreme events.

RAL Space**, in partnership with** JCR Systems **and** STAR Dundee**, have developed a new, innovative atmospheric sounding instrument called HYMS** (Hyper-spectral Microwave Sounder), which will measure the levels of oxygen and water vapour in the Earth's atmosphere, essential for weather forecasting.



HYMS has over 1,000 sampling channels, compared to just 24 on the instruments currently in development or in operation, enabling increased accuracy and sensitivity of weather forecasting. HYMS also enables the removal of man-made radio frequency signals (like 5G), which interfere with satellites by masking faint signals coming from the atmosphere. HYMS is therefore a 'future-proofed' instrument.

The team have **further enhanced the HYMS concept through miniaturisation – the radiometer volume ins reduced by a factor of 50 compared to conventional instruments, but without compromising performance**. This enables HYMS to be launched on small or nano satellites, reducing costs, increasing flexibility, and increasing observation frequency. For example, current meteorological satellites are very large and very expensive (costing approximately £300 million), so there are a limited number in orbit. This reduces revisit rates, meaning that it is only possible to observe a specific point of Earth's atmosphere twice per day. To better monitor extreme weather events, more frequent observations are required. Using a constellation of HYMS satellites will increase the frequency of observations, significantly improving the accuracy of weather forecasting.

CEOI support

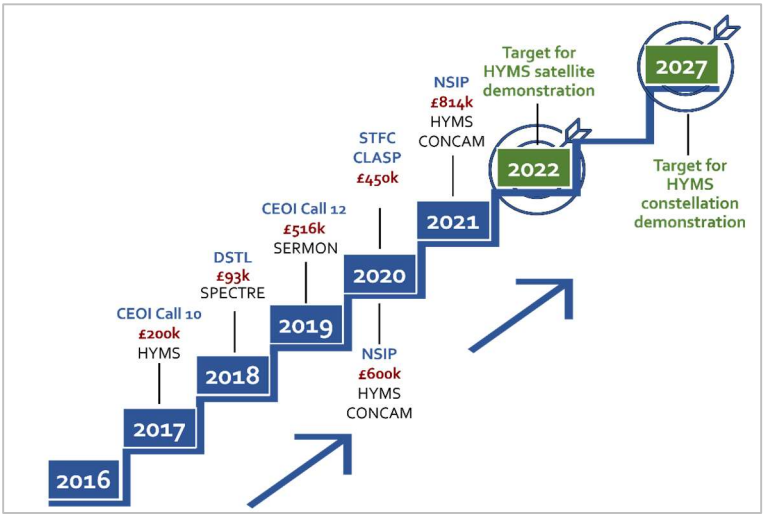
CEOI funding first supported the HYMS instrument concept in 2017, enabling the development of critical front-end components and demonstration in a laboratory environment. The team were able to test the radiometer sensitivity, as well as design the instrument in a compact form. Follow-on CEOI funding in 2019 for the SERMON project (Spectroscopic-system for EnviRonmental MONitoring), in collaboration with the Met Office and the European Centre for Medium-Range Weather Forecasts (ECMWF), supported the deployment of the instrument on board the NERC and Met Office operated FAAM aircraft. This further demonstration the HYMS concept and proved the instrument's flight worthiness.

Overall, CEOI grant funding has enabled RAL Space to raise the HYMS Technology Readiness Level (TRL) from level 1 to level 5.

RAL Space would not have undertaken the project without CEOI funding. The project needed national public funding as potential ESA funding had fallen through as it was not financially viable – critical components were not available and needed to be developed first – and the TRL was too low

to attract private investment.

Benefits and impacts



A range of outcomes and impacts have emerged from CEOI funding for the HYMS concept. Notably, the **project has leveraged approximately £1.9 million in further funding, including two Space Innovation Programme (NSIP) grants in 2020 and 2021, worth** £600,000 **and** £814,000 **respectively** to accelerate the development of the instrument as a small satellite payload. This project, in partnership with JCR Systems, STAR Dundee, and NanoAvionics, will support an in-orbit demonstration of HYMS, which is planned for 2022. The eventual goal is to deploy a constellation of small satellites with HYMS sounders. This highlights how the **CEOI supports the delivery of space-based infrastructure that enables world-class science, and drives UK space sector growth**.

The **HYMS instrument has potential defence applications**, and RAL Space has secured £93,000 from DSTL's Defence and Security Accelerator programme under the Invisible Battlespace call. The SPECTRE project (SPECtral Target Recognition Engine) will explore the applications of the HYMS instrument for signal jamming for front-line military capabilities.

RAL Space are also exploring potential commercial avenues for the HYMS instrument, including a spin-out company. The HYMS team **secured £450,000 from STFC's Challenge Led Applied Systems Programme (CLASP)D, which supports the application and commercialisation of STFC research**. To date, one patent has been filed, which is jointly attributable to CEOI and NSIP funding. This **highlights how CEOI catalyses investment and drives the space sector's long-term growth.**

CEOI funding has also **facilitated the development of strong partnerships and collaborations both in the UK and internationally**, including with JCR Systems, STAR Dundee, NanoAvionics, and the Met Office in the UK, and EUMETSAT and the ECMWF in Europe. CEOI's role as conduit between the UK and European earth observation communities supports such partnerships.

CEOI funding has also supported two student placements and the publication of four conference papers.

Next steps

The team is currently working towards an in-orbit demonstration of the HYMS instrument on a small satellite, with plans to launch in 2022. The team aim to have a demonstration HYMS constellation by 2027, which will require further investment. A HYMS satellite constellation will support improved weather forecasting, helping to mitigate against the impacts of extreme weather events.

RAL Space website: https://www.ralspace.stfc.ac.uk

2) On-Board Data Autonomy – Craft Prospect

Increasing satellite data processing efficiency with machine learning tools

Technology advances and new innovative payload designs in the EO sector are producing increased volumes of data. A key challenge is the timely and efficient delivery of this data to end-users and downstream applications. Autonomous decision-making and data processing on-board satellites in orbit reduces the reliance on human operators and infrequent ground station passes, resulting in faster, more cost-effective, and more timely mission activities. This ensure that end-users receive the data they need in the form they need it in.

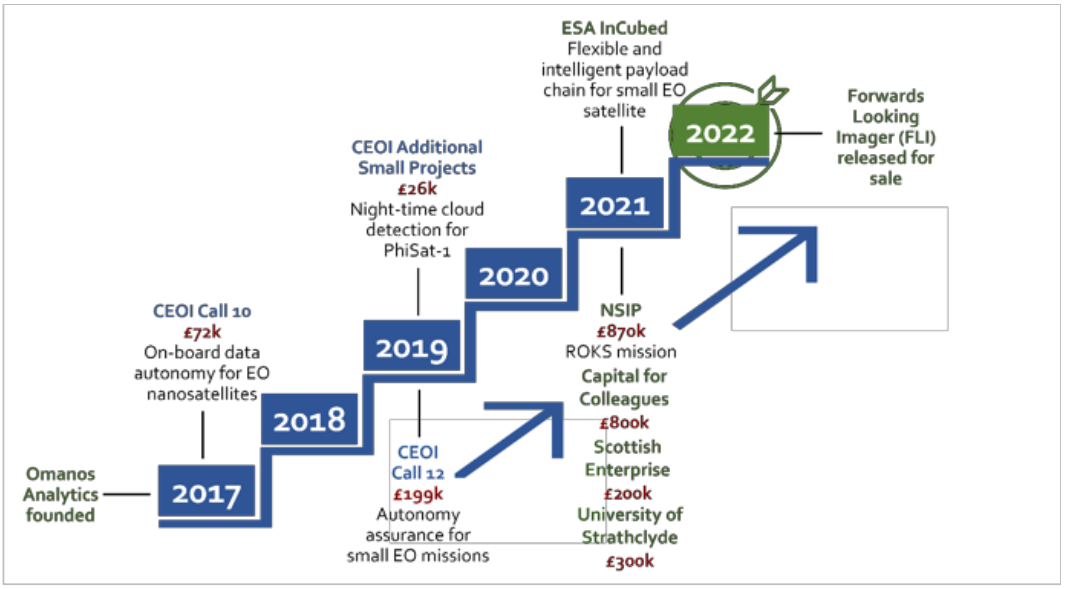
Craft Prospect is a space engineering company that delivers mission-enabling products and develops novel mission applications that **has developed a suite of innovative on-board autonomous decision-making tools for satellites,** enabling the transfer of decision-making and data processing from the ground to space, thereby increasing the efficiency and timeliness of data downlinks and mission activities.

