CEOS
Committee on
Earth Observation Satellites

New Space White Paper

CEOS New Space Task Team

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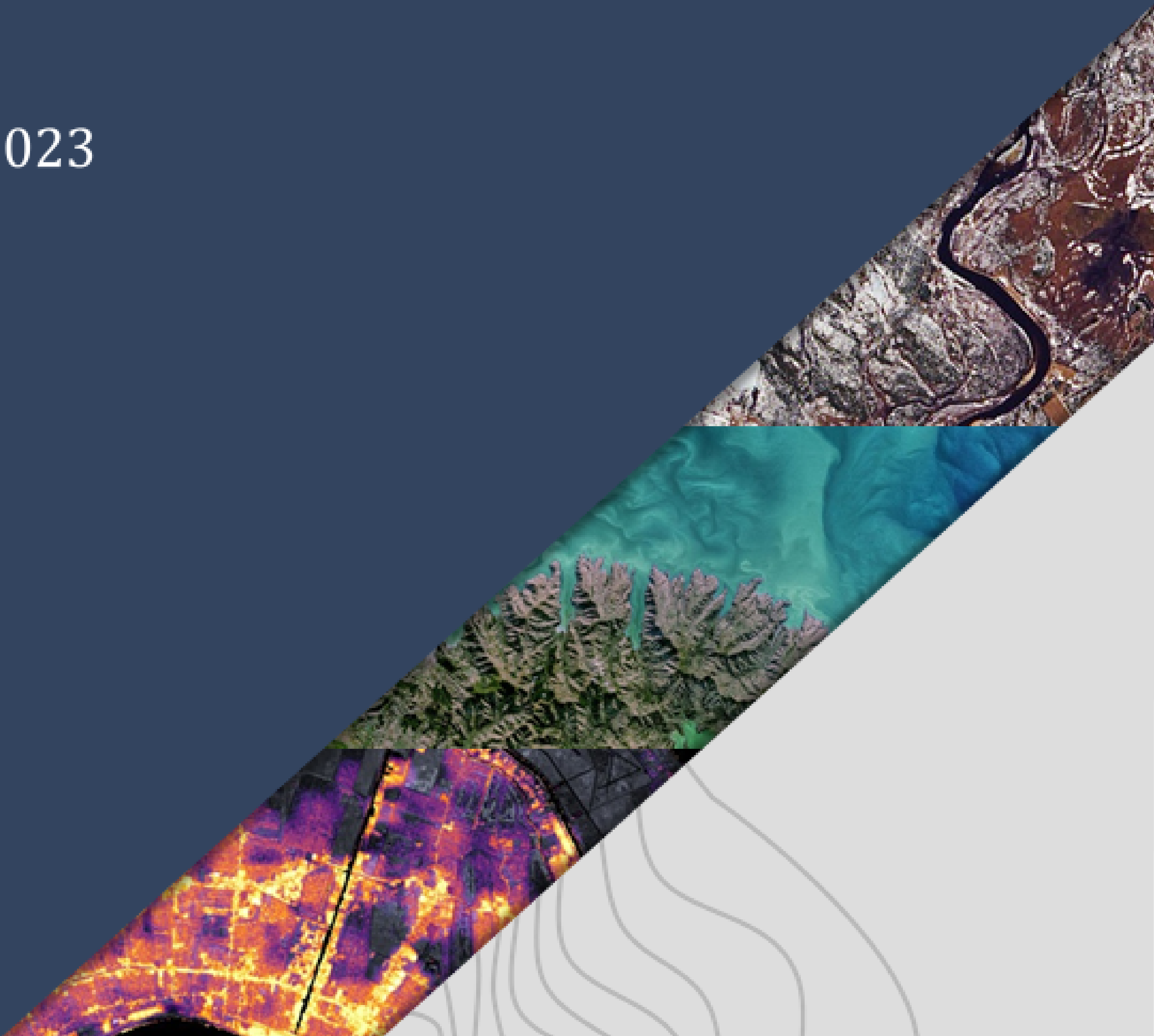

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1. Introduction & Objectives

The past decade has marked an era that has seen increased deployment of Earth observation (EO) satellite technology and the provision of EO data and services from the private sector to targeted user communities in response to more focused yet rapidly evolving user needs.

Large microsatellite constellations, built with additive manufacturing and data processing relying on the recent advances of Information and Communications Technology (ICT), have shown a growing potential to create jobs and to generate new information to serve public, commercial, and scientific needs. In this new EO paradigm, usually referred to as "New Space", much of the cost of the relevant new infrastructure is covered by investors that generally expect the return of their investment to be realised in the shortest possible term. While the Global Space Market reached €424 Billion in 2022 (about +8.% with respect to 2021), EO still represents only a small fraction (4 %) of this overall figure [Ref. Euroconsult, Space Economy Report, 9th edition, 2023].

However, with what we see as EO, the benefits that EO brings to society, and now an increasing commercial potential to provide products and services to paying users, the EO Market projected to change in the coming years. EO revenues from data sales and service provision are forecasted to almost double over the next decade from approximately €2.8 billion (in 2021) to €5.5 billion.

Technological advances have made space and space-based products more accessible for economic exploitation and, by extension, have created an environment that can potentially complement EO service delivery. For this reason, several CEOS Members and Associates (hereafter referred to as CEOS members) are exploring avenues for facilitating this innovative and rapidly expanding EO industry and for fostering partnerships with next-generation non-governmental entities that are closely linked to EO from space. CEOS has an important and active role to play in supporting both its membership and the commercial EO community by ensuring that any EO data and services are reliable, accurate and fit-for-purpose. This aligns with the CEOS mission statement:

CEOS ensures international coordination of civil space-based Earth observation programs and promotes exchange of data to optimize societal benefit and inform decision making for securing a prosperous and sustainable future for humankind.

At the 36th CEOS Plenary in 2022 a dedicated temporary CEOS Task Team was established with a one-year mandate to explore collaboration opportunities in New Space that would bring mutual benefit to all parties. This "New Space Task Team" (NSTT) brought together interested CEOS members at key CEOS meetings to share experiences of engagement with New Space actors. This White Paper has been authored by the NSTT and aims to summarise those experiences shared. What is written reflects only the views and experiences offered and shared to the CEOS community through this process. These collective experiences have helped to develop a set of recommendations for action within the CEOS framework that aim to enhance the outcomes of current activities undertaken by the CEOS entities (Working Groups, Virtual Constellations, ad hoc Teams) with respect to focused engagement with commercial New Space entities.

As the existence of a potential set of, as yet, untapped customers is a critical factor for the New Space business model to be viable, the topics referenced herein will likely quickly evolve beyond this document's current scope. CEOS is well-positioned to support these evolving discussions through its established working practises related to the provision of community-agreed evidence-based recommendations, guidelines and toolkits, as well as an established forum for convening further dialogue to inform and share future policy making experience with respect to space-based EO.

2. Definition and Scope of New Space Relevant to CEOS

While the term "New Space" is not unequivocally defined in literature, in the EO context, its use tends to describe the emergence of an entrepreneurial space industry characterised, inter alia, by financing from the private sector; widespread use of commercial-off-the-shelf (COTS) and miniaturised technologies; rapid prototyping and development; and innovative business models and procurement approaches. This emerging industry may have the flexibility to identify new commercial products and services that can be supported by space technology. A recent proliferation of small satellites (e.g. < 500 kg) and large constellations are two of the more common manifestations resulting from this shift.

Entrepreneurial companies often also provide EO data applications and value-added services (vertical integration), taking advantage of the disruptive innovations introduced by ICT. Notably, EO from space is producing increasingly large data volumes that require specific Big Data technologies, Artificial Intelligence (AI), and Machine Learning (ML) methods to analyse, manage and derive actionable information and insights.

The adoption of the most recent ICT technologies in the space industry represents a significant opportunity to innovate. Industry can process and analyse large amounts of data from satellites, convert them into valuable economic goods and connect providers and users, feeding dedicated services. The main tool to achieve these results take the form of "digital platforms" that allow customers and producers to connect, interact, and create or exchange value. The commercial interests of the private sector, with the associated risk-taking approach, is therefore the key ingredient of the space economy that results from investing in space business and entails both the upstream and downstream sector. The large commercial IT industry provides the infrastructure on which other platforms are built and has already set a business standard with first-mover advantage. Also, advances in manufacturing, miniaturisation of components and, consequently, small satellites have paved the way for the private sector to develop, in an affordable way, new services and business models through constellations.

Ground-breaking innovations are historically introduced by entrepreneurs rather than by traditional players and the relevant processes can take a long time and significant risk to materialise. However, once they are fielded and even with sub-optimal initial performances, they may have a significant impact on the established markets. The proliferation of start-ups and space entrepreneurs link the notions of New Space and "Breakthrough Innovation", in many cases with an excess of expectations. Commercial players with new economic and industrial models that include, e.g. rationalisation of the production lines oriented to additive manufacturing, the use of commercial-off-the-shelf components that allows reduction in production costs, etc., have broken through more traditional thinking. Moreover, the financial industry and venture capitalists have played a big role by funding initiatives of the private sector, especially regarding the delicate phase in which there are costs to be incurred while revenues are still to come. Access to credit is therefore a fundamental ingredient of success. On the other hand, traditional players generate leading edge-innovation if they can adapt their own business and technology models to this emerging trend, becoming themselves part of New Space.

Given the above reasons, for this white paper we consider the attributes of New Space rather than try to reach a definitive definition that may be challenged.

The main difference between the "New" and the "Old" space models in EO are not only the technology but also the specific approach of the enterprise to the business model.

Historically matured in the US, the innovative approach of "New Space" is also reflected in an efficient cost management and sharing of both development funds and operational risks between public and private sectors through Public Private Partnerships. The ownership of the upstream and downstream assets usually belongs to industry unlike the traditional space approach, where it belonged to the public sector. In this way the private sector has a greater incentive to respect the development stages of the program so as not to incur additional costs and attract private capital. At the same time, the private sector usually seeks for additional commercial avenues, stimulating competitiveness and product innovation that are necessary for enterprise sustainability. For this reason, there is the tendency to verticalize the production chain, from the data generation up to the provision of the services, where the real business is.

Furthermore, while in the traditional approach the public sector decided "what" and "how" defining the detailed requirements, in the new paradigm the public sector indicates only the "what" with high level needs, leaving industry to define the "how" and the detailed outcomes.

From a contractual viewpoint, private companies are involved through fixed price contracts, unlike cost plus contracts as the traditional space. In the latter case, the companies are awarded a contract for the total cost of the work to be performed with an additional amount for profit. On the other hand, the milestones of the fixed price contracts guarantee payments only upon the achievement of predetermined objectives in due time, rather than continuously as is usual in the system of cost-plus contracts. Under this alternative concept, any additional work required to complete the improvements would be the financial responsibility of the company, not the public administration.

Both industrial models can demonstrate their capacity for innovation and attract private investors, though this depends upon their capacity to implement new working methods and new ways of doing business by attracting external investments – public and private – and proposing innovative tools and services that are more tailored to users' needs. Hence, the gap between "New" and "Old" space is narrowing as innovative programmes can be proposed by both established companies and fresh start-ups. This constitutes a positive and stable trend that involves all the stakeholders committed to the space economy.

So far, EO New Space businesses have demonstrated growth and stability only when explicit public support, which includes the setting up of the framework conditions, has been granted to them. Successes have been felt where tangible support has come from national public authorities to develop the commercial space sector, usually following a strong political will and an innovative industrial policy of the sector, and supported by a suitable legal framework. In its absence, EO entrepreneurs have historically faced significant obstacles in proving their business models. In general, it is too early to assess the maturity of the global space commercial market at large for EO, which is at its nascent stage except for national security purposes or specific niches of expertise, remarkably in the US. In any case, a broadening of the customer base would be required for it to be self-sustaining. Until this is achieved, anchor customers within public entities will play an essential role in creating the demand required to sustain the business models.

Figure 1 summarises the various constituents of the New Space approach for Earth observation and the relevant framework conditions.

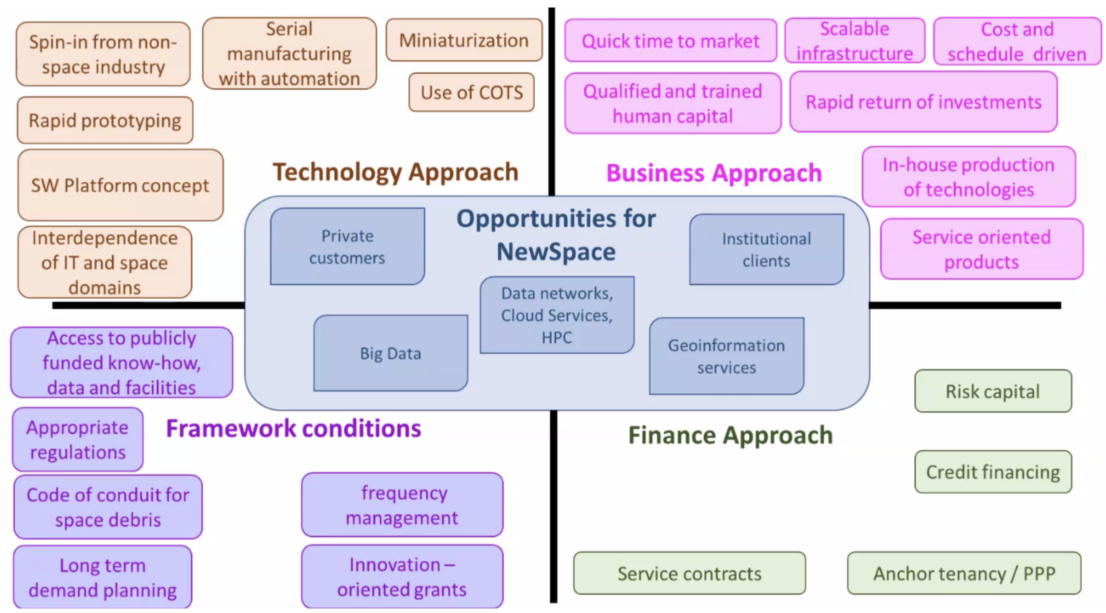

Figure 1: Constituents of the "New Space" approach

3. Interaction between Governmental/Public and Private actors in New Space for EO

In recent years there has been a significant change in the role of public institutions in the space sector.

In the past, it was mainly the public that played a role as an entrepreneurial force in the sector, while today that role is being taken, in perspective, by the private sector. This has resulted in an increase in commercial opportunities produced from space, with the private sector tending to take a leading role in creating value for society. This lively evolution in the USA, less so in Europe which does not have large private capitals, has contributed to transforming the way in which governments and public institutions operate in space and has opened new avenues for economic growth and technological development.

In a few years, the landscape of space activities has evolved thanks to the growth of industrial interests with the support of unprecedented private capital flows, especially in the US. In this context, private actors are playing an increasingly prominent role, pursuing the goal of conducting commercial activities in space independently or in a new form of collaboration with public institutions and governments.

Specifically, the reflections at government level are based on the need to achieve sustainable and sustained growth of the national space sector, through a combination of economic, industrial and legislative innovations

Public institutions play a unique role as funders of R&D and industrial incentives, establishing a link between the basic research in EO and economic forces, in response to public needs. The roles of public institutions for EO industry, as informed by the experience of CEOS members, can be summarised as follows:

- As a Regulatory entity
  - Facilitating, with regulations, country technologies and products to shape the internal EO market and enhance commercial market access where industry will emerge.
  - Ensuring and assessing reciprocity with foreign markets.
  - Developing, establishing or enforcing standards.
  - Regulating the implications of national security regulations for the emerging industry.
  - Defining a policy for the sector, in synergy with complementary ones (e.g., encompassing AI, IT, Sustainable Development Goals (SDGs), etc.).

Each country has the prerogative to regulate its own market and to take appropriate initiative at a domestic level. Each country is also responsible for the impact of their EO industry on national security.

- As a Legitimating entity

  - Support the nascent EO industry in institutional fora, identifying applications of EO and synergy among international policies.
  - Conferring market credibility to the EO industry through association.
  - Supporting the trajectory of novel EO industrial activities (e.g., for strategic purposes or for filling a gap).