CEOI support

CEOI first supported Craft Prospect in 2017 with a Pathfinder grant for the On-Board Data Autonomy (OBDA) project. Working with partners University College London, the University of Manchester and Bright Ascension, the project aimed to improve understanding of on-board data autonomy processing for Earth observing nano-satellites, including data selection, reduction, prioritisation, and distribution. The project surveyed existing space missions and techniques and also **explored non-space sector applications, including algorithms used in autonomous vehicles and commercial machine learning.**

CEOI support has enabled Craft Prospect to get the ODBA concept to a stage where it is ready for verification in relevant environments, essentially raising the concept Technology Readiness Level (TRL) from level 1 to level 4. Following this initial investment, Craft Prospect have further invested own funds onto the project and raised the concept to TRL 5 with its own investment.

Craft Prospect has also secured CEOI funding for the development of a new prototype assurance framework for data autonomy in small spacecrafts and Earth observing missions. Small EO missions and small satellites are limited by their physical size and power generation capabilities. Developed with the University of York, this project aims to address this challenge by making use of Craft Prospect's existing advanced system-in-the-loop and flight software simulations and supplying this solution at commercial and international scale.



Without CEOI funding, Craft Prospect would not have undertaken this project. This is because machine learning has only recently been seen as valuable for the space sector by funders. The project concept and resulting outputs have enabled Craft Prospect to secure further investment, highlighting how CEOI provides enabling, low-TRL grant funding for innovative concepts.

Outcomes and impacts to date

A range of outcomes and impacts have emerged from CEOI funding for this project. Since 2017 Craft Prospect has **increased its turnover and size**. The project has also **supported the development of a new product**, the Forwards Looking Imager (FLI). The FLI can be used, for example, as an early warning system for cloud cover by enabling a second, high-resolution camera to avoid the clouds and capture more cloud-free imagery in a single orbit, making it more useful for downstream applications. The Craft Prospect team are now gearing up for **their first international sale of the hardware product**, and have received interest from others.

CEOI funding has also supported the development of software (machine learning models) and a suite of reusable data autonomy tools. **The capabilities developed as a result of CEOI funding has enabled Craft Prospect to leverage additional funding**. For example, the team have received funding worth **£870,000** from the National Space Innovation Programme for its ROKS (Responsive Operations Key Services) mission. Clouds in the atmosphere can inhibit Quantum Key Distribution (QKD) services – the ROKS proof-of-concept CubeSat mission will carry FLI and QKD payloads, and is designed to be able to identify the presence of clouds, and respond accordingly to ensure efficient use of the onboard and ground infrastructure resources. **Additional investment of £300,000 was also received from the University of Strathclyde**, a leading university in quantum technologies.

Craft Prospect also secured a significant investment of £800,000 from Capital for Colleagues (C4C) through the issue of new ordinary shares. C4C provide on advice, investment, and support for employee-owned businesses. **Scottish Enterprise also became a shareholder**, having converted its loan provided through its Early Stage Growth Challenge Fund, into new ordinary shares.

A sister company, Omanos Analytics, was founded off the back of the on-board data autonomy project – the organisation uses satellite data to identify and monitor the social and environmental impacts of critical infrastructure projects in low infrastructure regions.

CEOI funding has also indirectly supported seven PhD students, three undergraduate students and one graduate intern – students have all worked on projects relevant to CEOI funding.

Next steps

Craft Prospect will continue to develop its on-board data autonomy capabilities through its current NSIP-funded ROKS project. The team is also collaborating with Surrey Satellite Technology Ltd (SSTL) and the University of Surrey on an ESA InCubed project which will develop autonomous downlink software and data processing capabilities for small EO satellites.

Craft Prospect website: https://craftprospect.com/

3) SEASTAR – National Oceanography Centre

From CEOI Pathfinder grant to ESA Earth Explorer 11 Mission Concept

Developed by the National Oceanography Centre (NOC) and Airbus Defence & Space, **SEASTAR is an innovative dual-beam interferometric synthetic-aperture radar (SAR) concept that improves SAR performance for oceanography**.

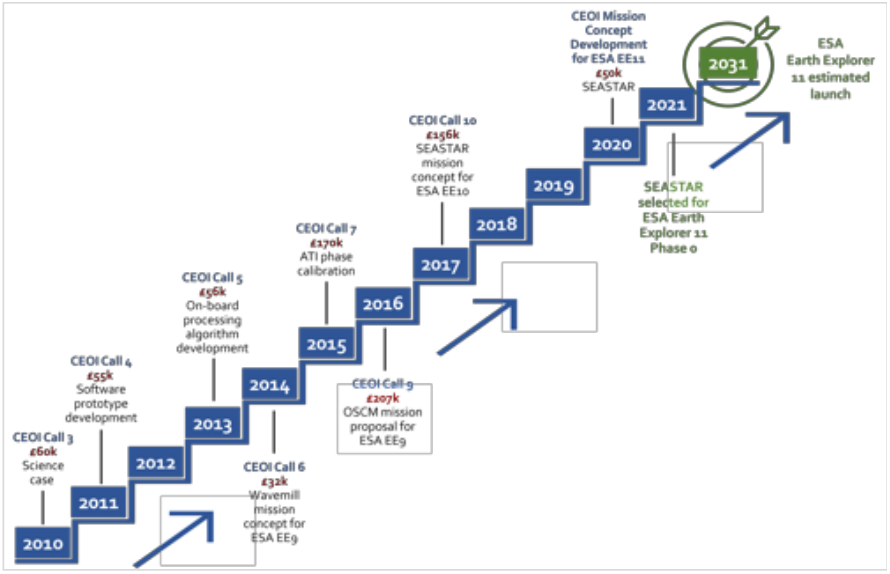
Understanding small-scale ocean processes and dynamics is important for understanding air-sea interactions linked to primary productivity supporting the marine food chain, as well as for environmental monitoring, including the dispersion of oil and plastic pollution. However, whilst high-resolution satellite images of ocean colour and surface temperature exist at scales below 10 kilometres, measurements of ocean surface dynamics at these scales are rare.

SEASTAR would deliver, for the first time, two-dimensional images of the total ocean surface currents and wind vectors at one km resolution and high accuracy.

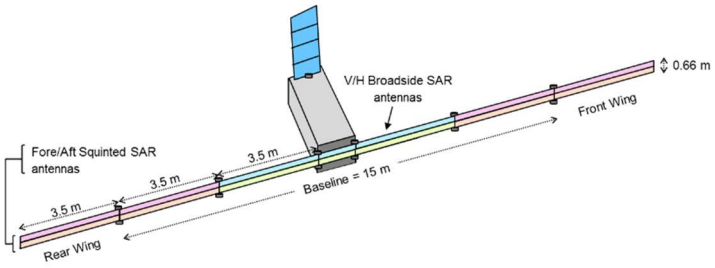
SEASTAR represents a major step in addressing the multidisciplinary needs of the ocean, air- sea interactions, coastal processes, cryosphere, forecasting and climate communities. Information collected by SEASTAR **would further scientifically study of ocean dynamics and small-scale ocean processes, important for understanding air-sea interactions linked to primary productivity supporting the marine food chain.** These small-scale dynamics are also **important for environmental monitoring, including the dispersion of oil and plastic pollution.** For example, SEASTAR generated data would: support improved ocean modelling, forecasting and climate projections; deliver novel observations in coastal and ice-covered seas; support coastal and offshore operations, including shipping, fishing and renewables; and support environmental monitoring and management e.g. tracking oil spills and plastic pollution, monitoring sediment transport, coastline changes, and exposure of infrastructure and natural habitats to natural hazards.

CEOI support

CEOI first supported the SEASTAR concept in 2010 (then known as 'Wavemill'). Early CEOI funding enabled the development of the squinted ATI SAR concept, hardware developments linked to antenna technology, instrument calibration strategy, and traceability to science requirements. CEOI funding also supported NOC and Airbus to prepare and submit the concept to ESA for the Earth Explorer (EE) 9 programme.



Since 2016, CEOI funding has supported NOC and Airbus to enhance the SEASTAR mission concept, evaluate the impact on performance of different instrument designs, and submit the improved mission concept to the ESA EE 11 programme. This enabled the SEASTAR team to work together on the technical specification to ensure it met the scientific objectives of the mission.



Overall, CEOI grant funding has enabled NOC to raise the SEASTAR Technology Readiness Level (TRL) and Science Readiness Levels (SRL) to satisfy the conditions of the ESA EE calls (typically TRL and SRL level 4 or above).

Benefits and impacts

NOC would not have undertaken this project development without CEOI funding as there is no alternative source of funding in the UK to support joint science/industry projects from public or private resources. Satellite earth observation (EO) technology development receives limited support from public funding sources, and private investments by industry is limited due to the risks of low TRL projects and of the ESA EE programme.

A range of outcomes and impacts have emerged from CEOI funding for the SEASTAR project. Most notably, the SEASTAR mission concept has recently been announced as one of four projects selected by ESA to proceed to the next stage of the Earth Explorer 11 programme. This is a significant achievement, and would not have happened without the support from CEOI, both in terms of grant funding, and technical advice in preparing the mission concept proposal to ESA.

Success with ESA has led to additional benefits and impacts. For example, it has increased NOC's international reputation and opened up new international collaboration opportunities. It has also supported the winning of new international contracts from ESA to further the development of the SEASTAR concept.

Moreover, CEOI funding has safeguarded and enabled the continuation of several post-doctoral researchers at NOC and supported the publication of four research papers.

The long-running relationship between NOC and Airbus has been crucial to the project and development of the SAR technology. At the same time, **the CEOI funding has enabled additional partners from academia and industry to be involved and collaborate on this project.**

Next steps

SEASTAR has now entered Phase 0 of the ESA Earth Explorer 11 programme. **This will enable the project to further study concept feasibility and increase scientific and technical readiness levels – NOC is leading a team of 70 international scientists to work on this.** If successful through Phase 0 and Phase A studies (it has to compete with three other mission concepts), SEASTAR would be launched in 2031/32.

If SEASTAR is launched, it could support improved climate models and forecasting, deliver increased observation capabilities in coastal and polar regions, support coastal management including shipping, fishing and off-shore renewables, and support environmental monitoring, for example, tracking oil spills and plastic pollution.

National Oceanography Centre website: https://noc.ac.uk/

4) TRUTHS – National Physical Laboratory

Improving confidence in climate change forecasts with a space-based 'standards laboratory' and calibration observatory

A key challenge for the international climate science community is to establish a highly accurate observational climate benchmark to enable the detection of climate change, with the ability to constrain and test climate forecast models on a decadal time scale.

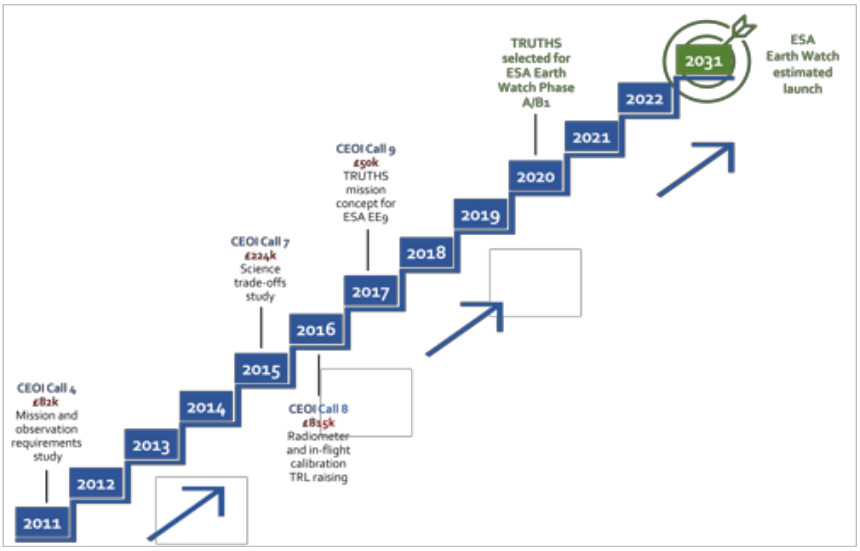
Developed by the National Physical Laboratory (NPL) – in collaboration with Airbus Defence & Space, the universities of Leicester, Reading, Swansea and Imperial College London, RAL Space, and Surrey Satellite Technology Ltd – the **TRUTHS mission will collect the most accurate measurements of energy coming into the Earth from the Sun, and light reflected off Earth's surface, to help understand how humanity's impact is changing the planet's energy balance – the driver of its climate.**

The measurements captured by the mission, will not only create a unique climate relevant dataset, but also **improve the performance of other missions through the transfer of improved calibration from orbit**, becoming a new gold standard reference for climate measurements – a 'space-based standards laboratory'. TRUTHS will enable a ten-fold improvement in accuracy of data and support rigorous testing of model forecasts, thereby enabling faster decision-making and progress monitoring of climate change mitigation strategies.

CEOI support

CEOI funding has supported the TRUTHS mission concept since 2011, including studies to develop the mission and observation requirements, and to assess the trade-offs between complexity, risks and costs against the scientific drivers. Since 2016, CEOI funding has supported NPL and Airbus Defence & Space with grant funding to increase the Technology Readiness Level (TRL) of the Cryogenic Solar Absolute Radiometer (the main solar measurement instrument) and the in-flight calibration system, both vital elements to the mission concept. CEOI funding and support has also enabled the team to enhance the TRUTHS mission concept by strengthening the science case for a proposal for the ESA Earth Explorer programme. This enabled the TRUTHS team to work on the technical specification of the concept to ensure it met the required standard for submission.

Overall, CEOI grant funding has enabled NPL to raise the TRUTHS TRL from level 3 to level 5 – a high enough maturity to be considered for ESA.



NPL may have undertaken this project without CEOI funding, however, **without CEOI funding, NPL would not have had access to the same resources, it would have taken longer to achieve, the scope of the project would have been limited, and TRL 5 would not have been achieved in a timely manner** to address the climate emergency. CEOI funding has allowed a coherence in effort and focus necessary to evidence the feasibly of a novel mission.

Benefits and impacts

A range of outcomes and impacts have emerged from CEOI funding for the TRUTHS mission concept. Notably, TRUTHS has been adopted as a mission to be financed under the ESA Earth Watch programme. This is a significant achievement, as ESA programmes are extremely competitive – TRUTHS was selected from 35 mission proposals. This achievement would not have happened without the support from CEOI, both in terms of grant funding to develop the technology and concept, and technical advice received in preparing the proposal.

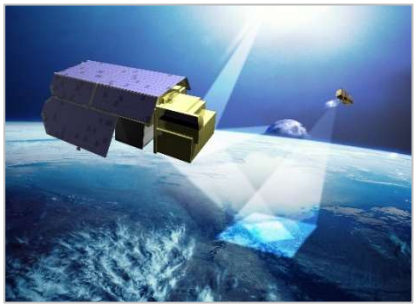
Selection to the Earth Watch programme has **supported UK businesses in winning contracts from ESA** to undertake feasibility study and pre-development activities to build the satellite. This will include key partners from the UK space industry, such as NPL, Teledyne e2v UK, RAL Space, the University of Leicester, Thales Alenia Space UK, CGI IT UK, Telespazio-UK, and Goonhilly Satellite Earth Station, as well as important contributions from companies and institutes from the participating nations: the Czech Republic, Greece, Romania and Switzerland. The **overall contract is worth approximately €16 million**.

The TRUTHS mission concept has also **increased NPL's international reputation and supported international collaborations and partnerships**. The mission has received strong support from international organisations (e.g. WMO, EUMETSAT and GCOS), whilst NASA is developing a sister mission (CLARREO) towards a satellite implementation – the organisation has met with the UK Space Agency and signed a memorandum of understanding with NPL and NCEO. The Chinese Meteorological Administration plans to launch a version of CLARREO, including a copy of TRUTHS, and acknowledges the UK as the origin of the idea.

NPL also attended the recent COP26 Climate Change Conference in Glasgow, presenting the latest developments of the TRUTHS project, and supporting the Space4Climate exhibition stand as part of the Green Zone programme.

CEOI funding has **supported NPL to develop strong partnerships in the UK**, including with Airbus Defence & Space, Surrey Satellite Technology Ltd, STFC RAL Space, the University of Reading and Imperial College London. CEOI funding has also supported three CASE PhD awards and the publication of six research papers.

Next steps



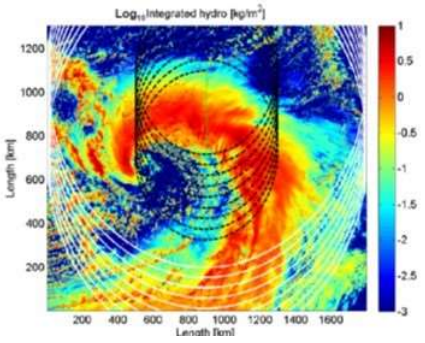
ESA is developing TRUTHS on behalf of the UK and other partner nations across Europe. It will be built by Airbus in the UK with an international industrial consortium and supported by European researchers. As part of the mission's development, TRUTHS has moved from Phase A (feasibility phase) into Phase B1 (early design phase), and the team are now looking forward to Phase B2. This will eventually lead to the 'adoption' of the mission and the selection of an industrial contractor to continue the build. The TRUTHS mission aims to launch around 2029. TRUTHS will help deliver improved confidence in Earth Observation data gathered from space, and the forecasts driven by this data.