All public bodies with an interest in EO can help to legitimate this emerging industry. CEOS is well positioned to support and promote innovative technical activities and perform gap analyses for strategic needs of common interest, the definition of which are mostly within the remit of the individual National actors.

- As a Resource provider
  - Supplying resources (i.e. capital and competence) to advance concept design towards the operational stage.
  - Conducting basic research and developing technology tailored to the EO industry.
  - Providing facilities, data, products or services to industry supporting the needs of the end users.
  - Coordinating complementary technology, market, and partners for a common effort in the EO New Space industry.
  - Creating capacity development and human capital by supporting academia and industry in specialised education and training tailored to an EO industry that is oriented to a novel labour market.
  - Providing frameworks, competences and/or services to support continuous development and evolution of the quality of EO New Space data.
- As a User/Customer
  - Defining a framework to aggregate the demand of EO-related space services and EO products, procuring them for institutional use and to generate an internal market with governmental-commercial links.
  - Procuring products and services from EO-related industry, both space and non-space, which better suit public needs and policies and provide direct feedback to assess the products and improve the results.
  - Being the initial customer for an unproven product, which would otherwise not have private clients.
- As an Investor
  - Co-funding EO industry through Anchor Tenancy set up or Public-Private Partnership (PPP) to establish investment trajectories for priority applications (e.g., a Very High Resolution satellite).
  - Providing funding availability to industry, e.g., with subsidised loans or facilitated access to institutional risk finance.

The National actors are indisputably the major players in these roles. They have the political, regulatory, and financial power to foster and accelerate the transition of the domestic commercial EO sector towards a stable and sustainable economic reality, if they decide to do so.

Although the advance of technology will play a role, it would also be important to envisage how the technologies will be used and which pattern they will follow. The history of innovation demonstrates that the market and the socio-economic implications of new technologies do not follow a predetermined scheme and can vary across countries due to different patterns of national technological specialisation. Corporate structure and governance, intellectual property rights (IPR), labour regulations, and competition policy are all critical influences on innovation and its adoption and emphasise the importance of the public institution in the context of technological progress.

4. CEOS Member Agency Experiences in their Interactions with EO New Space

Chapter 4 provides detail on specific CEOS Member Agency experiences in their interactions with the New Space sector. **What is written reflects only the views and experiences offered and shared to the CEOS community through this process and does not constitute a complete compendium of all CEOS member engagement with New Space.** More detail can be found in the minutes from the 2022 and 2023 CEOS SIT (Strategic Implementation Team), CEOS SIT TW (Technical Workshop) and CEOS Plenary meetings, where interactive discussions on this topic were held. All meeting documentation can be freely accessed from the CEOS meetings webpage.

The following are listed in alphabetical order and have been written by the Agency concerned.

4.1. CNES

Since 2016, there has been a drastic change in the satellite EO landscape. The sector has matured, with increasing private investment capacity in Earth observation, from space infrastructure to services, as well as the development and operation of services using Earth observation data.

CNES evolves in the way to address new EO challenges by adapting its relationship with the space industry. CNES works closely with many companies, including new players from space domain and beyond, and providing easy access to space technology, networking and market knowledge for all – as outlined in the Connect by CNES initiative.

The objectives of Connect by CNES include stimulating national economic development through the innovative use of satellite data and systems, and contributing to the social and environmental development of France, thanks to the use of satellite technologies.

In domains of mobility, health, and environment, the priority sectors are agriculture, forest, maritime, risk management, health and energy and the five key targets are international, start-ups, SMEs, large groups, and communities. Many services have been developed in all domains by French newcomers with the support of CNES.

The vision of the economic sectors by Connect by CNES is done through the construction of a strategy based on the national orientations (at the State, competitiveness clusters, representatives of the sector committed to innovation and institutional operators of the sectors related to the field levels, etc.), on the needs expressed in particular by major public players (local and regional authorities, etc.) and private players (leaders in their sectors) and players providing innovative solutions such as start-ups

CNES, in agreement with the French government, facilitates the ordering of products and services for institutions in order to raise their awareness more quickly regarding the contribution of space and also allow a leverage effect in the development of the players if its positioning allows.

CNES may interact with French ecosystem in many different ways. On one hand, CNES can develop PPP (Public-Private Partnerships) collaboration with the private sector. Starting in 2022, the four small satellites in the CO3D constellation (Constellation Optique en 3D) are set to map the globe in three dimensions from low Earth orbit, serving the needs of both the public and private sectors. CO3D will support industry with the development of low-cost 0.5m imagery and provide access to a DEM at global scale. In parallel with CO3D development, several initiatives have been established to promote the use of CO3D products.

On the other hand, through the "France's national Recovery and Resilience Plan" and "France 2030 Investment Plan", the agency is supporting new initiatives within the EO sector. Three new satellite EO operators develop their first satellite in optical, hyperspectral and atmosphere composition missions.

EO Lab was created in 2018 to support Connect by CNES in the promotion of space solutions for public institutes, local authorities, start-ups and SMEs. EO Lab provides technical support to users on the choice of space data depending on user needs, data processing, access to data and processing platforms, and training sessions.

CEOS 'standardisation' efforts are very beneficial for downstream industries (e.g., interoperability, CEOS-ARD, data quality metrics). CNES encourages CEOS to continue development of these types of activities.

4.2. CONAE

The CONAE National Space Plan, whose current version 2023-2032 is under review, governs Argentine space development. The main objective of this Plan is to develop knowledge and technology while transforming them into developments, innovations and applications to have information of space origin and its derivative products, and vectors to launch the satellites manufactured in the country. In this sense, CONAE proposes as one of its priorities to promote national technological development, motivating the creation and growth of new innovative technology driving companies, expanding its scope of participation nationally and internationally with the contribution of high added value in its production chain.

Since the 1990s, national companies have been growing together with CONAE, developing services in both downstream and upstream lines. Since then, the sector has matured, with a growing capacity for investment in Earth observation, from space infrastructure to services. Furthermore, they are no longer just products and services from satellite information, currently Argentine companies are betting on developing their own launcher.

CONAE also proposes, among its different projects, a new concept of space architecture, based on small satellites. This program of segmented architecture platforms must be a standardized architecture segment, in continuous technological updating, and with a series-type production organization with simplification of the testing and reviewing processes, preserving as much as possible the quality of the information, which in turn, is also generated under interoperability standards.

As well, CONAE makes use of the academic sector contribution to solve the technological problems both downstream and upstream, adapting to the continuous changes that New Space demands, strengthening its links with the space industry.

4.3. CSA

As Earth Observation data gains in recognition, we see an increasing interest from private companies to seek market potential for data, information products and services. For CSA, new space is more entrepreneurial space than in opposition to traditional space. In fact, we see traditional space companies initiating 'new space' programs.

The challenges for government organizations reside in both data utilization and service delivery. As a principle we have an open government policy which would result in making accessible the data that would be acquired from a private provider. The expectation that data acquired with public funds becomes accessible to all is particularly present in scientific research circles. This desire to share data purchased from entrepreneurial space conflicts with the need for the provider to cater to many clients therefore optimizing profits. The resolution of this conflict requires careful negotiation around the data policy, defining the parameters of commercial value and conditions for public good use or general public access. Parameters like resolution and latency take on additional importance to achieve a balance between public good and commercial interests. When entrepreneurial space companies offer services currently provided by government organizations, the client becomes the government as no entity can compete with a free public service. There is inevitably internal resistance changing from internal resources to external services in order to deliver public service.

Typically, entrepreneurial space entities seek support and funding to mature the technology on which they build data collection and services. Over the past years the CSA has used existing programs to issue calls for proposals or announcements of opportunity directed at start-ups, SMEs and new service providers. The Canadian government also encourages any company that can offer imagery to register as a qualified provider under a national acquisition standing offer. Obtaining some sort of 'seal of approval' from the Government or the CSA is the other keen interest of Entrepreneurial Space companies. This requires the development of the capability and mechanisms to acquire, validate and test data sets or services.

The Earth Observation ecosystem continues to evolve and will require public and private sectors to adapt and continuously adjust the balance to be truly complementary, interoperable and mutually supportive.

4.4. CSIRO & Geoscience Australia

While CSIRO (Australia's national science agency) and Geoscience Australia (GA, the trusted advisor on Earth sciences to inform government, community and industry decision making) are Government Agencies with different missions, they collaborate strongly in EO activities and share similar objectives driving our engagement with the international community and approach with New Space companies.

In 2019, when Canberra hosted the GEO Plenary and Ministerial, Australia developed the first-ever "Industry track" in a GEO Week, which provided a new forum for companies and public organisations to meet and discuss EO opportunities. For instance, CSIRO delivered a half-day workshop allowing CSIRO and other companies to present their Big EO data platforms (including Google, Sinergise, UK Catapult), and demonstrate their products live while discussing with the audience. The workshop was well received, and triggered follow-up conversations with industry partners. Providing such opportunities for CEOS Agencies to interact directly with New Space companies in targeted events foster new partnerships and collaboration ideas. CSIRO and GA have been active and engaged with New Space companies around key projects/technologies.

<u>EASI Hub & Open Data Cube</u>

CSIRO and Geoscience Australia have launched a high-performance data analytics platform that 'turbo-charges' the capacity to process and integrate huge amounts of Earth Observation (EO) data with other geospatial information and models. This platform is an extension of the Open Data Cube (ODC) infrastructure and offers the possibility to process data from commercial operators (New Space).

By leveraging this EASI (Earth Analytics Science and Innovation) technology, both agencies have collaborated on a new initiative called the Earth Observation for Climate Smart Innovation (EOCSI) to support the growth and implementation of Earth observation based products and services in South-East Asia. The platform is used to engage local government, education institutions and industry to take advantage of Earth observation for the development of climate smart applications. Considering the explosion of datasets made available to users over the last few years, Australia has been strongly advocating for the development data analytics platform using ARD format to make satellite data more accessible.

<u>AquaWatch</u>

Through its newly launched AquaWatch Australia programme, CSIRO and key partners aims to develop a fully integrated ground to space water quality monitoring infrastructure (a "Weather Service for Water Quality"). The program will leverage and support capabilities from New Space companies, for instance some involved in developing and launching multispectral and hyperspectral sensors with a focus on water quality related issues. In order to help us reach our goal of a safeguarded water quality across Australia and around the world, CSIRO is currently seeking additional partners which include New Space companies: industry can play a key role any part of the value chain in the programme (e.g., in-situ or satellite sensors production, installation, launch, ensuring scientific data produced is communicated to customers to meet their specific needs, etc.)

Analysis Ready Data (ARD)

Geoscience Australia has been a major contributor, through the LSI-VC and the CEOS-ARD Oversight Group, to the development and implementation of CEOS ARD definition, framework and specifications. CEOS ARD products are enabling users to get firsthand satellite data that are 'ready to use' for a wide range of applications including time-series analysis and the way forward to multi-sensor interoperability. Through these forums, GA has been actively engaging with different industry partners to advance interoperability and standardisation of ARD concepts improving data uptake, particularly in the commercial and New Space sectors. Systematic and regular provision of CEOS-ARD will reduce the burden on global satellite data users and, as a direct consequence, boost data use. The provision of this data is possible through many options including systematic processing and distribution, processing on hosted platforms, and processing via toolkits provided to users. CEOS-ARD is an important enabler of the system such as Open Data Cube (ODC) initiative. This is most visibly demonstrated via Digital Earth Africa. Digital Earth Africa hosts several PetaBytes of CEOS- ARD, allowing users across Africa to extract information from EO without pre-processing the data. Through CEOS-ARD, users are able to locate products that are suitable for ingestion into Data Cubes, and can have confidence that these different CEOS-ARD products will limit, as far as possible, barriers to interoperability.

Calibration & Validation

CSIRO and GA operate ground infrastructure and conduct dedicated field campaigns to help calibrate Earth Observation satellite missions.

CSIRO has established an autonomous vicarious calibration site at the Pinnacles Desert in Western Australia. Developed specifically for future spaceborne imaging spectroscopy sensors, this terrestrial vicarious calibration site also provides valuable calibration data for multispectral optical medium spatial resolution (<30 m) sensors such as Landsat 8 and Sentinel-2 operating across the visible to shortwave infrared spectral ranges and could also be leveraged by New Space. The Pinnacles site is instrumented to acquire continuous radiometric (and BRDF) data as well as associated meteorological and atmospheric composition data and is planned to be included within the international RadCalNet network.

CSIRO continues to operate the Lucinda Jetty Coastal Observatory, which has been making above and in-water optical measurements for validation of satellite ocean colour products for 10 years, and the Bass Strait satellite altimeter validation facility, which has been operating since 1992. GA continues to undertake field campaigns using UAV-mounted spectrometers for the validation of satellite derived Surface Reflectance. Geoscience Australia also maintains the Queensland Corner Reflector Array, for use in satellite Synthetic Aperture Radar calibration.

CSIRO is planning a coordinated national facility for Australian Earth Observation calibration and validation, called "AusCalVal". AusCalVal will coordinate across Australian stakeholders, including CSIRO and Geoscience Australia, to federate access to cal/val data streams across the EO-domain and make it available in one place. AusCalVal is also planning to implement new cal/val capabilities within Australia, pending funding, and aims to tailor these to the needs of the New Space community, including very-high resolution optical, SAR and thermal sensors.

4.5. DLR

The Earth observation market is developing dynamically and offers an increasingly attractive environment for private sector investments. The New Space sector in Earth observation is strongly growing, particularly in Europe and Germany. A growing number of new companies with innovative mission concepts and convincing business ideas establish themselves in Germany. Young start-up companies are also successful in the market with new product solutions in the application area. The wealth of data available in the European Earth observation ecosystem offers a wide range of market opportunities, but at the same time requires great expertise for the comprehensive analysis of the data, its efficient processing and the exploitation of the information.

The national Earth observation program implemented by DLR foresees measures that focus specifically on these new players and technological developments and strengthen their application and market potential. Focus lies on creating appropriate boundary conditions for New Space investments. At the same time, long-term dependency on public funding is being avoided, so that the risk of the investments remains in the private sector. Such measures are the promotion of research partnerships between New Space companies and universities or research institutes to investigate technological feasibility; the research partner receives the funding. The ESA program InCubed ('Investing in Industrial Innovation') is another important element to decrease development risks with a reasonable time horizon and to support commercial Earth observation providers on their way to the market launch of innovative technologies and systems. The scope of German InCubed projects range from various types of downstream applications over new services based on artificial intelligence to small satellite developments and in orbit demonstrations (TIR, LIDAR, hyperspectral). The Earth observation activities in the framework of DLR's overarching small satellite strategy are coordinated with the national Earth observation program. Furthermore, anchor customers create the necessary prospects that put New Space players in a favorable negotiating position with their venture capitalists. Therefore, DLR supports activities to network the New Space players with service providers and potential customers and conducts measures to increase their visibility in general. In addition, DLR is committed as a customer for Earth observation data from German New Space and startup providers to demonstrate the suitability for a great variety of applications in Germany and internationally.

4.6. ESA

ESA is engaged in various research and development programs in support of SMEs and startups interested in developing a technological or business idea, facilitating access to the market through seed funds, technical assistance, networking opportunities, and streamlining fundraising external minds.

In 2003, ESA created a network of Business Incubation Centers located in various European countries, assisted by a network made up of institutional, academic and industrial partners, capable of concretely supporting the development and growth of startups in the European panorama. The initiative has guaranteed support to more than 1,000 European startups.

To date, the program consists of 22 BICs and is actively engaged in transforming ideas innovations related to Space in entrepreneurial activities with a dual objective; on the one hand to support the innovation of the upstream segment by encouraging the further development of space infrastructures; on the other, to contribute to the extension of space applications in sectors other than space involving the entire downstream segment.

Startups accepted into the ESABIC program can take advantage of a two-year incubation period at the facilities made available by ESA and associated partners. Each BIC is managed by a local organization that has direct contacts with entities around the world academic, industrial and financial.