National Physical Laboratory website: https://www.npl.co.uk/

5) WIVERN – University of Reading

From CEOI Fast Track grant to ESA Earth Explorer 11 mission concept – improving extreme weather forecasting

Global measurements of wind and rain are important for weather forecasting and climate modelling. **In order to better predict extreme weather and mobilise action in likely affected regions, observations of the winds inside hurricanes and winter storms as they develop over the Atlantic are needed**.



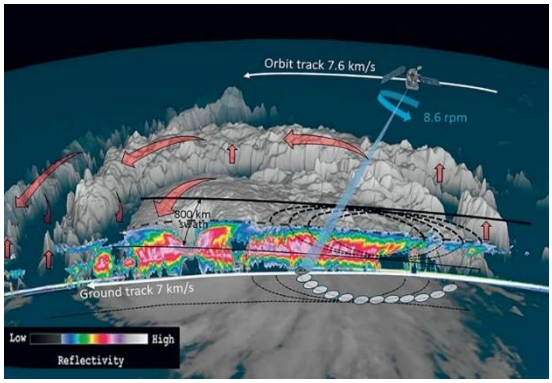
Developed by the University of Reading, in collaboration with the University of Leicester, STFC RAL Space, and Airbus Defence & Space, **WIVERN (Wind Velocity Radar Nephoscope) is an innovative radar concept that would, for the first time, measure winds within clouds.**

The WIVERN mission concept would benefit the prediction of high-impact weather and hazard warnings for weather forecast models and contribute to the climate record of cloud and precipitation profiling.

CEOI support

CEOI have supported the University of Reading's WIVERN project since 2015, which has developed a narrow beam 94GHz radar which will measure wind speeds within clouds and rainfall. This radar is operating at the STFC Chilbolton Observatory in Hampshire and gathering data on passing weather systems. **The WIVERN concept proposes to deploy a version of this radar on a satellite using a large conically scanning antenna.** WIVERN uses the same 94 GHz transmitter tube as NASA's CloudSat (launched in 2006). However, it provides a major advance by having two tubes transmitting closely spaced pulse pairs polarised horizontally and vertically so that, for the first time, the high Doppler velocities of winds can be measured from space. A rotating antenna means that it can sample a large area and observe winds over the whole planet at least once a day.

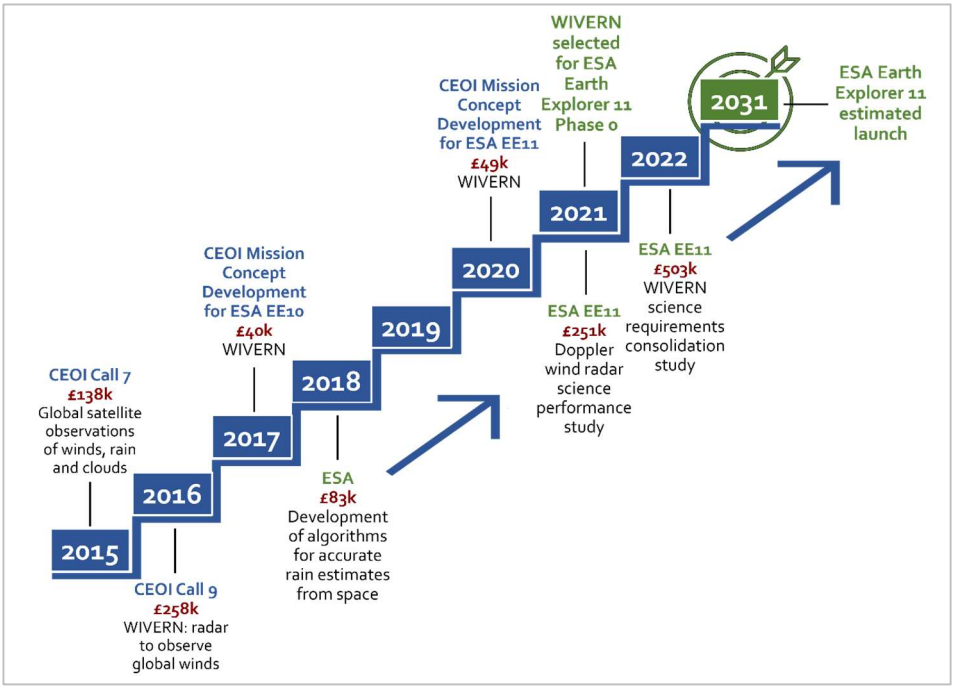
CEOI has provided grant funding support for the WIVERN concept since 2016 to develop this innovative concept, enabling the team from the universities of Reading and Leicester to optimise the feed to the rotating antenna, and develop a bespoke angular momentum compensation system, as well as validate and test the concept. WIVERN also received additional funding and support from CEOI for mission concept development activities for the ESA Earth Explorer 10 and 11 calls. This support enabled the WIVERN team to work on the technical specification of the concept to ensure it met the required standard for submission to ESA.



Overall, CEOI funding has enabled the University of Reading to raise the WIVERN Technology Readiness Level (TRL) from level 3 to level 5, a high enough maturity to be considered for ESA.

Benefits and impacts

The University of Reading would not have undertaken this project development without CEOI funding as there is no alternative source for this type of project from public or private resources. Low-level technology development receives limited support from other public funding sources, and private funding is limited due to WIVERN being a science-focused mission at a low TRL, with potential returns on investment hard to ascertain.



A range of outcomes and impacts have emerged from CEOI funding for the WIVERN project. Notably, the WIVERN mission concept has recently been announced as one of four projects selected by ESA to proceed to the next stage of the Earth Explorer 11 programme. This is a significant achievement, as ESA programmes are extremely competitive – this would not have happened without the support from CEOI, both in terms of grant funding and technical advice received in preparing the mission concept proposal.

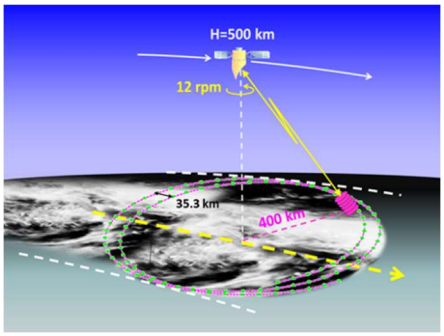
Selection the programme has supported the **winning of new international contracts from ESA totalling approximately £838,000** (of which £372,000 to UK organisations) to further the

development of the WIVERN concept. This highlights how **CEOI has strengthened the position of UK teams bidding to ESA, and generated a return on UK government investment in ESA**.

The CEOI funding has also enabled additional international collaboration opportunities with academia and industry – through WIVERN's selection to proceed to Phase 0 the ESA Earth Explorer 11 programme, **the University of Reading is leading a team of international scientists to further study the concept feasibility and increase scientific and technical readiness levels.** This has opened up further international collaboration opportunities, for example, with Turin Polytechnique (Italy), LATMOS (France) and MeteoFrance, the French national meteorological service.

Next steps

If successful through Phase 0 and Phase A studies (it has to compete with three other mission concepts), WIVERN would be launched in 2031/32. If WIVERN is launched, it would become the first and only mission in the world to measure wind in clouds using a radar on a satellite with a rotating antenna, enabling it to sample and observe winds over the whole planet at least once a day. WIVERN could support improved global models of wind and rain used in weather forecasting, particularly for extreme weather events like tropical cyclones and hurricanes – the same models are used for climate forecasts, so WIVERN would also make predictions of future climate more reliable.



University of Reading website: https://www.reading.ac.uk/

6) CIIR – University of Oxford

Developing a compact infrared sensor for international fast-build spacecraft missions

One of the key challenges of atmospheric science is to understand and measure gases and water vapour behaviour on Earth and on planetary bodies like comets – this is key to understanding our climate and the origins of the Solar System. However, current measurement instruments are reaching the end of their mission life – a new instrument is therefore required to maintain the long-term data series of global water vapour measurements.

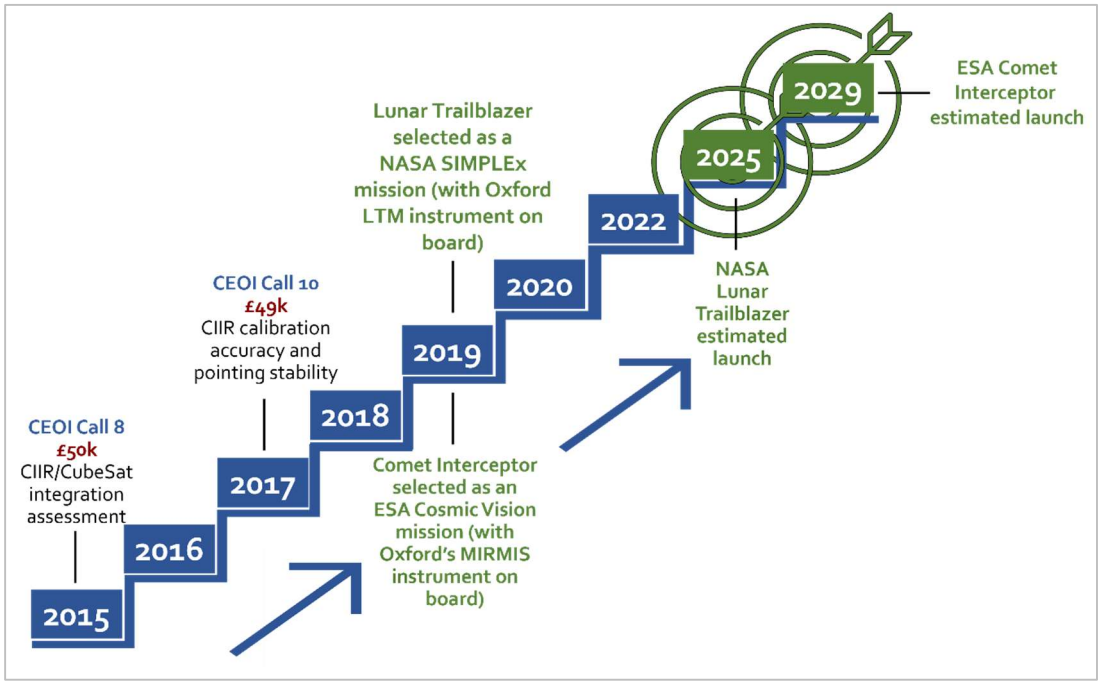
Developed by the University of Oxford, in collaboration with STFC RAL Space, Clyde Space and the Satellite Applications Catapult, the CIIR (Compact Infrared Imager and Radiometer) is an innovative approach to infrared sensing. **CIIR improves on previous instruments** by including two components to ensure it returns data that can reliably complement and enhance existing Earth Observation (EO) data sets. The system also uses a **compact modular approach designed to be easily tailored to specific mission requirements and integrated with small and cube satellites**, providing a low-cost and flexible instrument for missions.

CEOI support

CEOI provided two phases of funding to support the development of the CIIR. The first study, in 2015, supported the team to investigate the capabilities of a CubeSat-type spacecraft to fly the instrument. The second study, from 2017-2019, supported the development of the CIIR design to a level of maturity suitable for implementation as a CubeSat payload, and address concerns raised during the earlier phase regarding radiometric calibration accuracy and pointing stability.

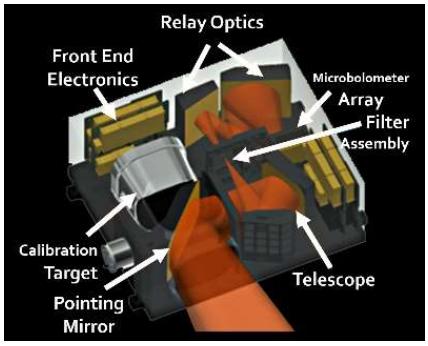
Overall, CEOI grant funding has enabled the University of Oxford to consolidate the CIIR Technology Readiness Level (TRL) at level 6 – a high enough maturity to be considered as an instrument payload for a spacecraft mission.

The University of Oxford may have undertaken this project development without CEOI funding, but it would have taken longer to complete.

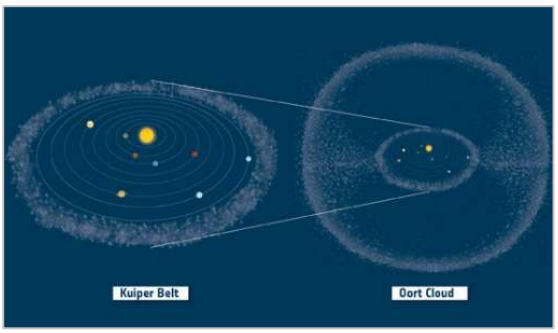


Benefits and impacts

A range of outcomes and impacts have emerged from CEOI funding for the CIIR project. Notably, it has been selected as one of two instrument payloads on board the NASA Lunar Trailblazer mission, led by Caltech, built by Lockheed Martin, and managed by NASA's Jet Propulsion Laboratory (JPL). The $60 million 'fast build' Lunar Trailblazer mission aims to determine the form, abundance, and distribution of water on the Moon and the nature of the lunar water cycle. The CIIR instrument – known as the Lunar Thermal Mapper (pictured) for this mission – will map the moon's surface temperature and water. The mission has already had a **large international impact,** with India, China and Russia all targeting lunar water missions. Moreover, the mission has **supported UK collaborations and partnerships** – the UK consortium includes the universities of Oxford, Durham and Cardiff.



The CIIR has also been selected as an instrument for ESA's Comet Interceptor flight mission, which will be the first mission to visit a long-period comet as it journeys into the inner Solar System from the vast Oort Cloud that is thought to surround the outer reaches of the Sun's realm (pictured). The CIIR – known as MURMIS (Multispectral InfraRed Molecular and Ices Sensor) for this mission – will measure the heat radiation being released from the comet's nucleus and study the molecular composition of the gas coma. The Comet Interceptor is a 'fast' or F-class mission, referring to the implementation time from selection to launch readiness in nine years. The flexibility of the CIIR to be tailored to specific scientific requirements, as well as its compact size and modular design make it particularly suitable for this mission – it is one of four instrument payloads on spacecraft A, which is one of three spacecraft on this mission.



Selection to the ESA Comet Interceptor mission has **supported international collaborations and partnerships** – the MURMIS team involves VTT (Finland), the University of Helsinki, the Academy of Finland, NASA's Goddard Space Flight Center, and the University of Central Florida – as well as the **winning of international contracts from ESA** to build the instrument. This highlights how CEOI support has strengthened the position of UK teams bidding to ESA, and generated a return on UK government investment in ESA.

CEOI support for the CIIR project has also facilitated the development of UK collaborations and partnerships, particularly with STFC RAL Space, Clyde Space Ltd, Satellite Applications Catapult. As the Professor Neil Bowles, Principal Investigator of CIIR, commented:

'[CEOI's] mechanism to work with industrial partners is very good…it brings them in early.'

The CIIR project also has commercial potential. The results from the CEOI study have helped to refine the business case for a CIIR-based thermal-infrared imaging data service company – the team are looking into developing a spin-out company. There are also potential patents with industrial partners to explore after the delivery of the NASA mission, whilst the electronics being produced with STFC RAL Space also have commercial possibilities.

Next steps

The NASA Lunar Trailblazer mission plans to launch in 2025, though this may be earlier if it can link with a commercial launch. The ESA Comet Interceptor mission plans to launch in 2029. The

University of Oxford are also in discussion with JPL around a mission to Saturn in the mid-2030s, including a bi-lateral agreement with the UK.

University of Oxford website: https://www.ox.ac.uk/

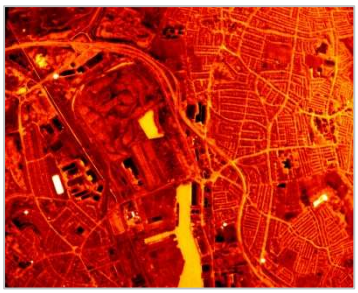
NASA Lunar Trailblazer mission website: https://trailblazer.caltech.edu/

ESA Comet Interceptor mission website: https://www.cometinterceptor.space/

7) DarkCarb

Developing low-cost, world-leading infrared imaging capabilities for commercial small satellite missions

There has been an increasing demand for high-resolution thermal imagery in recent years. Thermal imagery provides the capability to differentiate between objects and surfaces of different temperatures, useful for mapping heat emissions from buildings or installations and for disaster monitoring, for example wildfires. However, the majority of satellite imagery currently available is in the visible waveband and is captured at mid-morning or mid-afternoon, due to reliance on good light conditions.



Developed by Leonardo UK **and** Surrey Satellite Technology Ltd **(SSTL), the** DarkCarb project **has developed an innovative, low-cost mid-wave infrared imager (MWIR) for deployment on a small satellite platform.** The concept overcomes current limitations by enabling imaging at both night and day under any lighting condition, providing additional temporal information by comparing temperature changes on a still target, and using temperature information to monitor items otherwise invisible to visible sensors.

DarkCarb is a highly innovative development in the commercial satellite imagery market, providing affordable, high-quality and high-resolution imaging data for a range of applications, including: building thermal efficiency monitoring; industrial asset monitoring; disaster monitoring, such as wildfires and volcanic eruptions; and monitoring aircraft and ships for defence and security.