As regards technology programmes oriented to innovation, ESA has established since long time:

1. The Technology Development Element (TDE), which provides technical and financial assistance for early development stages across all service and technology domains. It tests the suitability of cutting-edge ideas for space applications, keeping a central role in scientific activities. In the frame of this programme, ESA's Technology Strategy is implemented on a regularly updated 2-year rolling work plan.

2. The General Support Technology Program, which has the objective to develop projects and prototypes of promising and tested technologies until they become mature products that can be used in new space missions to increase Europe's competitiveness. It involves all technological disciplines of the space sector (except for telecommunications, which has its own programme) ranging from de-risking to flight demonstration.

As regards specific initiatives in the Directorate of Earth Observation programmes, it is worth mentioning:

- The FutureEO programme, which aims to support the development of Earth observation in all its main aspects including the implementation of innovative enabling space infrastructures, for the development of new applications. Namely, the EO Science for Society element of the program focuses on the implementation of downstream proposals related to Earth Observation, which can provide a concrete response to the emerging and priority opportunities and challenges of our time.
- InCubed ('Investing in Industrial Innovation'), which is a Public Private Partnership co-funding programme. InCubed focuses on developing innovative and commercially viable products and services that generate or exploit the value of Earth observation imagery and datasets. The programme has a very wide scope and can be used to co-fund anything from building satellites to ground applications and everything between or to develop new EO business models.
- Earthnet's Third Party Missions (TPM) Programme enable access to data from European commercial and national missions as well as from international missions, supports ground segment harmonisation activities, and ensures ESA's presence in organisations, committees (e.g., DCB, UN, GEO, CEOS) and initiatives for promoting the cooperation in using Earth Observation data (e.g., in Africa, China). Earthnet also supports the International Charter on Space and Major Disasters. These activities ensure the complementarity and cooperation of optional ESA programmes with European national and commercial missions (including New Space missions) and international cooperation.

  The TPM programme currently comprises over 50 missions, with data sourced from more than 60 instruments supplied to users for research and development purposes. More than 12,000 research projects have used TPM data since 2008, with more than 2000 new registered science users in 2022. The TPM programme supports a large variety of remote sensing applications: agriculture, forestry and environment, security & crisis management, urban planning (mapping, civil engineering, infrastructure, mobility), maritime, and climate change, among others.

  Earthnet programme is also supporting activities related to data quality through its project EDAP (Earthnet Data Assessment Project) - dedicated to assessing the quality and suitability of various missions including some New Space Missions.

Copernicus is the big enabler of EO New Space in Europe. In addition to data provided by the Sentinel satellites, the contribution missions play a crucial role in delivering complementary data. They ensure that a whole range of observational requirements is satisfied.

The Copernicus Contributing Missions (CCM) are missions from ESA, their Member States, Eumetsat and other European and international third party mission and commercial operators that make some of their data available for Copernicus.

There are around 30 existing or planned Contributing Missions. They fall into the following categories:

- Synthetic Aperture Radar (SAR) to observe day and night the land and the ocean;
- Optical sensors to monitor land activities and ocean dynamics;
- Altimetry systems for sea-level measurement;
- Radiometers to monitor land and ocean temperature;
- Spectrometers for measurements of air quality.

Even when the Sentinels are operational, the Contributing Missions will continue to be essential, delivering complementary data to ensure that a whole range of observational requirements is satisfied.

The novel Category 1 element of the CCM specifically supports the development of the European Earth Observation data market, by providing Anchor Customer contracts to emerging data suppliers of satellite based EO data

The objective is to enable a first step towards the concept of hybrid constellations, i.e. commercial EO data from private constellations bringing complementarity with data from Sentinel & Sentinel Expansion missions

ESA/EU commit to become an anchor customer once the satellite mission/constellation is in its initial operations phase and is able to deliver Earth Observation data, subject to Copernicus standards regarding data quality and data delivery performances

Data pilot activities on an annual basis to demonstrate the EO data quality and data delivery capabilities to the Copernicus Services or to other users indicated by the European Commission. These activities aim to assess the development of a European emerging data supplier towards operational status.

4.7. EUMETSAT

EUMETSAT has been engaged with commercial providers of meteorological observations since 2021. At that time, EUMETSAT Member States agreed that the purchase of space-based observational products from commercial suppliers would be compatible with the EUMETSAT Convention. EUMETSAT Council however expressed and number of conditions, which were that such procured data should represent an ancillary activity compared to EUMETSAT core activity which is to establish, maintain and exploit EUMETSAT's systems of meteorological satellites, contributing to the operational monitoring of the climate and the detection of global climatic changes. Such procurement of commercial data should be advantageous from a policy and technical perspective for EUMETSAT's Member States, and shall obey to EUMETSAT procurement rules, relying of the procurement of European technologies representing best value for money.

This has culminated in EUMETSAT's first commercial data service procurement in August 2021, the procurement of commercial radio occultation data. The source data are provided by a commercial entity, who flies the observing satellites and produces rudimentary data products. These are further processed by EUMETSAT, using operational data processing chains, including quality control, and then disseminated to users globally. After an initial period of validation started in August 2021, the service has been operational since February 2022 and will expire in August 2024.

Some features are important in establishing such an operational service and specific clauses have been put in the contract with the commercial provider. These requirements are mainly related to the access to information on raw data, so that EUMETSAT can perform a quality control equivalent to the one performed on its own data. This includes also information on the satellites in orbit and guarantee on continuity of the data delivery.

From the nearly two years of experience in dealing with commercial providers, the capacity of industry to respond to all EUMETSAT operational requirements has been demonstrated. In this context, EUMETSAT Member States are considering expending the service further, and are also discussing the possibility to establish a permanent, but limited, budget line to procure commercial data.

An interesting feature of the service is that EUMETSAT Member States, aligned with the recently approved WMO's Unified Data Policy, have decided to procure commercial data with global redistribution licences. This is shared now by other agencies procuring commercial data, which leverages the benefits to the global meteorological community.

Another interesting feature is to note that the European market for commercial meteorological observations is not developed yet, leading to little competition at the moment. To ensure that they will benefit from European innovation and competition, EUMETSAT Member States have decided to place contracts for short period of time (1 or 2 years), so that they can go back to the market on a regular basis. Once competition in Europe will exist, this might change as the continuity of data service is essential for operational applications.

4.8. European Commission

The EU Space Programme includes the Copernicus missions for EO, Galileo for GNSS, EGNOS for navigational signals, SSA for surveillance and tracking, and GOVSATCOM for secure satellite communications. One focal point for their campaign "An investment in a Future Ready Europe" is to provide a competitive edge - completing current satellite constellations, and developing and launching the next generation of satellites.

The Copernicus Expansion Missions include CO2M (CO2 Monitoring), ROSE-L (L-Band Synthetic Aperture Radar), CRISTAL (Copernicus Polar Ice and Snow Topography Altimeter), CHIME (Copernicus Hyperspectral Imaging Mission), LSTM (Land Surface Temperature Monitoring) and CIMR (Copernicus Imaging Microwave Radiometer).

New Space is a global trend encompassing a series of technological and business model innovations leading to a reduction in costs, shorter life cycles and a bolder approach to risk taking in the space sector.

Several trends are unfolding in the satellite industry, including the move to smaller satellites, bigger smallsat constellations, more satellites in LEO rather than GEO, use of standardised components from across sectors, improved resolution, reduction of launch costs, and the use of BigData and AI processing platforms.

The three entities i.e. Copernicus Sentinels, New Space and Expansions should work together to contribute towards the Copernicus Hybrid constellation.

4.9. GISTDA

Earth observation is a core mission of Geo-Informatics and Space Technology Development Agency (GISTDA), Thailand. More than 20 years, GISTDA has operated a Thai Earth Observation satellite system to derive benefits from EO data, serving public uses and commercial activities. Recently, as space domain has welcomed new technologies and business models, GISTDA is aware of emerging opportunities brought by New Space that able enlarge space accessibility and utilization, especially for emerging space countries.

As the Thai space agency, the government entrusts GISTDA with the responsibility to propose the National Space Act and National Space Master Plan to elevate New Space in the country. Four goals have been pointed comprising bridging the digital divide, environmental safety and sustainability, promoting regional collaboration, in addition to technology development and investment for the future world. The National Space Master Plan consists of strategies enabling new mechanisms to support commercial space activities such as national policy, manpower development, focused research and space missions, regulations, tax, subsidy, funding, etc. Furthermore, the National Space Act will be legislated within 3 years, targeting cultivating space actors, initiating Thailand's space program, and fostering new services and products, including promoting the New Space Economy. Under the umbrella of the National Space Master Plan and strengthened by the National Space Act, projects and activities have been stated to be implemented within the next 10 years to enhance the space value chain in Thailand from the upstream sector to the downstream industry.

With recognizing upstream activities as a foundation of the space economy, Thailand has prioritized incubating space technology developers. The Space Economy Lifting off event arranged by the National Innovation Agency (NIA) and GISTDA is aimed at raising space-related companies, advancing their capability and expertise, including supporting the development of new products and services. Knowledge transfer programs, business consulting, as well as opportunities for fundraising and matching with investors have been provided to the participants. The event has aggregated startups from broad areas of the space economy covering satellite development, utilization of data from satellites, Unmanned Aircraft Systems, aerospace solutions, AI and IoT, etc. Moreover, GISTDA provides infrastructure for satellite manufacturing such as Assembly, Integration, and Test (AIT) services to facilitate space actors in the region.

Downstream space economy has been an active market in Thailand, in particular geospatial applications and solutions for agricultural, urban, and natural resource management. To support the downstream business, startups are the important actors as they are agile to meet rapidly changing demands of the market. GISTDA has initiated Sphere, an open Geospatial Platform containing ready-to-use geospatial digital data with API. The platform is equipped with versatile tools to assist users in developing applications and services, for example, Analysis Ready Data, Map API, Map Maker, Base Map, DataCube, etc.

Space is a global business by nature. International networks bring Thailand to keep up with the latest innovations and learn demands from users. GISTDA places a strong emphasis on CEOS as a highlight forum for driving value from Earth Observation. Currently, we have engaged the CEOS Working Group on Calibration and Validation (CEOS WGCV) to establish enduring confidence in the precision and quality of Earth Observation data. GISTDA believes that, by providing a framework for quality assessments and certifications, businesses leveraging Earth Observation information can gain more trust from the non-space sector and deliver highly reliable products and services. The WGCV empowers New Space companies to expand their market reach and solidify their reputation at the global level.

New Space is a new paradigm for the industry. Private enterprises and public agencies in Thailand embrace the opportunities to leverage more value from orbital infrastructure. Recommendations and insights from international cooperation, especially CEOS, can enhance the policy and legal conditions to ramp up the businesses and attract ventures, making emerging space countries and Thailand to be parts of the ecosystem, eventually leading to an increase overall value of the global space economy.

4.9.1. ASEAN SCOSA Workshop

The Association of Southeast Asian Nations (ASEAN) Subcommittee on Space Technology and Applications (SCOSA) held a Space Workshop from 29 May - 1 June 2023 in Thailand. During the workshop a session entitled The Earth Observation: Policy and Technical Gaps was organised. The combination of the survey questionnaire and workshop discussion is set to gain a better understanding of the needs and challenges in the region and to debate New Space's potential to fill these gaps. The representative nations are Brunei, Indonesia, Japan, Philippines, Singapore, Thailand, and Vietnam.

Across the ASEAN, satellite imagery is widely utilized for a variety of purposes, particularly for disaster risk reduction and management, national resource inventory, and environmental protection. To support their national objectives, countries have relied on both publicly available and commercial data. Datasets from public initiatives, such as Landsat and Copernicus missions, have been introduced into many applications to manage national challenges.

Although freely available public satellite-derived data are commonly used across the
Although freely available public satellite-derived data are commonly used across the
ASEAN region, the need for more tailored data from a nation's satellites still exists and commercial missions often seek to fill the gap. Such gaps include those where spatial

and/or radiometric resolution requirements are not met, where revisit times are not frequent enough, and where there is a lack of data, such as synthetic-aperture radar (SAR), over a region of interest. One positive result of identifying this gap was that near equatorial SAR satellites were designed and recently launched and these provide better revisit time for the specific ASEAN area to minimize this gap.

Most ASEAN member states welcome the use of commercialized data and services. However, due to the limited allocation of budget from the government, they must prioritize their national level needs and balance the service subscription from commercial players.

4.10. ISRO

In 2020, Government of India announced opening of Indian Space Sector for non-government entities to be co-travellers. Indian Space Research organisation (SRO), the national space agency role is to focus on research and development and meet the requirements of national imperatives in the area of natural resources management, disaster management and advance technology demonstrations. A regulatory body instituted namely "Indian National – Space Promotion and Authorization Center (IN-SPACe)" to promote, handhold, permit, monitor and supervise space activities and accord necessary authorizations and permissions.

Further, Indian Space Policy-2023 has been positioned for defining the roles of Indian Industry in activities of building and operating remote sensing satellites, setting up of ground stations, satellite data acquisition and dissemination. ISRO is making public funded satellite data of 5m and coarser, rich heritage of archived data and satellite derived data freely available, so that industry can come up with innovative solutions using such data. Further, differential pricing policy has been implemented through which price discount is being extended to eligible industry seeking EO data from ISRO satellites.

Policy also allows ISRO owned facilities & technical expertise sharing with industry, so that it can grow faster & utilise the already developed capabilities of ISRO over the years. It will nurture the start-ups to come up & handhold established industries to take up independently some of the bigger & value added works.

The demand-driven approach for space application sector has been also introduced. As per this, the satellite missions are required to be funded by the concerned User Ministries and hence creation of new assets to be made contingent on confirmation of demand from user agencies/ entities. This is basically to bring a sense of accountability and optimal utilisation of EO data.

IN-SPACe has started seed fund scheme to promoting space technology to the start-ups and help them bring their ideas to life and get their projects off the ground. This support also include access to funding, mentorship, training and networking opportunities.

ISRO and IN-SPACe is also working towards the establishment of additional EO satellites to fill the data gaps, through public private partnership.

Following the reforms, several Indian space sector startups have been able to raise venture capital for their planned projects. Several new start-ups entered into space domain, the deep tech & application area and started interacting with ISRO. This depicts the rising confidence amongst investors in the vibrant Indian space sector and the expected impact of this deregulation, as brought about by the reforms.

In such a short span of time, the growth of New Space in upstream and downstream activities (satellite manufacturing, EO applications and ground segment) are visible. Such efforts will enhance the diffusion of space technology, boost the space economy within the country and will give a major fillip to the private sector space industry and start-ups.

4.11. JAXA

In recent years, the Japanese space industry market has actively involved the private sector, including 'New Space' companies. To further encourage and develop this industry, the government has been utilizing public-private partnerships, rather than government only programs.

In June 2023, the Japanese government revised the Basic Plan on Space Policy. The document noted how rapid and global expansion of "Space Transformation" can bring socio-economic change through activities in the space sector. In order to address such change, policies to enhance further public-private partnerships are stipulated.

JAXA has programs underway to respond to these policy requirements: the Consortium for Satellite Earth Observation (CONSEO) and demonstration projects by public-private partnerships.

In September 2022, JAXA established CONSEO as a unique platform that brings together players from across industry, academia, and government to envision and create the future of satellite Earth observation for Japan. The program has the following goals:

1. Deliver recommendations of the overall strategy of Earth observation satellite for Japanese society;
2. Promote co-creation among industry, academia and government to establish an ecosystem supported by them, and install outcome from Satellite Earth Observation to the society, industry, academia and government and;
3. Share the value of Satellite Earth Observation to gain support from the public for its promotion.

Convening diverse players from across the private sector, CONSEO functions as a "think tank" for government space policy. While issuing recommendations of the overall strategy of EO satellites in Japan, CONSEO delivered possible options regarding the next optical mission concept responding to an urgent request from the government after the loss of Advanced Land Observing Satellite-3 (ALOS-3) caused by launch failure. Through this effort, requirements from the private sector, including the prospect of societal and economical value, were presented for the government to consider in their plans for the mission. The demonstration projects with public-private partnerships (PPP) are promoted by JAXA, especially in the downstream applications.