CEOI support

CEOI funding supported the DarkCarb concept from 2019 to 2021, enabling the development of the innovative MWIR imager. The project re-engineered and re-designed Leonardo's SuperHawk infrared detector (pictured), already used in military applications, and made it compatible for space missions. The SuperHawk is a high-performance integrated detector cooler assembly and is the smallest thermal mid-wave infrared pixels commercially available in the world.

CEOI funding supported the development of the detector assembly, including re-configuring the instrument with a longer life, a lower vibration engine cooler, and new electronics to provide the interface between the detector and the imager. CEOI funding also facilitated the re-design of the proximity electronics to SSTL's standards, and enabled thermal-vacuum and vibration testing to ensure the instrument is suitable for use as intended.

Overall, CEOI grant funding has enabled Leonardo and SSTL to raise the DarkCarb Technology Readiness Level (TRL) from level 2 to level 5. This improvement has enabled the DarkCarb concept to be successfully flown in an airborne demonstration mission (under SSTL's own investment), which has further raised the TRL to level 7. This means the concept is ready for commercial investment and to be launched as a satellite payload.

Leonardo and SSTL may have undertaken this project development without CEOI funding, as it may have been funded internally. **However, without CEOI funding the collaboration between Leonardo and SSTL would not have happened, and the project would have taken longer to start – CEOI accelerated the concept development and provided focus.**

Benefits and impacts

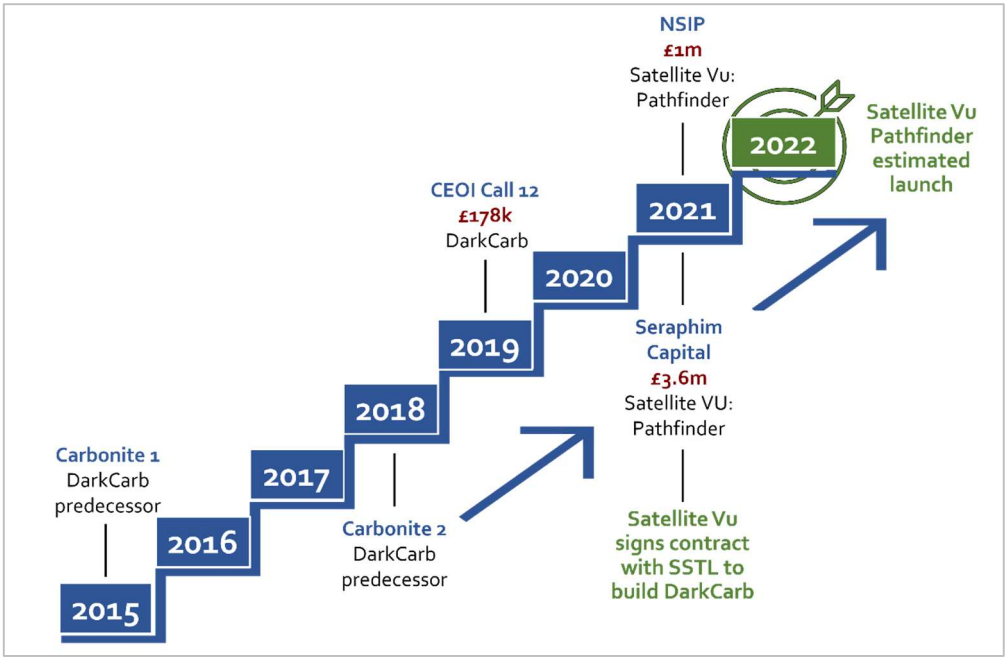
A range of outcomes and impacts have emerged from CEOI funding for the DarkCarb concept.

Notably, **the DarkCarb concept has leveraged further funding and investment** for SSTL through a contract with Satellite Vu, a recently established space technology company which provides high-resolution thermal imaging services.

The contract is to build the first of seven planned satellites for a low EO constellation which will offer a view into temperatures across cities and around the world, part Satellite Vu's MWIR Pathfinder mission. This follows on from **Satellite Vu's £1 million** National Space Innovation Programme **(NSIP)** Pathfinder mission project. Using SSTL's DarkCarb product, the project will develop and build the world's first small satellite and will deliver high-quality thermal video and thermal still imagery of the Earth. Satellite Vu has also raised £3.6 million investment from Seraphim Capital to support the Pathfinder project.

The DarkCarb project highlights how CEOI funding helps catalyse UK Space Agency investment and drives UK space sector growth. As Andrew Haslehurst, SSTL's Chief Technical Officer, commented, referencing Satellite Vu:

'From a £100,000 CEOI grant, there is now a multi-million pound business.'



Next steps

The DarkCarb project concept will be a payload on Satellite Vu's MWIR Pathfinder mission, with a planned launch for the end of 2022. This will be the first of seven infrared satellites, eventually forming a constellation which will enable the measurement of thermal emissions from any structure on the planet, supporting climate-related heat mapping and thermal efficiency monitoring; disaster monitoring of wildfires and volcanic eruptions; infrastructure and industrial asset monitoring; and monitoring aircraft and ships for defence and security scenarios.

Leonardo UK website: https://uk.leonardocompany.com

SSTL website: https://www.sstl.co.uk/

Satellite Vu website: https://www.satellitevu.com/

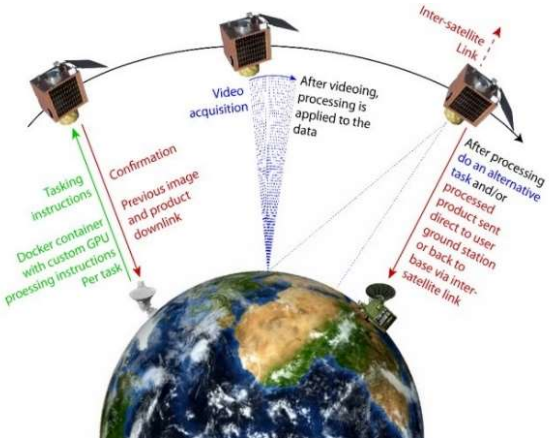
8) OVERPaSS – Earth-i

Improving satellite data and video processing for increased efficiency and utility

Technology advances and innovative payload designs in the Earth Observation (EO) sector are producing increased volumes of data. **A key challenge is the timely and efficient delivery of this data to end-users and downstream applications.** Optimising data processing on-board a satellite (for example, videos and images) can substantially reduce the amount of data a satellite needs to store and downlink, increasing the satellite's overall utility, and resulting in faster, more cost-effective, and more timely mission activities.

Earth-i, in collaboration with the Mullard Space Science Laboratory (MSSL, University College London), Cortexica Vision Systems, and Surrey Satellite Technology Ltd (SSTL), have **developed low-power, high speed computation technology that enables the performing of complex data processing on-board satellites**, rather than on the ground. This will **accelerate the delivery of high-quality images, video and information rich analytics to end-users**, providing a major advance in rapid derivation of information from high resolution still and video imagery from space.

For example, processes such as the enhancement of image resolution, cloud-detection, and video compression currently take place on the ground, meaning the satellite has to store and downlink large volumes of data, even if the imagery might be unusable. Moving these processes on-board satellites will make imagery activities more efficient and increase the probability of capturing usable date. Moreover, it will reduce the need for ground infrastructure for interpretation of data, increasing the timeliness of mission activities.

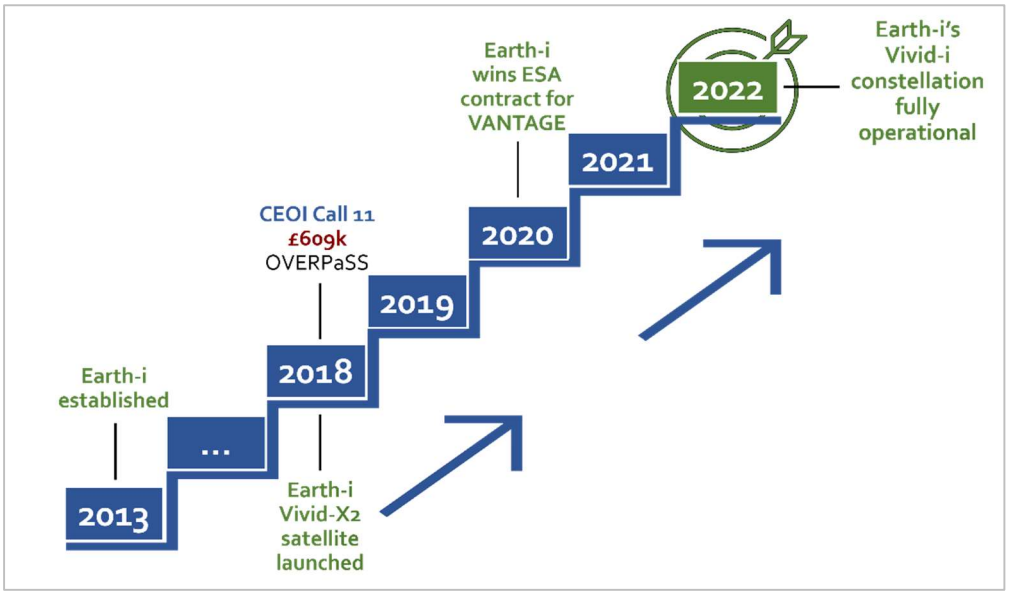


CEOI support

CEOI funding supported Earth-i's OVERPaSS (On-board VidEo Rapid ProceSSing) project in 2018, with the aim of implementing, testing, and demonstrating ultra-high-resolution optical image analysis techniques, involving both software and dedicated hardware, such as Graphical Processing Units (GPUs). The project exploited techniques used to image the Beagle 2 lander on Mars and applied these methods to EO imagery.