The ALOS-2 PPP Demonstration Project aims to promote practical and operational use of ALOS-2 L-band SAR data, using the 8-year archive hosted on the "TELLUS" Japanese government cloud platform. JAXA launched this project in cooperation with data analysis companies, universities, research organizations and local governments in June 2022. Since then, 14 projects in JYF2022 and 17 projects in JFY2023 have been carried out.

One good practice is the improvement of support system by the national and local government for farmers with unfavorable agricultural production conditions in hilly and mountainous areas.

Using ALOS-2 data together with farmland assessment tool developed by a startup company, efficiency of the local government's conventional assessment procedure was improved. This ALOS-2 PPP project will continue until ALOS-4 becomes operational and will be expanded using more high temporal resolution data collected by ALOS-4.

Another demonstration project is the Greenhouse gas Observations of Biospheric and Local Emissions from the Upper sky (GOBLEU) Project. This is a partnership with a non-space private company that shares the same goal of addressing Climate Changes and collecting EO data for this purpose. JAXA has partnered with a Japanese airline to bring a sensor similar to the GOSAT sensor into the cabin of their aircraft to conduct real-time observations over large cities, the source of anthropogenic emissions, with higher resolution. While not impacting the aircraft itself, data collection over Japan, especially the larger cities are effectively accomplished during ordinary passenger flights. This practice was submitted for the first Global Stocktake of the Paris Climate Agreement.

JAXA has created promising programs with public-private partnerships and encourages other CEOS Agencies to explore similar opportunities in their respective regions. In particular, JAXA is promoting co-creation among diverse players from government, industry and academia in the Asia-Pacific region, noting the opportunities for engagement presented by the Asia-Pacific Regional Space Agency Forum (APRSAF).

4.12. NASA

NASA's Commercial Smallsat Data Acquisition (CSDA) program was initially a pilot (Private-Sector Small Constellation Satellite Data Product Pilot) to identify, evaluate, and acquire data from commercial sources that support NASA's Earth science research and application goals. NASA's Earth Science Division (ESD) recognizes that data from commercial systems has the potential to complement existing NASA data sources to advance Earth system science and applications development for societal benefit. The Pilot successfully ended in 2020 thus transitioning into a sustained program, demonstrating the usefulness of commercial data for advancing scientific research and applications. However, the restrictive nature of the end user license agreements (EULAs) made standard scientific collaboration difficult. In 2021, CSDA licensing agreements expanded to broaden the applicability for scientific applications across the US Government. These licensing uplifts will make the data more readily-available across the government and improve both value and interagency collaboration. The objectives of the NASA CSDA program are to establish a continuous and repeatable process to onboard new commercial data vendors, enable sustained use and dissemination of purchased data by the Earth science community, ensure long-term data preservation, access, and distribution, and coordinate with other US government agencies and international partners on the evaluation and scientific use of commercial data. The NASA CSDA Program evaluates commercial data offerings according to the following criteria: data accessibility, metadata quality/completeness, user support, data utility for research and applications, and data quality.

4.13. NOAA

NOAA seeks to leverage recent innovations by the commercial aerospace industry in small satellite technology, access to space, communications and ground services (aka "New Space") in order to:

- Improve the agility and resiliency of the architecture;
- Shift from using large, multi-instrument satellites flown on a set cadence, toward a disaggregated architecture of smaller satellites to place observational capabilities in the desired locations when needed;
- Allow for rapid and efficient replenishment of on-orbit assets and responsive to changes in observational needs.

The future of LEO will validate the merits of commercially-based disaggregated architecture with a Quick Sounder mission, demonstrating how disaggregation, agility, and operational observations can be achieved through the exploitation of new business models, including revised approaches to hardware procurement, mission authorisation, and mission development oversight.

The sample system capabilities needed to accomplish the LEO vision for 2040 includes:

- Rapid on-orbit asset replenishment, ATP to launch in approx. 3 years.
- Quality instruments calibrated and validated to meet mission science.
- Flexible ground system(s) to add or delete assets with little modification.
- Common algorithms for similar measurements, to allow for evolution and continuous improvement.

Joint Venture Program is co-investing in technology development by government agencies and industry. The program has identified about 20 projects for FY2022 Tech Exploitation. It will also exploit observations made by other government agency satellites.

The NESDIS Commercial Data Program (CDP) has been running since 2016. The team issued a "Request for Information" (RFI) to the general space community to determine industry capability to provide operational quality terrestrial weather and space weather observations.

The program awarded IDIQ (indefinite delivery/indefinite quantity) contracts to two small companies to provide Radio Occultation observations for use in NOAA weather and space weather operations, and are currently executing their 4th delivery order, purchasing 6000 RO observations per day over a six month duration.

NOAA's commercial weather data operated by IDIQ contracts includes a range of data sharing licence options ranging from unlimited rights to distribution to NOAA only. The data sharing licence allows NESDIS to share the near-real time data with US Government Agencies, international WMO meteorology and hydrology centres, and CGMS partners for non-commercial use only. After 24 hours, NESDIS can distribute all data to any entity with no restriction on use or further distribution.

Commercial data provides for an enhancement of our operational mission and ongoing data delivery, and information that is collected must be compatible for sustained and repeat use.

4.14. NSO

The Netherlands Space Policy focuses on the optimal use of space assets, by supporting developments that involve end users or have requirements traceable to the end use of the product, regardless whether it is a hardware product, such as a space instrument, or a space based information product or service. Use of space assets for societal and/or economical benefits can be for scientific, commercial and/or operational purposes as long as the end user is involved in defining the user requirements. With its technology, development and user stimulation programmes and through ESAs technology programmes, NSO supports (New) Space companies in developing their products and services, in line with that priorities set forward in the Netherlands Space Policy. NSO also fosters cooperation between (New) Space Companies, both nationally and internationally.

To stimulate the development of space based products and service NSO purchases Earth Observation data of the Netherlands and makes these data available through the satellite data portal (www.satellietdataportaal.nl) only for users originating from the Netherlands. That data are purchased commercially, based on best value for money. Both "traditional" space companies as New Space companies can bid.

Currently The Netherlands is developing a Long Term Space Agenda for the next 10-15 years.

4.15. UKSA

The UK Space Agency has a crucial role in implementing the UK government's National Space Strategy and supporting the thriving space sector in the UK. Its remit includes catalysing investment across the sector, delivering missions and capabilities that meet public needs, and championing space to inspire people and support a sustainable future.

Earth Observation (EO) is identified as one of the eight UKSA priority areas, with a focus on using EO to drive discovery and tackle climate change.

The international space landscape has been changing for many years, and there has been a steady increase in 'New Space' actors using private funding to focus on developing smaller, ready-to-use technologies to provide data and services for paying customers.

Within this emerging landscape the opportunities presented by the move towards a more commercialised sector, the role of UKSA and wider Government is shifting in order to support and catalyse investment across this landscape, use the strengths and opportunities of both the 'new space' commercial approach with the quality, assurance, reliability and long term planning afforded by working in the more traditional ways with ESA , EUMETSAT etc on much larger, more complex and more costly cutting edge science and technology missions.

It is clear that public investments have enabled the emergence of New Space by providing grants to help commercial and technological innovations, for example helping to reduce hardware costs by supporting satellite system miniaturisation, and de-risking development of satellite applications to encourage private investment. It is also clear that the skills sets valued by new space companies have very often been gained on missions and systems in the public sector.

UKSA plays a convening role, linking New Space concepts and capabilities with new investors and potential users of new data and services via trade shows or through our various sector-facing bodies, like Space4Climate. This has activities to allow the space sector to collectively break into an untapped market of potential new users and encourages the development of applications and services which could use the space data or products.

UKSA also optimises ESA investments to support the UK sector by creating opportunities for UK entities in programmes such as InCubed2, ESA Scout missions in FutureEO, or by purchasing third party mission data.

Support can be indirect in nature too. UKSA plays a key role in promoting standards and the concept of 'trusted data'. For example the UK is leading the TRUTHS mission, which will enable an upgrade of the performance of the global EO system both in space and on ground by establishing an SI-traceable reference data set which can be used to cross calibrate other satellites - be they public or private and improve overall data quality.

The UKSA is also well placed to address the challenges that New Space emergence creates, for example by championing space to encourage new people into the sector, as well as developing new skills and capabilities to address the growing skills gap.

In conclusion the UKSA recognises the space landscape is developing over time and encourages innovation, development and growth of the whole sector. The longer term institutional programmes can provide the background data, skills and expertise needed for the commercial sector to thrive. The newer business models drive down the costs of space, enable risk sharing and constructive dialogue. Therefore the UKSA encourages CEOS to embrace the change in the sector and create the conditions for dialogue and best practise sharing as well as establishing the standards needed for the interoperability of the data – however and whoever collects it.

4.16. USGS

USGS sees rapid changes afoot in the New Space community across all aspects of the EO value chain (launch, satellite and ground system operations, data hosting, and data access). USGS is using a wide range of commercial data via contracts held by partner U.S. agencies, including data from companies that fit the Task Team's definition of New Space. Through its National Civil Applications Center and the USGS co-chaired U.S. interagency Civil Applications Committee, our agency has for years worked closely with U.S. defense and intelligence agencies within the U.S. National and Allied Systems for Geospatial Intelligence (GEOINT) to document civil land-imaging requirements which can be met by commercial EO data providers. In addition, the CAC inform the national security community on federal-civil issues of common concern, such as the ability to use of electronic light tables like the Global Enhanced GEOINT Delivery service.

This activity is a feature of a U.S. policy through which the U.S. National Geospatial-Intelligence Agency (NGA) and now the U.S. National Reconnaissance Office (NRO) procure commercial data to be shared with civil agencies for Federal agency projects. While not the only mechanism by which Federal agencies procure commercial EO data, it is the preponderant approach in terms of dollar value and number of Federal agency users. In May 2022, the NRO awarded ten-year contracts to three U.S. commercial EO data and service providers: Maxar Technologies ($3.2 billion, according to the company), BlackSky ($1.0 billion, according to the company), and Planet Labs (amount undisclosed by the company).

According to the NRO, this Electro-Optical Commercial layer data falls under a "U.S. Government Plus" End User License Agreement (EULA), meaning it may be shared with, *inter alia*, "…***foreign governments, inter-governmental entities***, [and] international defense and coalition partners ***for U.S. government purposes…*** (emphases added)". Since 2022, the NRO has also initiated much smaller study contracts with commercial Synthetic Aperture Radar and hyperspectral imaging firms, with similar broad provisions for Federal civil agency use.

In FY21, 68 federal civil organizations - including 2,559 individual federal civilian users - accessed commercial data through the NGA's Global-GEOINT Enhanced Delivery Service. USGS scientists use commercial data to analyze a wide range of Earth system phenomena across its five mission areas: core science systems, ecosystems, energy and mineral resources, natural hazards, and water resources.

USGS also has a very productive arrangement with a commercial cloud service provider to host an authenticated copy of the Landsat data archive for user access. Through this service, in U.S. Government Fiscal Year (FY) 2022, the number of Landsat data/product accesses and downloads was *4.01 billion*. Through August of this FY 2023, that number has grown to approximately *18 billion*. These figures dwarf the already previously exponentially growing number of Landsat data downloads directly from EROS (which remains an option for the public). USGS believes this arrangement is resulting in broader and easier EO data access for a new generation of scientific researchers and public and commercial service providers.

From a public good perspective, USGS believes that publicly and privately owned and operated infrastructure within the EO value chain should augment, and not replace, existing public systems to monitor and forecast weather, oceanic, and land surface phenomena. Replacement of the former by the latter would risk "hollowing out" core governmental capabilities and effectively privatizing public services.

Opportunities for New SpaceAs well as providers of data, CEOS Members and Associates are users/customers of EO data, including commercial. The ideal Earth observation scenario would be for all to contribute to a global Earth observation system in perfect complementarity for global public good. There are, however, national considerations that support areas of redundancy and now there are growing commercial considerations for competition resulting in several new players addressing a developing market.

The entry of New Space actors in EO brings opportunities, challenges and even threats. Some general principles apply to our consideration of areas of opportunities for New Space:

a. New Space can complement sovereign systems through providing different measurements of similar observations and coverage of different areas with similar measurements.

b. New Space can provide additional services that are tailored to the end user and are complementary to the broader "public good" services from governmental organisations.

c. New Space can free up public resources where the collection, distribution of data, or provision of services is commercially viable.

d. New Space investors are looking for a return on investments that translates into a drive to optimise their market.

e. New Space companies seek to understand the specific user needs to respond with appropriate quality.

f. Commercial value depends on many factors but typically employs relatively low cost-of-production solutions to operational (i.e., service) needs. Hence, the data collected may not possess the characteristics (e.g., sub-system redundancy, high platform stability, stringent instrument calibration and data validation, long-term data consistency) to support the advancement of Earth system science research and forecasting capabilities.

A collective challenge resides not only in areas of collaboration opportunities but mostly in defining the framework for this balance between commercial viability and contributions to public good.

4.17. Thematic Area Observation Gap Opportunities

CEOS entities and their expert membership address many technical aspects of EO (calibration and validation, data handling and interoperability, etc) and cover a multitude of thematic domains (land, oceans, atmosphere). The following section addresses a key aspect where commercial entities could play a potentially large role, namely that of filling current observation gaps in specific thematic domains.

This section represents detail on those contributions offered through this process, but it does not constitute a full gap analysis of EO opportunities for New Space.

4.17.1. Agriculture, Forestry & Other Land Use (AFOLU)

The AFOLU reporting sector requires information on land use change and biomass to estimate carbon emissions and removals for national greenhouse gas inventories. The guidelines providing methodologies for reporting, typically from the United Nations Intergovernmental Panel on Climate Change (UN IPCC), highlight the need for long-term time series and data continuity and consistency. For example, the United Nations Framework Convention on Climate Change (UNFCCC) greenhouse gas reports use 1990 as the reference year. These requirements for long-term time series and continuity have to some extent limited the use of New Space in fulfilling the needs of the AFOLU sector compared to long-term programmes like Landsat and Sentinel-2. Additionally, the AFOLU reporting sector requires well-documented, transparent, and open/free access to datasets, algorithms and their accuracy and precisions. At national scales, where large regions are assessed, free data, mainly from public agencies, are particularly important in carrying out AFOLU emission and removal estimates. National inventories are leveraging New Space for statistical validation of approaches or for stratified area sampling. In contrast, in the private sector, i.e., voluntary markets, New Space is having an important role for documenting smaller-scale AFOLU activities.

Key data feature characteristics include high-spatial resolution, in the order of 10 metres, in order to detect management influences on land cover and biomass or degradation, fine-scale transitions, or to enable classification of challenging land covers like wetlands. Revisit is currently achieved through the Sentinel and Landsat missions. Potentially, time-of-day of overpass could be expanded to have morning and afternoon acquisitions and this would overcome challenges in tropical regions where cloud cover is problematic. Access to open, free data, and well-documented algorithm development and robust quality control and quality assessment statistics are required to enable transparency, repeatability, and verification. Observation gaps are related to detecting land management, particularly for agriculture and pastoral systems, and for retrieving biomass or vegetation structure using waveform lidar. Next Generation Landsat and Sentinel missions, as well as the Copernicus Expansion and Designated Observable missions of ESA and NASA, fulfill continuity for land cover change, but gaps in lidar remote sensing remain at the end of life for GEDI (NASA's Global Ecosystem Dynamics Investigation mission). The application of emerging commercial data includes exploring the use of products such as Planet's 'planetary variables' to provide estimates of biomass and biomass change, or the use of Maxar imagery for individual shrub and tree detection.

4.17.2. Sustainable Development Goals

Commercial satellite data and services are not widely used by United Nations Custodian Agencies or countries to address Sustainable Development Goal (SDG) objectives. The primary reasons for this are licensing restrictions, high cost, and subsequent inequalities between users which is contrary to SDG principles. Though some CEOS Agencies have arrangements with New Space data providers (e.g., NASA CSDA), these are only for science purposes and would restrict use for country-level SDG needs.