The project discovered that all algorithms developed have their uses for on-ground processing, though not all are suitable for on-board processing. For example, super-resolution and 3D reconstruction algorithms are too resource hungry and have long run times, so are suitable for on-ground only (the power demands of the algorithms against on-board resources need careful balancing); whereas the neural net cloud clearing and compression algorithms seem to be much better than traditional algorithms, and can be run on-board.

The project also found that on-board processing is beneficial for other tasks leading towards spacecraft autonomy, for example, AOCS (Attitude and Orbit Control System) monitoring and correction, prioritisation of data capture and downlink, and satellite power and thermal regulation. Overall, the CEOI funding enabled Earth-i to apply machine learning algorithms to cloud detection, edge processing for imaging payloads, and new satellite video processing techniques.
Overall, CEOI grant funding has enabled Earth-i to raise the OVERPaSS Technology Readiness Level (TRL) from level 2/3 to level 7.



Earth-i would not have undertaken this project without CEOI funding. Some minor aspects of the project could have been done by Earth-i with internal resources, but the **investment and partnership opportunities enabled by CEOI funding would not have happened**.

Benefits and impacts

A range of outcomes and impacts have emerged from CEOI funding for the OVERPaSS project. Notably, **Earth-i's machine learning algorithms have been deployed in the cloud for on-ground processing within ESA's video analytics and exploitation platform,** VANTAGE.

Earth-i secured the VANTAGE contract in 2020, in partnership with IT services company CGI. VANTAGE is a cloud-based online environment where users can analyse videos acquired from space and extract value for their own research and/or business purposes. It offers an archive of videos acquired from satellites, including data from the Earth-i Vivid-X2 satellite launched in 2018. Alongside the data will be a repository of tools to process these videos and extract value from them, including derivation of 3D models, detection of objects of interest in the videos, extraction of movement vectors, or building up cloud-free composite images (pictured).

CEOI funding **has helped Earth-i to win business internationally** – it has exported its machine learning technology to one country, whilst discussions with a further two countries are ongoing. This highlights how **CEOI helps to drive and sustain UK space sector growth.**

Next steps

Earth-i's Vivid-i constellation, which is being designed and manufactured by SSTL and plans to be fully operational in 2022, offers a potential first on-board application for the OVERPaSS technology. Its deployment in a satellite constellation will transform the ability of EO instruments to provide contemporaneous data and products for end users in industry and government to benefit from higher quality imagery, video and analytics, and faster processing and delivery times. **This will enable a wide range of new and innovative downstream services for a variety of sectors,**

including agriculture, construction, defence and security, energy, insurance, infrastructure and utilities (e.g. water), and planning and land use. Moreover, the technology is now being considered in the design reviews for several visible imaging instruments to go on potential future missions.

Earth-i website: https://earthi.space/

9) Added Value Programme – CEOI

Facilitating knowledge exchange and collaboration across the UK Earth Observation academic and industrial communities

Alongside its Earth Observation (EO) technology grant funding programme, the CEOI provides **enhanced access to networking and knowledge exchange opportunities** for the UK industrial and academic EO communities through its Added Value programme of events. The strand has brought together **and facilitated collaboration and knowledge exchange** between the **UK EO research community, technologists, end-users, and policy makers**

Delivered in collaboration with Qi3, specialists in technology marketing and business development, the knowledge exchange strand of the CEOI brings together UK scientists and engineers from academia and industry to develop UK capabilities in EO technologies and instrumentation.

As well as delivering knowledge exchange, the CEOI also **hold regular bi-annual meetings with ESA** to improve ESA's understanding of UK EO technology capabilities and priorities, and improve UK understanding of the opportunities presented by ESA, the EU, and Copernicus.

CEOI also provide an **EO technology horizon scanning and road mapping function** on behalf of and in collaboration with UKSA, supporting and developing a pipeline of UK EO technologies and instrument concepts for potential mission activities.

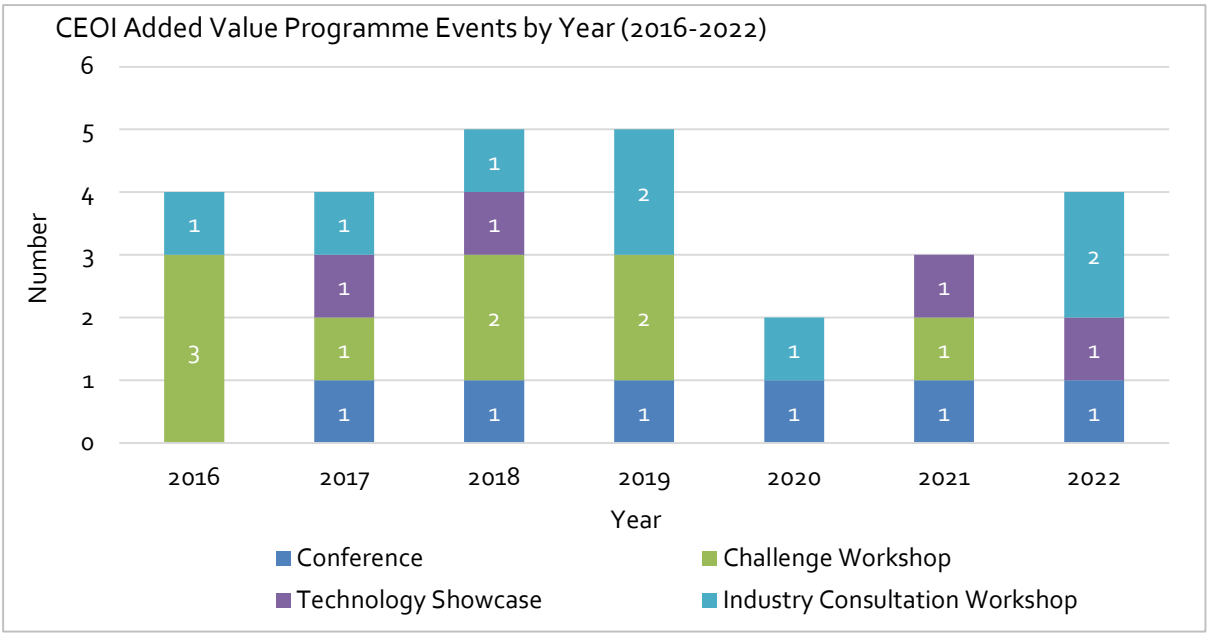
CEOI delivery

Since 2016, CEOI has **delivered 24 events**, averaging at four per year, with **over 1,850 participants representing over 60 organisations**.

Event and workshop participants represent the breadth of the EO community, including: **ESA**; **government departments** (Ministry of Defence, DSTL, Ofcom); **academia** (Birmingham, Glasgow, Imperial College London, Leeds, Reading, Southampton); independent research institutes (National Oceanography Centre, National Physical Laboratory, Fraunhofer CAP); and businesses, both **large defence firms** (Airbus, Thales Alenia Space) and **SMEs** (Craft Prospect, In-Space Systems, Oxford Space Systems, Pixalytics, Surrey Nanosystems, Twin Paradox).[30]

Workshops have brought together the UK EO research and industrial communities on a variety of topics, including: advanced manufacturing techniques for EO and space technology (with the Satellite Applications Catapult); autonomous remote sensing; polar earth observation (with the British Antarctic Survey); quantum technologies for satellite gravity mapping and measurement (with NCEO and the UK Quantum Technology Hub for Sensors and Metrology); miniaturisation of high-performance remote sensing instruments (with the Satellite Applications Catapult); EO instruments to enable future 'land surfaces' geo-analytical services; and the latest innovations in infrared, visible and multispectral remote sensing.

[30] This is a representative sample of the over 60 organisations participating in CEOI events from 2016-present.



NB. CEOI have delivered one event in 2022 to date (an industry consultation workshop on humanitarian relief).