That said, it should be noted that New Space satellite data can provide very high spatial and temporal resolution and allow "tasking" to acquire data over specific locations and times. These features are not available with current CEOS satellite assets, yet they could be quite valuable for supporting SDG needs in areas with complex land features, high cloud cover, or the need for high temporal sampling. For example, high spatial resolution data could be used to validate land classification models and precision tasking could be used to increase temporal sampling to reduce cloud cover issues. New Space missions could also address gaps in specific measurements such as hyperspectral bands or radar that are not currently available from CEOS missions as well as global dataset validation.

4.17.3. Precipitation

CEOS supports a dedicated "Virtual Constellation" (a CEOS coordination mechanism to meet a common set of requirements within a specific domain) in precipitation. The P-VC (Precipitation Virtual Constellation) community requires satellite observations to provide information on global precipitation measurements of intensity, extent and duration. The precipitation products generated from these observations are largely driven by the user community, including hazard and water resource management, hydrology, weather forecasting, and the climate and modelling communities. A major consideration in providing satellite observations for precipitation measurements is that the temporal variability of precipitation requires multi-sensor / multi-satellite measurements. While (space Agency-provided) geostationary sensors generate regular and frequent visible/infrared data, such observations provide only indirect measures of precipitation, and thus there is a reliance upon the more direct, but less frequent, observations made by passive microwave sensors. Providing timely precipitation products in near real time is crucial for disaster management and operational weather and hydrological services, while ensuring consistency over time scales from a few hours to decades is challenging, particularly for monitoring climate-scale changes. The former requires the necessary data-transmission infrastructure, while the latter requires a consistent baseline-series of sensors, such as the JAXA AMSR-series and the NASA/JAXA TRMM/GPM missions, augmented by observations provided by NOAA, EUMETSAT and US DoD sensors. The P-VC community currently relies upon well-documented datasets and products provided largely by public agencies (e.g. NASA, JAXA, NOAA, EUMETSAT). Access to open and free datasets from these agencies is crucial in supporting national and international research and product delivery to the user communities. Historically, the role of space Agencies in supporting New Space has been indirect, although the development of new sensor technologies, satellite systems and provision of free data has helped incubate New Space. Universities have also developed New Space partnerships (such as NASA/MIT for the TROPICS mission). Current New Space initiatives are targeting key niche sectors of the market, particularly exploiting low latency (observation-to-user) primarily for weather nowcasting.

The physical nature of precipitation and engineering constraints dictate the development and costs associated with opportunities for New Space for precipitation retrievals. The variability of precipitation, both spatially and temporally, requires good sampling, although spatial resolution is constrained by physical and engineering considerations, while temporal sampling is limited by budget costs. To date, these considerations have largely precluded the development and expansion of observations by commercial entities. However, new cubesat and smallsat technologies have provided the opportunity to develop small sensors, such as the NASA TEMPEST and TROPICS missions, and the ESA Arctic Weather Satellite (precursor of the EUMETSAT EPS-Sterna constellation mission), which in turn has cultivated a New Space sector focused on developing and building cubesats specially for exploiting near real time weather information. In particular, since the agency missions only provide around 3-hourly data (from passive microwave sensors), the inclusion of observations from the New Space sector provides an opportunity to improve the temporal sampling in order to improve the representativeness of precipitation and allow better characterisation of the lifecycle of precipitation systems. Next generation agency missions, such as the NOAA-LEO/JPSS series, EUMETSAT EPS-SG series, JAXA AMSR-series and NASA AOS will ensure a degree of continuity to which the commercial sector will contribute.

4.17.4. Greenhouse Gases (Atmospheric Composition)

A commercial greenhouse gas emissions monitoring service company, GHGSat, has launched multiple small satellites offering estimates of methane emissions at the infrastructure level, like wellheads, pipelines, and storage facilities. These 'high emitters' contribute significantly to total emissions at fossil fuel drilling sites (Cusworth et al., PNAS 2022). Other forthcoming missions operating at these fine-scales include the upcoming Carbon Mapper and Auroro/GHOST missions as well as MethaneSat, which aims to expand these measures to include agricultural areas, such as rice fields and livestock facilities. Recognising the potential of these datasets, both ESA and NASA have assembled dedicated teams to evaluate the scientific value and data quality of these initiatives.

Currently, the only available studies using “New Space” data are from GHGSat given that it is the only New Space company to have deployed hardware so far for GHG emissions assessment (Varon et al., GRL 2019; Maasakkers et al., Sci Adv. 2022). However, as the effectiveness of these remote sensing measures, both public and private, in constraining the methane budget have been demonstrated (e.g. Duren et al. Nature 2019), and with impending launches of similar missions, it is anticipated that New Space initiatives will offer new constraints on specific CH_4 and possibly also on CO_2 (still to be demonstrated) anthropogenic budgets, help pinpoint targets for emissions reduction, and assess the efficacy of such remediation efforts (Cusworth et al., ERL 2020).

The existing constellation of GHGSat instruments can only measure around 1% of the total methane budget, focusing on high emitters, the easiest targets for remediation efforts. While the expanding network of New Space and public instruments will considerably increase CH_4 (and possibly CO_2) measurements at the facility scale, it remains uncertain how much of the total anthropogenic carbon budget these tools can quantify. Moreover, these data aren't expected to quantify natural carbon fluxes directly. Additionally, most of the data collection and processing is classified as intellectual property, limiting independent evaluation, and the data might not be publicly accessible unless altered to prevent the reconstruction of intellectual property components. While there is complementary value in these measurements, the lack of transparency poses an issue especially for the purpose of assessing the effectiveness of emission reduction policies. These limitations might severely impede the direct utilisation of New Space data, except for corroboration with other datasets and results.

CEOS can bolster these efforts by ensuring full transparency of algorithms and datasets needed for CO_2 and CH_4 emissions quantification from current and future publicly funded missions (e.g. EMIT, Sentinel 2/3, CO2Image), setting standards for emissions reporting, radiometric and emissions validation, and collaborating with stakeholders like the International Methane Observatory (IMEO) and the World Meteorological Organization (WMO) to identify use cases and requirements for optimal use of these data. CEOS should also promote use cases that benefit from a multi-scale approach, combining high-resolution New Space data with broader observations from publicly funded missions, and explore strategies to bridge expected observation gaps (particularly after 2028, when EMIT and CarbonMapper cease operations). CEOS could further take up the role to coordinate efforts at the multi-scale by ensuring better coverage including the New Space missions. This CEOS effort should be reciprocal by improved transparency to data generation, which could come by providing assessment mechanisms, like the Science Readiness Levels (SRL, see link) or NASA's Data Maturity Levels, see link, and by providing access to dedicated coordinated validation mechanisms.

4.17.5. Climate

For the monitoring of Earth's climate from space, New Space data are already being used in some long-term homogeneous time series data sets - Climate Data Records (CDRs) - and will likely contribute to many more over time. NewSpace's promise of more affordable and rapid development and launch, and associated opportunities for more frequent sampling and redundancy, is potentially transformative for climate monitoring.

Nevertheless, in most climate work, data set homogeneity is paramount. Historically, that has been achieved through careful post-observation correction of data collected by multiple satellites and instruments. The data segments are merged to form a single, seamless, consistent, and well-calibrated record of the environmental variable. Over the past two decades, more accurate, sophisticated, and stable flight systems have decreased the extent and cost of this post-observation work. Keeping post-observation processing costs low requires flight system consistency, durability and managed stability of orbits, instrument pointing, and detector calibration.

The potential value of New Space to climate may therefore vary with intended data use. For shorter term climate process studies that need high quality observations for several years, New Space systems can likely meet requirements with little or no adjustments, depending on the instrument type. For example, monitoring large events (e.g., wildfires) or environmental phase changes (e.g., Arctic Sea Ice) can likely be accomplished using traditional remote sensing methods. However, for longer-term (multi-decadal) climate monitoring, the typically small climate change signals relative to natural variability (e.g., sea level rise), satellite and instrument stability and durability are critical.

Given this, it is not surprising that Global Navigation Satellite Systems (GNSSs), which use precisely time-stamped signals and position determination for navigation applications, are already being used in CDRs for monitoring atmospheric profiles through radio occultation. For other types of satellite systems, such as imagers and sounders, sufficient stability from New Space systems will likely require coordinated orbits with research-quality instruments. In this approach, less rigorously calibrated or stable instruments are flown in orbits that cross those of more stable and better-calibrated research satellites. In this manner, the less stable instruments can be routinely and systematically co-calibrated against the overlapping observations of the research grade system. This technique has been successfully employed, e.g., in the Global Precipitation Mission's Intersatellite Calibration (GPM XO) programme.

Finally, unfettered data access is critical in climate work given its inherently global scope and impact, societal implications, and many non-commercial research uses. This access is possible from New Space, however acquiring the data sharing rights for open public access may come at costs that limit one of the accepted benefits of New Space.

Overall, New Space technology has the potential to make significant contributions to climate science, monitoring and services. With proper design, operation, and maintenance, New Space satellites can meet climate requirements. However, it is important to carefully evaluate their stability and accuracy before relying on New Space and, most importantly, the likely benefits, fitness for purpose, and full end-to-end costs, including all post-observation and analysis-ready preparation activities required to generate decision-ready climate information. Climate-oriented agencies seeking NewSpace partnerships should ensure contractual language encompasses all needed requirements.

4.17.6. Disasters

Disaster management must address the different stages of disasters: prevention, preparedness, response, mitigation, and recovery. All these phases need space-based technologies and require many challenging features such as high revisit, easily accessible data, fast availability, as far as possible free and open data, and spatial resolution requirements ranging from low to very high depending on the type of disaster. For emergency response situations, urgent satellite tasking is compulsory in addition to the need for acquisitions to be systematically free and open. In addition to all these features, a very good radiometric accuracy and data quality is required to guarantee high quality results and users' confidence.

Traditional satellites are reliable, have rapid communication, observation, and positioning tools, which become particularly vital to relief and mitigation operations when ground-based infrastructure is damaged. In this sense, these satellites have a specific architecture as monolithic missions with very high technological impact and high reliability.

The New Space concept has other characteristics. These are satellites whose production is done in series, with simplification of testing and revision processes, using COTS (commercial off the shelf) components based on pre-established criteria that are generated through a component spatialisation programme. More and more New Space constellations are aiming to offer very regular revisits (daily, or even more frequent) at any point on the earth, with metric or even sub-metric spatial resolution but average image quality. For the crucial "emergency response" phase, these New Space systems are of major interest, despite their intrinsically limited quality. For the other phases of the Risk Cycle (prevention, preparedness, recovery), New Space mission characteristics are often not really aligned with the quality requirements that disaster events demand for their monitoring, or that hazard comprehension demands for their scientific and technical knowledge. In addition to this, today there are many companies dedicated to the downstream, and in particular to the sale of ready-to-use products that they develop from satellite information. In some cases, to have a quick overview of the disaster, or to estimate the impact, such derived information coming from the New Space companies may be very useful, of course depending on the disaster type. The downside is that, in general, the value-added products are not accessible to all economies, and emergency response teams often require not only value-added products, but satellite images too in order to feed their geographic information systems. Data access including, of course, data licensing may therefore be a very crucial point for effective and efficient use.

Much remains to be done to cooperate with New Space companies to ensure New Space satellite data accessibility and quality, perhaps for example by applying methods of cross-calibration with traditional satellites that acquire data with good quality control and quality assessment. On top of this, companies need to be convinced that, when an emergency occurs, the need surpasses immediate economic benefit and certain programmes are needed to facilitate free and open access to data in order to be able to assist the affected region. Very few private space technology companies plan to launch dedicated disaster constellations in the coming years, using their own funds. The most common situation is the one illustrated by WildFireSat. The Canadian government has committed financially to developing a 5-year mission dedicated to monitoring wildland fires in collaboration with private space technology companies - WildFireSat. Three consortiums are currently on the shortlist for bidding and being awarded the contract to build this mission, and some of them could be considered 'new space' entities. Corrected and geolocated WildFireSat data and derived end-user products will be made freely and publicly available over Canada, in line with Canadian government open data policies. For the moment there are no firm commitments or agreements in place regarding the provision of WildFireSat data outside Canada, though this is an active area of discussion. However, talking about constellations that would be fully conceived and launched by emergent private space technology, it is difficult to predict the quality of the New Space data and how well it will be accepted by disaster managers.

4.17.7. Agriculture

New Space data has been utilised very often for agricultural purposes, for example within the NASA Harvest Programme. Remote Sensing has an established role to play in crop type mapping, but for those aspects that require consistent radiometric calibration, like crop biophysical variables and yield, there are gaps.

Fine to moderate (10m) resolution thermal (and finer resolution microwave - 10-30m) data is essential for soil moisture and evapotranspiration monitoring and this is also useful in yield forecasting and condition monitoring. These are the GEOGLAM (Group on Earth Observations' Global Agricultural Monitoring) initiative's target core variables (together with crop type mapping and area estimation). Of course, thermal data needs to have the same overpass time/date where optical sensors are involved and if they aren't flying on the same payload. Hyperspectral data also has great value for other agricultural monitoring activities that are outside of GEOGLAM's purview and that are not yet represented in CEOS. This includes for precision agriculture, pest and disease detection, crop nutrient status, and soil carbon. These all have great commercial potential, in the order billions of dollars of commercial value each year, which has already been identified by commercial satellite providers such as Planet, Maxar, Satellogic, and Iceye. CEOS Agencies are already working with these companies to develop use cases for their satellites in exchange for free access to their data. This is a supporting role that CEOS Agencies are providing to industry who eventually plan to monetise these use cases. However, it is unclear how GEOGLAM operational R&D, as well as its already operational constituent monitoring organisations, will bear the cost of commercial data in the future if and when they no longer see value in this exchange of data for use case and/or business development.

4.17.8. Capacity Development

The CEOS Working Group on Capacity Development and Data Democracy (WGCapD) has not traditionally been engaged with the private sector to support the delivery of its Work Plan activities. High resolution products such as digital elevation models, data products, specific bands (e.g. coastal blue band), and higher spatial/radiometric resolutions are not typically presented in WGCapD capacity-building activities. However, working with the private sector would provide end-users with knowledge about other Earth observation data sources that could engender new applications that might not have been previously possible. This engagement would be beneficial for private sector companies too as the reach of WGCapD has been demonstrated with, in some cases, single-workshop attendances of over 1000 participants thus providing an excellent platform for raising awareness about private sector data product availability. Furthermore, a substantial part of the academic user community attends WGCapD activities and their research could unlock applications with undoubtable commercial value. Therefore, joint capacity-building activities would be mutually beneficial even though they have not been pursued thus far. WGCapD would be keen to have CEOS agreement with commercial entities on free access data policies (e.g. some demo products) for promoting EO data for societal and climate change-based capacity development programmes, such as in response to the Sustainable Development Goals (SDG) part of the 2030 Agenda for Sustainable Development, or applications under overarching priority 2 ("Harness the potential of space to solve everyday challenges and leverage space-related innovation to improve the quality of life").

The topic of data archives held by private sector companies is also very important to the CEOS community. One of the price factors of the data is related to how recent the acquisition was made while historical archives have very little commercial value. However, historical data is vital to understanding trends in Earth's processes, and reliable and prolonged access to archives must be guaranteed to prevent interruption in continued applications. This topic warrants a conversation between CEOS and commercial data providers to guarantee that data access and commercial interests are preserved and how CEOS could be involved in its democratisation.

4.17.9. Land Surface Imaging

Land surface imaging is the cornerstone of the EO landscape. For decades the commercial sector has offered land surface imagery, typically at higher spatial resolutions than civil space agencies. The 'New Space' EO movement started in the land surface imagery domain but CEOS agencies have been involved in Public-Private Partnership (PPP) missions with the commercial sector (e.g., SPOT/CNES, TerraSAR-X/DLR, Radarsat/CSA) for many years. Now we see agencies also establishing partnerships with 'New Space' companies (e.g., NASA CSDA, NASA Harvest, ESA Earthnet Data Assessment Project EDAP, Copernicus Contributing Missions CCM), in recognition of the ability that these datasets have to fill observational gaps and increase temporal coverage for users.

The CEOS Land Surface Imaging Virtual Constellation (LSI-VC)'s main objective since it was re-established in 2016 has been to grow and simplify the amount of EO data available to the community, with a focus on non-expert users. This has largely been done through championing the CEOS-ARD (CEOS Analysis Ready Data) concept. With such a broad 'user' base and wide range of applications, it is difficult to define specific observational gaps. In general, land surface imagery users are seeking increased spatial resolution, increased temporal coverage (more frequent revisits, longer time series) and enhanced spectral resolution. New Space has the potential to contribute to all of these gaps. Even in the domain of moderate resolution imagery, additional interoperable observations will decrease revisit times and, in the case of optical, increase the chance of successful cloud-free acquisitions. All additional observations could be considered gap-filling opportunities.

With that said, the LSI-VC subgroups have more specific focus. We defer to the comprehensive input from the AFOLU (Agriculture, Forestry and Other Land Uses) roadmap team regarding forestry (see section 5.1). Regarding agriculture, the GEOGLAM subgroup of LSI-VC has put substantial effort into defining specific observational needs for each of their EAVs (Essential Agricultural Variables). Table 1 demonstrates the scale of the activity. The requirements are grouped into two categories: “always on” / wall-to-wall (global coverages) and “tasked acquisitions” / sampling. The latter is identified as the domain where commercial space, including New Space, is the biggest potential contributor.

						Systematic Acquisitions (Wall-to-Wall, Year-Round Monitoring)				Tasked Acquisitions (Small Croplands, Hotspots; Refining via Samp				
Spatial Resolution (Goal to Threshold)						50 - 500 m	500 m - 10 km	10 - 30 m	10 - 30 m	3 - 10 m	3 - 10 m	<3 m		<3 m
Spectral Range and/or Mode (Goal = Threshold, except where noted)						VIS RE NIR SWIR Thermal + Cloud Bands	Passive Microwave	VIS RE NIR SWIR Thermal + Cloud Bands	SAR dual (Threshold) to quad (Goal) polarization; multifrequency (Threshold: L,S,C; Goal: L,S,C,X,P)	VIS RE NIR SWIR (+ Thermal + Cloud Bands)	SAR dual (Threshold) to quad (Goal) polarization; multifrequency (Threshold: L,S,C; Goal: L,S,C,X,P)	Goal: VIS RE NIR SWIR; Threshold: VIS NIR		SAR Multifrequency
Cloud Free Obs. Frequency (Goal to Threshold)						1--2x daily	daily	weekly	2-4x weekly	1-2x weekly	2-4x weekly	1-2x yearly	1-2x monthly	weekly
Coverage Notes						Wall-to-Wall				Cropland Extent	Cropland extent (cloudy & rice)	Cropland Extent (non-cloudy)	Refined Sample of All Fields	Cloudy Croplands
				Goal Update Frequency	Threshold Update Frequency									
Essential Agriculture Variables for GEOGLAM	Agricultural Domain Variables	Core Agriculture Mapping Variables	Agriculture Mask	Monthly		X		X	X	X	M/S	S	S	
			Cropland Mask	Monthly		X		X	X	X	M/S	S	S	
			Irrigated Cropland Mask											
			Rangeland Mask											
			Seasonal Fallow Mask											
			Seasonal Cover Crop Mask											
			Temporary Cropland Mask											
			Perennial Cropland Mask											
			Managed Grassland Mask											
			Crop Type Masks	Monthly		X		X	X	X	M/S	S	S	
			Crop Type Area	Mid of Season				M/L	M/L	X	X	M/S	X	
			Field Boundaries	Every 3 years				L	L	L		M/S	M/S	
		Agriculture Management Practice Variables	Seasonal Fallow Mask											
			Seasonal Cover Crop Mask											
			Agriculture Burned Area Mask											
			Reference Crop Calendar	Every 5 years		L		X	X					
			Current Crop Stage	Weekly		L		X	X	X	M/S			X
			Land Management Calendar											
		Core Agricultural Productivity Variables	Crop Condition Assessment	Weekly		X	X	X		X				
			Growing Degree Days											
			Rangeland Condition Assessment											
			Crop Yield Forecast	Monthly		L	X	X	X	X			X	
			Crop Yield Estimation	End of Season		L	X	X	X	X			X	
			Water Productivity	Daily		X	X	X	X	X	X			
	Meteorological and Land Surface Variables		Fractional Cover	2-3 Days		L	X	X	X	X	X			
			Evapotranspiration (Reference and Actual)	Daily		X	X	X	X	X	X			
			Seasonal Dynamics of Surface Water Availability	Daily		X	X	X	X	X	X			
			Soil Moisture (Surface and Root Zone)	Daily			X		X		X			X
			Aboveground Agricultural Biomass	2-3 Days		L	X	X	X	X	X			X
			Soil Organic Carbon Concentration											
			Residue Cover											
			Runoff											
			Land Surface Temperature											
			Air Temperature											
		Essential Climate Variables	Wind Speed											
			Precipitation											
			Leaf-Area Index	2-3 Days		L	X	X	X	X	X			X
			fAPAR	2-3 Days		L	X	X	X	X	X			X
			Incoming Radiation											
			Relative Humidity											

Table 1: Acquisition requirements for Essential Agriculture Variables

Another potential area of observational gaps is in the Land Surface Temperature (LST) domain, specifically for LST Climate Data Records. LSI-VC will, together with the joint CEOS/CGMS (Coordination Group on Meteorological Satellites) Working Group on Climate (WGClimate), be following up on an activity first raised by WGClimate for the need for a deeper analysis looking at the availability of LST datasets, specifically those processed into CDRs. This study of the future continuity of LST measurements might reveal gaps in the LST CDR that could be filled by commercial space.

The United States Joint Agency Commercial Imagery Evaluation (JACIE) Land Remote Sensing Satellites Online Compendium contains details about past, present, and future Earth observing satellites and the sensors they carry. This resource has been developed and is managed by the Requirements, Capabilities and Analysis for Earth Observation (RCA-EO) team at the United States Geological Survey (USGS). This compendium includes technical specifications of both CEOS and commercial EO missions and would be a helpful resource in combination with the CEOS Missions, Instruments and Measurements (MIM) Database to assess gaps in CEOS observations that might be filled by the commercial sector.

Of great interest to the commercial EO sector is Analysis Ready Data (ARD). ARD are data that have been processed to allow analysis with a minimum of additional user effort and are increasingly used in EO applications and services. CEOS-ARD specifications were established with the overall objective of reducing the burden of data preparation for satellite data users, with a specific focus on the 'non-EO-expert' community. The hope is that the CEOS-ARD specifications will facilitate easier use of satellite data by promoting cloud accessibility and enhancing remote EO data processing capabilities. The commercial sector, including New Space, are already embracing the concept, and the hope is that it will provide additional data that will fill observational gaps for the growing user community base. LSI-VC has a number of ongoing engagements with the New Space sector in this direction and ARD are expected to be a catlyst for the increased application of LSI data in general, including in the commercial sector. Other associated trends are advances in Artificial Intelligence (AI) and Machine Learning (ML) to deliver insight from the vast volumes of data. The New Space sector is already advancing the AI/ML application of LSI data, and this perhaps presents an opportunity for CEOS.

4.17.10. Ocean Surface Vector Winds

Ocean Surface Vector Winds (OSVW) from scatterometers have a legacy of collaboration between various global agencies that have ensured a long-term continuity of the data. EO datasets from in situ and satellite-based platforms are thus available from various repositories. Space based OSWV are either from C band or Ku band scatterometers and they vary in terms of their observing frequencies and geometries. However, for users scrutinising these collections to find the right dataset for a particular application is a challenge. Further, different kinds of mechanisms in accessing, analysing and visualising the data across various global repositories add to this challenge.

OSWVs are used for forcing the numerical weather prediction (NWP) models. Many agencies use OSWV data for assimilation purposes in their NWP models. These NWP models produce simulated fields at the required spatial resolution every 6 hours. These are aimed at studying meso-scale ocean features whose spatial-temporal scales are a few kilometres to 50 km, and from a few hours to days. Currently, the Indian Space Research Organisation (ISRO) is engaged in providing OSWV measurements from SCAT-3 on board EOS-06 (Oceansat-3) at a nominal 25 km resolution with a 2-day repeat. However, for the study of mesoscale features we should ideally target a better resolution of preferably less than 10km. The repeated measurements of the mesoscale features are also ideally done every 6 hours (for studying their diurnal variability) and this can be achieved by a constellation of satellite scatterometers. Right now, EOS-06, METOP-C and CFOSAT SCAT are catering towards the needs of OSWV. The legacy would continue with a series of planned scatterometers, including METOP-SG. One of the important gap areas in this aspect is an assumption that ocean roughness is only due to surface wind, but here ocean currents also have a role to play. Thus, we miss ocean currents in retrieval of OSWV. NASA's Doppler scatterometer would be a technological innovation in the future to address this issue. Another important aspect is that high wind conditions in the event of cyclones are not very well captured by scatterometers. Similarly, low wind conditions, which promote most air-sea interaction processes are also ambiguous in most scatterometer measurements. Currently, accurate OSWV information is only available in the range of 3-30m/s. This emphasises the need for dual band scatterometers operating in low and high frequency ranges to observe high and low winds respectively. Another potentially important aspect for New Space would be to support the integration of all scatterometer data into a common format, calibrating it with respect to a reference mission and to produce climate quality OSWV products for users.

A long term, climate quality OSWV would cater to various users in meteorology, oceanography, and climate applications areas, and also to industries involved in surveillance, fishing, green energy resource assessments, shipping, insurance, etc.

4.17.11. Sea-surface Temperature

Observation of sea-surface temperature (SST) from space is dominated by national space agency platforms using thermal infrared or microwave sensing instruments, including popular instruments such as VIIRS, AMSR-2, AVHRR, SEVIRI, SLSTR and GOES-ABI whose data are typically global in scale with at least daily revisits. New Space has not had any significant contribution to the field of observational SST oceanography up to now. Most scientific requirements for SST remote sensing are met by the current constellation of national space agency satellites, including planned future microwave sensing missions AMSR-3 (Jaxa) and CIMR (ESA), and high spatial resolution IR missions like TRISHNA (CNES/ISRO) and SBG (NASA). There is an effort by an emerging company, Earthdaily, to build and deploy a low cost satellite constellation with thermal infrared capabilities, but the SST accuracy and spatial coverage of the ocean is unknown. A possible factor limiting participation for commercial providers is that accurate SST remote sensing for science and climate change requires careful and consistent pre-launch/in-flight calibration that may be beyond their expertise or interest.

There is an emerging need to push the boundaries of both spatial resolution and temporal revisit that are not being entirely addressed. These requirements are for high temporal repeat/high spatial resolution observations in dynamic coastal ocean regions where changes in sub-mesoscale (0.1- 10 km) can occur in time periods of an hour. A typical polar orbiting or non-sun synchronous temporal repeat observation of 12 hours is not sufficient to track these changes. A faster observing geostationary platform will likely not have the necessary spatial resolution. A New Space effort to perform these types of observations from satellite constellations/aircrafts/drones could be a potential niche growth area (to fill the gap).

4.17.12. Ocean Surface Topography

Commercial engagement in monitoring ocean surface topography is an emerging topic. There is potential for new space to improve the spatial and temporal sampling of ocean surface topography measurements, complementing the traditional institutional missions funded by CEOS Agencies.

The CEOS OST-VC is preparing a white paper: *'A coordinated international constellation of virtual satellite altimetry: towards 2050'*. This white paper, which should be ready by mid-2024 at the latest, will provide an update of the previous document dating from 2009, with the emerging needs of the altimetry user community and, where appropriate, the shortcomings of the current virtual constellation. This document could provide key elements for identifying potential opportunities related to New Space development.

4.18. Opportunities for New Space to support science

CEOS Members and Associates support the EO scientific community, from whom innovation and expert solutions stem. New Space has a potentially active role to play in cutting edge innovation and solutions that have hitherto largely been seen as the domain of publicly-funded governmental bodies. The following section proposes some areas where commercial EO provision may play an active and possibly key role.

What is written reflects only the views and experiences offered and shared to the CEOS community through this process and does not constitute a full gap analysis of EO opportunities for New Space to support science.

4.18.1. Global Navigation Satellite System - Radio Occultation

Spaceborne radio occultation (RO) refers to a sounding technique in which a radio wave from one spacecraft passing through the atmosphere arrives at a receiver on other spacecraft. After the proof-of-concept demonstration of Global Positioning System (GPS)/Meteorology (GPS/MET) RO experiment for sounding Earth's atmosphere in 1995–1997 (Ware et al., 1996; Kursinski et al., 1997), the technique has been rapidly adopted by multiple government and commercial satellites on low-Earth-orbiting (LEO) to form several receiver constellations. In addition, the L-band services from global navigation satellite systems (GNSS) have also grown significantly from the United States GPS and the Russian Global Navigation Satellite System (GLONASS) to recent European Galileo and Chinese Beidou systems.

By measuring the precision phase delay at two L-band frequencies between GNSS and LEO satellites, the GNSS-RO technique can determine the bending angle of radio wave trajectories from the ionosphere, stratosphere and troposphere very accurately. The bending angle profile contains useful information on atmospheric/ionospheric refractivity, which is a function of temperature, pressure, water vapor pressure, electron density, and radio wave frequency.

Assimilating GNSS-RO data into numerical weather prediction (NWP) systems has significant benefits to reduction of forecast temperature errors in the upper troposphere and lower stratosphere [Healy et al., 2005]. The impacts of GNSS-RO observations are amplified in the data assimilation (DA) systems because they help to improve the adaptive bias correction and quality control procedures used for satellite microwave radiances [Auligné, et al., 2007]. Such impacts do not seem to be saturated by the daily number of GNSS-RO measurements in controlled observing system simulation experiments (OSSEs) [Prive et al.,2022]

GNSS-RO observations have been widely used by the science community to better characterize and understand atmospheric processes. The excellent vertical resolution of GNSS-RO measurements made it possible to quantify global gravity wave (GW) distributions from temperature perturbations in the upper troposphere and lower stratosphere [Tsuda et al., 2004]. It also helped to provide the first global observational survey of planetary boundary layer (PBL) height, using the minimum vertical gradient of the refractivity or water vapor partial pressure [Ao et al., 2012]. The GNSS-RO amplitude (i.e., SNR) can be used to infer water vapor abundance over the marine PBL [Wu et al., 2022a].

Because the RO technique is fundamentally traced back to meters, it depends little on radiometric calibration or sensitivity drift. As a result, the GNSS-RO data serve as a robust source to study long-term temperature variations in the atmosphere. Randel et al. (2015) showed that zonal mean GNSS-RO temperatures in the lower stratosphere and near the cold point are strongly coupled to the upper troposphere on time scales of 30–60 days, likely linked to the Madden–Julian oscillation (MJO). In addition, there are strong seasonal cycle, quasi-biennial oscillation (QBO), and El Niño–Southern Oscillation (ENSO) variation. Recently, the RO bending angle measurements were used to study atmospheric disturbances induced strong volcanic eruptions [Carr et al., 2022; Babu et al., 2023].

The radio wave limb sounding from GNSS-LEO constellations has provide an unprecedented coverage for ionospheric electron density (ne) that has large variations at a wide range of spatiotemporal scales. Combined observations from the recent Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC-2) [Hsu et al., 2018] and Spire [Angling et al., 2021] in 2022 have achieved over 20,000 profiles/day for the D/E ionosphere [Wu et al., 2022b] and ~12,000 profiles/day for the F-region ionosphere [Wu et al., 2023]. This sampling can provide a global ionospheric map at a 2ox2o latitude-longitude and 2-hour local time resolutions on a monthly basis. The GNSS-RO amplitude and phase measurements have also been used to study ionospheric scintillations [Tsai et al., 2017; Wu 2020] and sporadic-E [Wu et al., 2005; Arras et al., 2009].