Benefits and impacts

The CEOI knowledge exchange programme **successfully brings together the best of academia and industry,** co-creating the way forward for EO technology development and taking business up the Technology Readiness Level (TRL) scale. Stakeholders and project leads noted that the benefits of participating include networking with industry and academia, as well as potential customers and end-users. This highlights how the **CEOI supports the development of UK EO capabilities**. As two stakeholders commented:

'CEOI have done a credible job of convening the EO community.'

'CEOI has been doing technology transfer between academia and industry for decades.'

CEOI's horizon scanning and road mapping work has delivered two key reports. The EO Technology Strategy (2017, updated 2019) highlighted areas of UK technology strengths together with the growth trend of the future market. The EO Mission Capability Review (2018) highlighted a number of technologies and mission concepts, one of which, the National Physical Laboratory's TRUTHS instrument concept, is now an ESA Earth Watch mission (see separate case study). Two further projects, Earth-i's Vivid-i video imaging work (see separate case study) and Teledyne e2v's cold atom quantum sensor technology were also highlighted and have since secured CEOI grant funding, demonstrating how **CEOI supports a strong pipeline of UK EO technologies** and **drives and sustains growth in the UK space sector.** This also highlights the importance of CEOI's role in identifying new, emerging and priority technologies (for example, quantum technologies).

Next steps

The CEOI is running a programme of events in 2022, including: industry consultation workshops in non-space sectors covering humanitarian aid and disaster relief, and novel medical imaging; a technology showcase event promoting the achievements of recently completed CEOI-funded projects from the 11th, 12th and 13th calls; and the annual UK EO conference, in partnership with NCEO, the Remote Sensing and Photogrammetry Society (RSPSoc), and the Satellite Applications Catapult.

CEOI website: https://ceoi.ac.uk/

10) LHR – STFC RAL Space

Monitoring atmospheric processes with an innovative, miniaturised instrument on an ESA Scout mission

Studying changes in atmosphere composition increases our understanding of climate change impacts, including changes in ozone (affecting UV exposure) and water vapour (affecting surface temperature and the water cycle), and measuring greenhouse gases (GHGs) like carbon dioxide and methane. However, current space measurement instruments are large, complex, and expensive.

RAL Space**, in collaboration with** QinetiQ**, have developed an innovative instrument for the remote sensing of trace gases, including GHGs, the Laser Heterodyne Radiometer (LHR)**. The LHR has the **performance advantages of high sensitivity, high spectral resolution, and high spatial resolution, combined with relatively low complexity**, making it **highly suitable for miniaturisation**. This enables the LHR to fit as a small satellite payload, making it a cost-effective and versatile instrument with the ability to compete with, and in some cases exceed, the performance of the costly, heavy and bulky instruments currently used. Moreover, several such small spacecraft can be deployed as a constellation, increasing the potential scientific impact of missions.

Improved measurements of GHGs are needed to address scientific questions related to the carbon cycle (carbon dioxide) and to develop emission measurements services, both for space and terrestrial applications – the LHR instrument can address this need.

CEOI support

CEOI funding has supported the LHR concept development through seven projects since 2007. The LHR technology uses the hollow waveguide IP, acquired from QinetiQ's miniature LIDAR for space. Following on from initial NERC funding which established the scientific principles, CEOI funding from 2007 to 2016 was used to address the challenge of miniaturisation and support the testing of the instrument's suitability for sensing carbon dioxide. This funding enabled RAL Space to raise the LHR Technology Readiness Level (TRL) from level 1-2 to level 4.

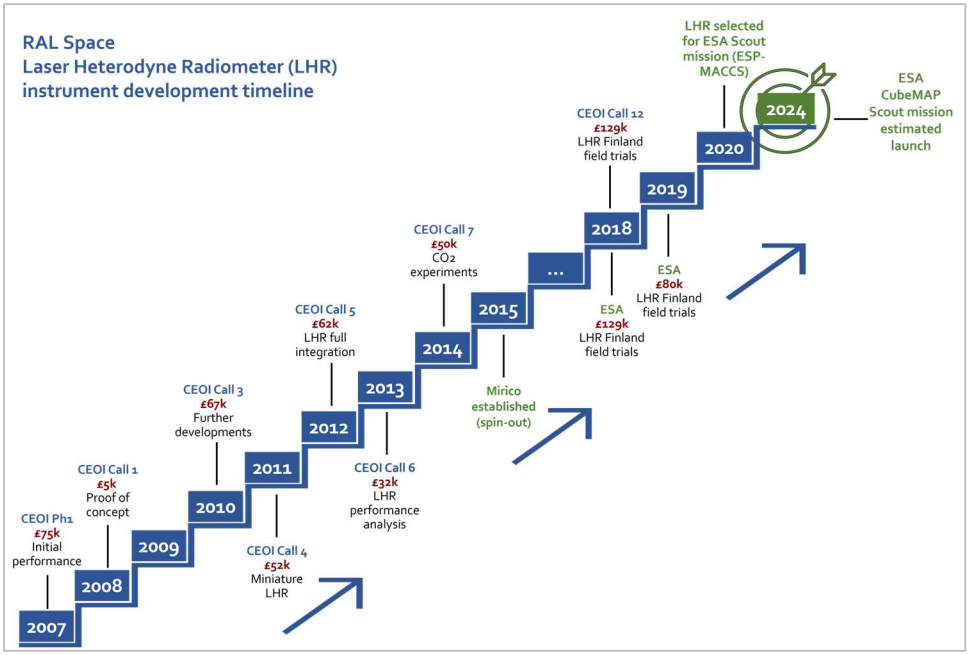
Since 2016, CEOI funding has supported the development and operation of the LHR instrument as part of ESA's FRM4GHG campaign in Finland. The CEOI funding, matched by ESA funding, supported the re-engineering of the LHR to measure methane, as well as the development of a dedicated solar tracker to enable stand-alone operation of the instrument. **Participating in the campaign enabled the LHR to be validated against conventional, industry standard GHG measurement instruments, and was a significant contributor in the preparing the way for the instrument's operational adoption as an ESA Scout mission**.

CEOI funding since 2016 has enabled RAL Space to raise the LHR TRL from level 4 to level 5. Moreover, the terrestrial application for the LHR instrument was raised to level 6.

Benefits and impacts

RAL Space would not have undertaken the project without CEOI funding as there is no alternative source of funding for this type of project from public or private resources. The LHR concept was very novel, and required early TRL funding over a long period (and eight CEOI funding rounds) in order for the technology to mature to a sufficient level. Private funding is limited due to the risks associated with investing in low TRL projects, with potential returns on investment realised over long timescales.

A range of outcomes and impacts have emerged from CEOI funding for the LHR project. Notably, LHR was selected by ESA as its first Scout mission, CubeMAP (previously EPS-MACCS), a trio of nanosatellites (pictured) to quantify atmospheric processes and how they impact Earth's climate.



Scout missions are a new element of ESA's EO programme and aim to prove new concepts using small satellites that add scientific value to current satellite data. Scout missions are agile, less expensive than other missions (€30 million compared to €400-500 million for ESA Earth Explorer missions), and have shorter timescales (three years compared to 15 years for Earth Explorer). The LHR, given its low complexity and compact form, was ideally suited to such a mission.

This achievement would not have happened without CEOI support to develop the novel LHR technology to a sufficient maturity to be considered by ESA. The overall CubeMAP contract is worth €24 million, with the **RAL Space contract worth £14 million**. This highlights how CEOI has **strengthened the position of UK teams bidding to ESA, and generated a return on UK government investment in ESA**.

CEOI funding for the LHR Finland campaign **helped RAL Space develop contacts with ESA and supported collaboration with partners** in Finland, Australia, Germany, Belgium and the Netherlands. Moreover, the campaign provided **skills development and training opportunities** for early-career researchers at RAL Space.

Furthermore, **RAL Space have established a spin-out company,** Mirico Ltd, to exploit the LHR technology in terrestrial applications. The SME provides gas sensing products for medical, industrial and agricultural industries, highlighting how **CEOI funding drives growth in non-space sectors**.

Next steps

ESA is developing the LHR instrument as part of its CubeMAP Scout mission, primed by GomSpace in Denmark with an international industrial and research consortium, including RAL Space, Enpulsion in Austria, Hyperion in the Netherlands, and KSAT in Norway. The CubeMAP mission plans to launch in 2024 and will measure water vapour, carbon dioxide, methane, ozone, nitrous oxide and aerosols, enhancing our understanding of the greenhouse effect and climate change.

Other future steps include further developing the LHR technology to unlock its full capabilities, as well as miniaturising and autonomising the instrument so it can be used as a ground-based network of sensors (to be combined with EO data) for GHG emissions services for the oil and gas industry. STFC RAL Space website: https://www.ralspace.stfc.ac.uk