4.18.2. Global Navigation Satellite Systems - Reflectometry

In spite of early works [1-3] envisaging their use for the microwave sensing of a handful of the Earth's geophysical properties, the studies following the launch of NASA's first GNSS-R, CYGNSS [4], constellation in 2016 have highlighted their utility for a swath of disparate applications prompting the development of a variety of Level-2 and Level-3 products while spawning accelerating interest by commercial providers who have been steadily building up their fleets of GNSS-R observatories in LEO. Areas where the potential benefits of incorporating spaceborne GNSS-R observations have been demonstrated include ocean, cryosphere, and land applications. In this scenario, the Institute of Electrical and Electronics Engineers (IEEE) Standard for Spaceborne Global Navigation Satellite System-Reflectometry (GNSS-R) [x] was developed to provide a set of specifications and recommended practices that can be used to describe any known and future spaceborne GNSS-R data set, allowing users to work with different GNSS-R data sets at the same time. This work establishes the fundamentals of a potential network of satellites providing inter-comparable data to the scientific community. [x] https://standards.ieee.org/ieee/4003/7484/

For a wide range of ocean surface applications, one of the more fundamental surface properties GNSS-R systems attempt to sense is surface roughness indicated by their estimates of "mean-square slope". Subsequently, this is used as a means of sensing ocean surface winds given the fact that a rougher fully developed sea is synonymous with higher winds prevailing over its surface and as a result reducing received power [5]. Retrieved GNSS-R surface winds have been used to develop heat flux products [6], as inputs to storm surge modeling and prediction tools [7], for full all-weather reconstruction of storm profiles [8], and assimilated into global models for improving tropical cyclone forecasts [9] to name but a few applications. Additionally, deviations of observed "mean-square slopes" from modeled predictions at known wind speeds have been leveraged as a means of sensing microplastics concentrations [10] as well as algal bloom formations [11]. Other ocean applications like the estimation of mesoscale ocean current flows are enabled by the use of GNSS-R observations for altimetric retrievals as part of group delay or phase approaches [12].

Interest in the use of GNSS-R reflections for applications relating to the cryosphere has been chiefly motivated by the varied temporal scales over which sea ice dynamics occur and the potential of GNSS-R observatories to provide more insight into their properties given their more dense coverage. This has entailed the use of a combination of phase, waveform shape and amplitude information all aimed at sensing one or more of the following properties: sea ice present/not present, type/age, thickness and melt rate [13-15]. The efficacy of GNSS-R reflections in providing deeper insights into related dynamics has already led to the development of commercial "sea-ice" GNSS-R data products [16].

The most fertile ground for the use of GNSS-R reflections for novel applications has been over land. It is well established that soil permittivity is impacted by its various constituents but undergoes some of its more significant changes as a function of volumetric moisture content at L-band. This in turn introduces commensurate perturbations to surfaces' measured surface reflectivity which in turn can be leveraged to sense soil moisture. A wide range of empirical, semi-empirical and model based approaches [17-19] have demonstrated the viability of using GNSS-R systems for the monitoring of global soil moisture with competitive retrievals compared to more established radiometric observatories. Closely related and of particular interest is the use of spaceborne GNSS-R observations for the retrieval of various vegetation indices including Vegetation Optical Depth (VOD), Above Ground Biomass (AGB) and the like by leveraging the known exponential decay of signal intensity as a result of observation geometry and biome characteristics [20, 21]. Similarly, the heightened sensitivity of spaceborne GNSS-R systems to inland water and related dynamics together with their placement in a specular bistatic geometry, giving rise to a variety of scattering behaviors, has enabled their use for a range of applications. This includes the generation of global inland water masks with the potential for frequent updates on intervals as short as 2 weeks [22], monitoring with ~1 day latency the various phases of the Indian monsoon [23] as well as mapping storm surge across the USA's Gulf Coast [24] to name a few. The sensing of more intricate properties of water bodies of interest has also been demonstrated including river discharge levels [25], river slopes [26] and reservoir water storage levels [27] all with correlations on the order of 90% relative to independent reference datasets. While the placement of numerous preceding receivers in a ~35 inclined orbit has limited their coverage to the tropics, more recent studies have also demonstrated the ability to utilize GNSS-R surface reflectivities for monitoring surface freeze-thaw state [28] by leveraging the generally higher reflection amplitudes over thawed surfaces, compared to their frozen counterparts, as part of an empirical retrieval approach.

4.18.3. Automatic Identification System (AIS)

Automatic Identification System (AIS) is an automatic tracking system used on ships and by vessel traffic services (VTS) for identifying and locating vessels. It is used mainly for collision detection but also for maritime domain awareness in national defence and security applications, search and rescue operations, and environmental monitoring. It is the main vessel localisation tool available today, but it was not originally designed to track ships as it can be tampered with or simply turned off.

Satellite-based AIS, where low-orbiting satellites are used to detect and characterise in near-real time the passive electromagnetic signature of any ship (cooperative or not), anytime (day or night) and under any weather condition, provides a means to track the location of vessels anywhere around the world, especially over open oceans. It also provides unmatched coverage when compared to terrestrial-based AIS systems.

The commercial use of this type of satellite data was first investigated by the NRO in 2019, when an integration study contract for commercial RF[1] was awarded. Since then there has been an increasing demand for this data source from across the user communities (e.g. maritime agencies, insurance companies, environmental organisations, governments).

[1] In 2019 HawkEye 360 Inc. was awarded a contract for a commercial RF survey study from the NRO. Through that contract, HawkEye 360 examined the integration of commercial RF capabilities and products into the NRO's geospatial intelligence architecture.

Consequently, in Sep 2022 the NRO kicked off a pilot programme to collect data from satellites[2] that track emitters of radio frequency (RF) signals. Study contracts were awarded to 6 commercial companies to e.g. model and simulate current and future RF-sensing capabilities or conduct accuracy and quality assessments, and will allow NRO to assess operational and decision-making usefulness of this type of data. The contracts had a 6-month base period of performance, with two 24-month options and additional options to extend further.

In Europe, in the frame of ESA's Third Party Missions programme, ESA is currently assessing the potential use of RF data from two companies[3] for research and development purposes, and other companies are proposing AIS in their developments.

4.18.4. Hyperspectral Imaging Spectroscopy

Since 2016, New Space has been invested in greenhouse-gas monitoring with the initial launch of GHGSat-D. This demonstration mission led the way for a constellation of now 8 GHGSat spacecraft (with three more planned) designed to detect point source emissions of methane from oil and gas facilities as well as agriculture activities (i.e., from cattle feedlots). Other companies and public-private partnerships have since formed to provide greenhouse-gas point source detection, with launches planned in 2024 for MethaneSAT (MethaneSAT LLC / Environmental Defense Fund) and CarbonMapper (CarbonMapper LLC / Planet / JPL), and missions in planning phases for companies such as Orbital Sidekick (i.e., GHOSt and Aurora), Bluefield (i.e., Bluebird), Scepter and Kuva Space These instruments make use of hyperspectral imaging spectroscopy to retrieve point-source column methane concentrations in the shortwave infrared region ~1,650 nm with relatively high spectral resolution < 1 nm. Around this spectral range, column concentrations of carbon dioxide point sources can be retrieved and thus several of these missions are now developing carbon dioxide products. Hyperspectral missions with full VNIR or VSWIR range and coarser spectral resolution (8-10 nm), e.g., ASI's PRISMA, NASA's EMIT, DLR's EnMAP, tend to have lower detection thresholds for point-source emissions.

The commercial greenhouse gas missions can be characterized as having a narrow field of view, between 12-20 km and relatively high ground sample distance on order of 8 to 30 m. MethaneSAT will have a field of view of 200 km and a ground sample distance of 150 x 450 meters placing the mission between public greenhouse gas missions using wide swath imagers and the commercial sector. The precision (random error) of the commercial greenhouse-gas missions is around 0.5 to 2% of background concentrations of methane, around 15-20 ppb. At this level of precision, the instruments are successful in detecting point source emission rates larger than 100 kg per hour under ideal

[2] Aurora Insight, HawkEye 360, Kleos Space (US subsidiary), PredaSAR, Spire Global and Umbra Lab were awarded the commercial RF study contracts. Through the agreements the companies were giving NRO access to their systems and business plans so the agency could decide what commercial data it might purchase for operational use.
(https://spacenews.com/nro-signs-agreements-with-six-commercial-providers-of-space-based-rf-data/)

[3] ESA is currently assessing the data from Spire Global (European subsidiary in Luxembourg) and the French Unseenlabs company

circumstances (i.e., high surface albedo, low wind speeds). Compared to public-sector greenhouse gas 'area-flux' missions such as GOSAT, Sentinel 5p (TROPOMI), OCO-2 (for CO2), these instruments have higher spectral resolution (~0.1 nm) to enabling precisions to well-below 1% for ~2 ppb in the case of Sentinel 5p. The revisit of the commercial spacecraft depends on whether the acquisitions are made continuously or whether they are made in targeted mode as well as the number of spacecraft within each constellation. So far, none of the commercial missions provide routine, mow-the-lawn, global observations with regular cadence.

Data access varies between companies, with GHGSat available only via subscription, CarbonMapper plans to make products freely available after a roughly 1-month time lag, and MethaneSAT data will be freely available with no data latency. Commercial data acquisition by public-space agencies (NASA, ESA, CSA) are currently being evaluated, with NASA leading a 'commercial data space acquisition' activity for GHGSat in 2023. Various data portals have been established or are being developed using cloud-based architectures, with the SPECTRA Emissions Intelligence Platform available for accessing procured GHGSat data, an interactive portal to access airborne CarbonMapper data (https://data.carbonmapper.org/#1.5/25/0), and by subscription the Methane Watch portal developed by Kayrros. In the future, the Methane Alert and Response System (MARS) developed by the International Methane Emissions Observatory (IMEO) of the United Nations Environment Program, will potentially provide data standards and data access to point source emissions in fulfillment of the Global Methane Pledge.

Overall, New Space has filled an important observation gap in being able to detect point source emissions of methane from leaking oil and gas infrastructures on land and in the coastal ocean, as well as emissions from high-intensity agriculture operations. These observations have helped identify super and ultra-emitters of methane and contributed to the recognition of point source emissions in the growth of global atmospheric methane and the observations should be able to help in mitigating methane emissions in countries where partnerships exist. Controlled release experiments and aircraft campaigns led by CarbonMapper and MethaneAir play an important role in calibration and validation strategies and in helping better understand the detection thresholds and success in observing point source emissions. In comparison to public-space greenhouse gas missions designed for area-flux estimation rather than point-source detection, understanding the background concentrations of methane and carbon dioxide in the atmosphere for documenting global variability and year-to-year growth anomalies remains a domain covered by Sentinel 5p, GOSAT, OCO-2, and to planned missions such as ESA's CO2M and DLR's MERLIN.

4.18.5. Synthetic Aperture Radar

In the four decades since the flight of the first civilian synthetic aperture radar (SAR) satellite, Seasat, the number of SAR satellites observing Earth has dramatically increased. SAR sensors naturally provide consistent imaging, regardless of the light conditions or cloud cover. Consistent imaging is ideal for change detection applications. SAR imagery has been commercially available throughout, and small satellite constellations created new market dynamics in the past decade, providing the radar community a new perspective.

For some radar imaging and change detection applications rapid temporal sampling and high resolution is vital. Focusing on this need, the commercial radar market includes many systems operating at X-band (~3 cm wavelength) where active microwave Earth Observation (EO) imaging supports a large bandwidth (1200 MHz, 0.125 cm resolution). These traits make commercial X-band imagery relevant for infrastructure monitoring, land cover land use change, and even human activity level assessments through parking lot surveys in tens of km wide areas.

Interferometric SAR (InSAR), is a technique where two images acquired in the same geometry are used to sense the distance to the target object in the image, which can be used to generate deformation maps or elevation maps. Commercial small satellite SAR systems started offering interferometric observations recently using a small fraction of their satellite commercial SAR constellation. Scientific utility of the commercial SAR data will increase significantly with the spread of interferometric imaging.

Polarimetry sheds light into the geometric structure of the target in the image, enriching the data, and expanding its utility in remote sensing applications. Small satellite SAR systems currently do not offer polarimetric diversity and it remains a product only available through larger sensors.

4.18.6. Thermal Infrared Remote Sensing

Thermal infrared remote sensing in general has a long history of and promising future for providing important data for a broad range of research applications, including agriculture and precision farming, forest fire detection and monitoring, urban heat island studies, water resource management, water and energy budget research, glacier and polar ice monitoring, disaster assessment and response, oil and gas exploration, and exploration of geothermal energy sources. While commercial sources of thermal infrared satellite data are relatively new, they provide great promise for high resolution imaging of localized areas of interest, and improved temporal coverage at moderate resolution.

4.18.7. Very High-Resolution Commercial Optical Imagery

Very High-Resolution (VHR, < 2 m ground sampling distance) commercial optical imagery has been available for nearly a quarter century, since 1999. Over this period of time a number of novel earth science applications have evolved with the capabilities of these imaging systems. Advances in understanding earth system processes at the submeter scale from space, from any location on the planet, accelerated our knowledge of how the earth operates as a system through many scales of observations when linked to free and open moderate and coarse resolution data. Here we provide a number of novel scientific use examples from commercial VHR data in the visible to shortwave infrared (VSWIR) wavelengths that have advanced our knowledge over the past decade.

In ecological applications VHR data provide information for continental scale surveys of sparse individual trees outside of forests for estimating their extent and carbon content (Reiner et al., 2023; Tucker et al., 2023). It allows for estimating tree height in boreal ecosystems with open canopies with varying illumination and viewing geometry that can provide reference for allometric estimates of carbon storage (Montesano et al., 2017). Studies of surface hydrology have been advanced with the ability to detect small water bodies and change in surface area (Mullen et al., 2023; Qayyum et al., 2020), distinguish fine scale natural vegetation in coastal margins from other land uses (Rapinel et al., 2014), monitor water quality and turbidity in reservoirs (Mansaray et al., 2021), and assess the distribution of benthic habitats (Gabr et al., 2020; Lazuardi, 2021). VHR data have been used to monitor invasive plant encroachment (Lake et al., 2022), vegetation restoration projects in tidal marshes (Chapple & Dronova, 2017), and to estimate the above ground biomass of mangrove stands (Zhu et al., 2015).

VHR stereo products have enabled the production of 2 m posting digital elevation models of the earth's surface (Porter et al., 2018). These data can be used to quantify where and how it is changing for vegetation height from post hurricane impacts (Lagomasino et al., 2021), to landslide events and estimating vulnerability (Amatya et al., 2021; Kirschbaum et al., 2019; Shugar et al., 2021). Cryospheric studies can use VHR stereo to estimate snow cover depth (Cannistra et al., 2021; Deschamps-Berger et al., 2020) and ice volume (Bhushan et al., 2021; Shean et al., 2020).

Crop monitoring has been advanced with the ability to distinguish the extent of individual smallholder fields in the developing world (McCarty et al., 2017; Neigh et al., 2018) and estimate within field yield variability at the industrial scale (Skakun et al., 2021), as well as crop type mapping at the fine scale (Cai et al., 2023). While, fine scale SWIR bands have enabled crop residue and tillage intensity mapping to monitor agriculture conservation practices (Hively et al., 2018).

Impacts and assessments of natural ecological disasters and events in a timely manner can now be more readily identified. With higher resolution data the distribution of locust outbreaks that lead to famine can be differentiated from drought (Alemu & Neigh, 2022). Wildfire damage assessment can be more site specific to assist decision making for postfire treatments (Chung et al., 2020). These data provide near-real-time monitoring of volcanic hazards from active eruptions at high spatial and temporal resolution (Ganci et al., 2020; Rösch & Plank, 2022). These are just a few examples of many that exist in the literature of how commercial VHR imagery is supplementing our moderate and coarse resolution Earth observing fleet of instruments.

4.18.8. Hyperspectral Imaging

Earth-monitoring hyperspectral sensors record data at hundreds of narrow, contiguous spectral bands, potentially spanning the ultraviolet to the thermal infrared regions. This high spectral resolution enables researchers to detect subtle differences in the reflectance and emission properties of materials on Earth's surface. While commercial sources of satellite hyperspectral data are relatively new, they provide great promise for expanding the temporal and spatial coverage and spatial resolution of heritage systems and for enabling enhanced research and applications in the following areas:

1. Environmental Monitoring: Hyperspectral data are a powerful tool for monitoring environmental changes. Researchers can track alterations in land cover, vegetation health, and water quality with greater precision than through the use of other data sources. For instance, the identification of invasive species in an ecosystem or the detection of early signs of stress in crops due to drought becomes more robust. Additionally, hyperspectral data enhance the capacity for the assessment of air and water pollution, with the potential to contribute to improved environmental management.

2. Mineral Exploration: Hyperspectral remote sensing plays a crucial role in mineral exploration. By examining the unique spectral signatures of minerals, scientists can identify potential mining sites and assess their economic viability. This has significant implications for resource management, and has potential to minimize the environmental impact of mining operations.

3. Climate Change Studies: Hyperspectral data can provide detailed information on vegetation dynamics, and surface temperatures. Researchers can use this data to monitor and model climate-related processes more accurately, enhancing our ability to predict and mitigate climate change effects.

4. Disaster Management: Hyperspectral data can aid in disaster management by improving mapping of the extent of wildfires, floods, and earthquakes. This information enables better resource allocation and faster response times for relief efforts.

5. Biodiversity Conservation: Hyperspectral remote sensing can aid in mapping and monitoring ecosystems, which is crucial for biodiversity conservation. By identifying unique spectral signatures associated with different species or habitats, scientists can assess the health and distribution of various ecosystems. This knowledge can inform conservation strategies and helps protect endangered species.

6. Agriculture and Food Security: In agriculture, hyperspectral data can improve crop yield predictions, optimize irrigation, and identify disease outbreaks early. This capability is vital for global food security.

7. Urban Planning and Development: Cities are expanding at an unprecedented rate. Hyperspectral data can assist urban planners in monitoring urban growth, assessing infrastructure needs, and managing resources efficiently.

5. Current Activities Supporting New Space

5.1. Calibration & Validation References

The mission of the CEOS Working Group on Calibration & Validation (WGCV) is to ensure long-term confidence in the accuracy and quality of Earth Observation data and products and to provide a forum for the exchange of information about calibration and validation, including the coordination of cooperative activities. Of relevance to the New Space topic, the CEOS WGCV can provide support for calibration and validation of instruments, helping to increase confidence in measurements, providing traceability, and ensuring data is fit for purpose. CEOS WGCV aims to provide references for calibration, validation, and data quality, as well as methods and protocols for cal/val, access to tools and expertise for New Space.

CEOS WGCV provides:

- References for radiometric calibration/validation
- References for geometric and image quality calibration/validation
- References for SAR calibration (under development)
- References for thermal missions (under development)
- GHG Sensor calibration resources
- Best practices and references for cal/val

A number of sites are qualified as reference sites. CEOS WGCV follows a rigorous metrology approach to characterise these sites as fiducial reference measurements. A fiducial reference measurement (FRM) is defined as:

- Ideally having documented SI traceability (e.g. via round-robin characterisation and regular pre-and post-deployment calibration of instruments) using metrology standards and/or community recognised best practices;
- Independent of the satellite geophysical retrieval process;
- Having an uncertainty budget for all FRM instruments, and derived measurements, is available and maintained;
- FRM measurement protocols, procedures and community-wide management practices (measurement, processing, archive, documents, etc.) are defined, published and adhered to by FRM instrument deployments;
- FRM are accessible to other researchers allowing independent verification of processing systems;
- FRM are required to determine the on-orbit uncertainty characteristics of satellite geophysical measurements via independent validation activities.

Further details on reference sites likely of particular interest to the New Space sector can be found in Appendix C.

CEOS WGCV also provides a set of **best practices documents** that facilitate cal/val activities and allow comparison of results. The documents are available on the CEOS Cal/Val Portal.

The New Space sector can find properly characterised references within CEOS that can be used to anchor its own satellites' observations. Therefore, they can be compared and used together with other missions and can demonstrate the fitness for purpose of these new data sources. In general, New Space missions cannot guarantee the same quality and reliability as CEOS/governmental agencies and the missions, thereby creating skepticism about their data quality in the user community. For New Space missions to become valuable for Earth science, they must meet the quality requirements set by the science community. Their teams are interested in increasing the reliability of their data while ensuring a fast data delivery and return on investment. WGCV Cal/Val support can help to progress this. Providing such Cal/Val support will reduce their operating costs and add value to their end products. It will enhance their science/application/service capabilities and strengthen their competitiveness. It will also shorten their start-up time and time to market.

Interoperability between satellites/products will facilitate increased opportunities to use these new data sources for global societal benefit applications (agriculture, water use, forest and vegetation monitoring, pollution monitoring, climate, etc.).

Benefits to CEOS:

There are a growing number of public and commercial providers of high resolution space-borne Earth observation data. Key to using data from these new sources is a good understanding of their characteristics, how they are calibrated, and their quality and technical capabilities. Interoperability between satellites/products will allow increased opportunities for global applications (agriculture, water use, forest and vegetation monitoring, pollution monitoring, climate applications, etc.). The data can be used together only if we can trust its accuracy and characterisation. Therefore, harmonisation in Calibration and Validation approaches is fundamental. The Global Earth Observation System of Systems (GEOSS) can work only if quality standards and references are put in place.

5.1.1. References for geometry and image quality calibration/validation

CEOS WGCV has defined a reference dataset composed of edge images and corresponding MTF (Modulation Transfer Function) curves. Users can access the edge images through the CEOS CalVal Portal (https://calvalportal.ceos.org/web/guest/mtf-reference-dataset). A reference paper associated with the reference dataset can serve as a new tool to either implement or check the MTF measurement that relies on the slanted edge method (see reference publication: "Comparison of MTF measurements using edge method: towards reference dataset". Françoise Viallefont-Robinet et al 2018)

CEOS WGCV is also working on reference ground control points for geometry. A step forward is achieved using the Sentinel-2 Reference Image (GRI) and a library of Ground Control Points (GCPs) derived thereof, which can serve as a reference for medium resolution sensors (around 10 m – 50 m resolution).

5.1.2. Intercomparison of CEOS & New Space Datasets

CEOS WGCV has started a number of activities aimed at intercomparing algorithms or approaches for Cal/Val. The objective of these activities are to better understand the uncertainties component by comparing different outputs from different approaches and to propose further improvements to the various algorithms. This comparison framework facilitates the understanding and knowledge of the various products from New Space and space agencies allowing better harmonisation between missions.

The current intercomparison exercises include:

- ACIX: Atmospheric Correction scheme intercomparison

- CMIX: Cloud Masking scheme intercomparison
- DEMIX: DEM intercomparison and impact on orthorectification process
- BRIX: Intercomparison of Biomass algorithm retrieval
- SRIX4VEG: Intercomparison of Surface reflectance for vegetation.

CEOS WGCV is also assessing the development of a "Match Up Database for New Space". It will consist of coincident satellite data together with Fiducial Reference Measurements (FRM) for radiometry, typically over RadCalNet sites.

5.1.3. SI-Traceable Satellite (SITSat) Coordination

With the emergence of a number of SI-Traceable Satellite missions (SITSats), the CEOS WGCV has considered the need for a group to coordinate on issues of common interest and to foster mutual benefits. SITSats have great potential to increase the accuracy of climate records and can also serve as high quality references for both CEOS Agency missions and the commercial sector – including 'New Space'. Both of these topics are headline priorities for CEOS and the 2022-2023 ESA SIT Chair. The WGCV has proposed the establishment of a joint Task Team with the Global Space-Based InterCalibration System (GSICS) which will include representatives from agencies operating and developing such missions, and others as interested, as a means to promote dialogue and coordination.

The Task Team will work on collaborative activities, discuss future developments, mission coordination, new technologies and spectral domains, interoperability topics, and serve as a forum for international coordination on SITSat missions, aiming to build an integrated system approach to their development and utilisation.

The Task Team will build on the findings of the workshop "SI-Traceable Space-based Climate Observing System (SITSCOS): a CEOS and GSICS Workshop" hosted by the UK Space Agency at the National Physical Laboratory in London in September 2019. The goal of the workshop was to assess the benefits and requirements of a space-based climate observing system, summarising current measurement capabilities, climate-based needs, and future implementation plans, together with recommendations. More details are available in the published SITSCOS Workshop report.

The SITSat Task Team will provide an opportunity for mission coordination, gap analyses, efficient tasking and acquisition planning, etc. It will allow coordination on technical topics, reporting of uncertainty and traceability information, interoperability, methods of dissemination etc. It will aim for a systems-based approach rather than having missions being developed and operated in isolation, along the lines of a CEOS Virtual Constellation.

5.2. Cal/Val Maturity Matrix

In 2030, it is projected that there will be over 8000 commercial satellites with the most explosive growth in the hyperspectral and hybrid sensor domains (source: the U.S. National Geospatial Intelligence Agency). Space agencies identified a need for tools for the systematic evaluation of commercial satellite data to understand how it may be integrated into their programmes. NASA launched the CSDA (Commercial Smallsat Data Acquisition) Project and ESA the EDAP (Earthnet Data Assessment Project) in response. Mission success is dependent upon quality assurance. Characterizing data quality significantly increases the value of datasets. Many aspects of data quality are aimed at facilitating communication to users. In the past few years, CEOS has developed a comprehensive definition of mission quality through Analysis Ready Data (CEOS-ARD), interoperability, Fiducial Reference Measurements (FRM), uncertainty evaluation (e.g. Sentinel-2, Sentinel-3, Landsat 9) and traceability (e.g., CLARREO, TRUTHS, Libra missions). A framework brings together this work to define a combined quality assurance standard. The Cal/Val Maturity Matrix assessment framework is aimed at verifying claimed mission performance and adheres, where applicable, to community best practices to the extent that data is “fit for purpose”.

The assessment is divided into two parts:

1. Review of mission quality as evidenced by its documentation.
2. Validation analysis performed by mission quality assessor.

Data providers can refer to this framework as they define products and evidence themselves.

Having a common framework between ESA and NASA simplifies the process for vendors and makes results more comparable. The assessment process is an interactive activity between assessors and mission operators. The framework was structured by the development of a Cal/Val Maturity Matrix. The Maturity Matrix is composed of a Validation Summary that summarises validation activity undertaken by the assessor and by a Data Provider Documentation Review that reviews the mission quality as evidenced by its documentation. It comprises product information which is a review of descriptive information accompanying products, metrology information that underpins evidence for observation quality and product generation section, which is a review of “fitness for purpose” of the product generation.

Undertaking assessment through a standardised maturity matrix facilitates communication with data providers (New Space). The Assessment process is an interactive activity between assessors and missions; through this interactive process, New Space could gain knowledge on data quality and increase the reliability of their data while ensuring a fast data delivery and return on investment.

The quality framework and Maturity Matrix facilitate data comparisons and help gain knowledge on data quality and fitness for the purpose of New Space data, therefore facilitating synergies between New Space and CEOS missions.

5.3. CEOS Analysis Ready Data (CEOS-ARD)

The phrase “Analysis-Ready Data” is inherently ambiguous, raising the immediate questions of: *“analysis-ready for what and who?”*. In 2016, the CEOS LSI-VC set out to provide at least one concrete definition of ARD – specifically CEOS Analysis Ready Data (CEOS-ARD). The resulting definition is:

CEOS Analysis Ready Data (CEOS-ARD) are satellite data that have been processed to a minimum set of requirements and organized into a form that allows immediate analysis with a minimum of additional user effort and interoperability both through time and with other datasets.

The core of the concept are the CEOS-ARD Product Family Specifications (PFS), which provide a series of requirements for various parameters across four broad categories: General Metadata, Per-Pixel Metadata, Radiometric and Atmospheric Corrections, and Geometric Corrections. For each parameter both a 'Threshold' and 'Target' requirement are detailed. To be assessed as CEOS-ARD compliant, a data provider must submit a self-assessment of their product against the PFS, which is then reviewed by the CEOS WGCV.

There are currently PFS for the following types of products:

- Surface Reflectance
- Surface Temperature
- Normalised Radar Backscatter
- Polarimetric Radar
- Aquatic Reflectance
- Nighttime Lights Surface Radiance
- Ocean Radar Backscatter

These specifications are built on the collective knowledge and experience of CEOS agency experts and provide a useful reference of the most critical processing steps, corrections and metadata that should be undertaken by data providers to ease the use and increase uptake of their data – particularly by non-expert users.

The PFS are openly published and all data providers, including those from the commercial sector and new space are encouraged to undertake a self-assessment of their products against the specifications. The specifications are not prescriptive in how a data provider should produce their products, rather they ask that they clearly document and make available their process and references.

Having data recognised as meeting the requirements of CEOS-ARD signals to potential users that it meets a certain level of pre-processing and documentation. The review from CEOS experts is a clear value-add, and WGCV peer reviews have often included substantial feedback and one on one dialogue.

Once assessments are completed, products are promoted via the ceos.org/ard datasets table and datasets can be promoted using CEOS-ARD branding. Datasets are further promoted via CEOS social media and newsletters. We are currently exploring the addition of CEOS-ARD tags and branding to major cloud platforms to further signal datasets compliance with the CEOS specifications.

The CEOS-ARD Oversight Group and LSI-VC has engaged with a number of New Space providers regarding CEOS-ARD assessments and continues to seek to establish dialogue with the sector.

Commercial partners engaged via forums such as VH-RODA, JACIE, annual ARD Workshops, and the ESA Living Planet Symposium (LPS) have indicated that formal standardisation of the concepts captured in the CEOS-ARD Framework will allow them to commit resources towards adapting their products and processes to produce 'Analysis-Ready Data' as standard products. Formal standardisation of the concepts developed through CEOS-ARD is likely necessary to achieve broad uptake, particularly by the commercial sector.

CEOS (Patrick Quinn of NASA) is co-chairing the Open Geospatial Consortium (OGC) Analysis Ready Data Standards Working Group (ARD SWG), which will aim to develop a multi-part Standard for geospatial Analysis Ready Data, using the work done on CEOS-ARD as a basis. CEOS will seek to ensure broad community representation in this SWG, including the commercial sector and New Space. It is critical that such a standard has broad buy-in and adoption.

CEOS has been developing these important connections to industry via the VH-RODA, JACIE, and LPS meetings; targeted engagement (e.g., invitations to LSI-VC meetings); as well as through strong representation at the industry-led ARD2x series of meetings (https://www.ard.zone/). The most recent of these workshops, the ARD23 Satellite Data Interoperability Workshop, aimed to advance interoperability and collaboration in the Earth observation and remote sensing industry. It expanded the scope of collaboration to include interoperability at the data level as well as sensor fusion and derived products. These meetings have proven to be critical engagement opportunities for CEOS-ARD and is a clear example of CEOS working team engagement with New Space.

5.4. CEOS Interoperability Framework

The 2022 CEOS Plenary recorded a decision for a CEOS Interoperability Framework to be developed as a multi-Working Group and multi-Virtual Constellation activity, to improve Data and Service Interoperability between datasets. The activity was proposed to build on the interoperability started with CEOS-ARD.

"Interoperability" is generally defined as "ability of two or more systems or components to exchange information and to use the information that has been exchanged." (ISO 25964 *Thesauri and Interoperability with other Vocabularies* (ISO 25964-2:2013)) In the F.A.I.R. (Findable, Accessible, Interoperable and Reusable) guiding principles for scientific data management and stewardship, it's also described that data is interoperable when it can be integrated with other data and systems to leverage open standards and specifications. (The FAIR Guiding Principles for scientific data management and stewardship | Scientific Data (nature.com))

Both CEOS members and New Space companies have been developing, launching, operating versatile satellites and producing and archiving increasingly large amounts of data. If those can be findable, accessible, and re-usable, it enables users to fill any observation gaps and build more sophisticated products. Based on these motivations, WGISS has developed and operates WGISS Connected Data Assets by collecting CEOS partners' product catalogues into the [CEOS International Directory Network (IDN)](), which enables a new space user to find and access CEOS agencies' data.

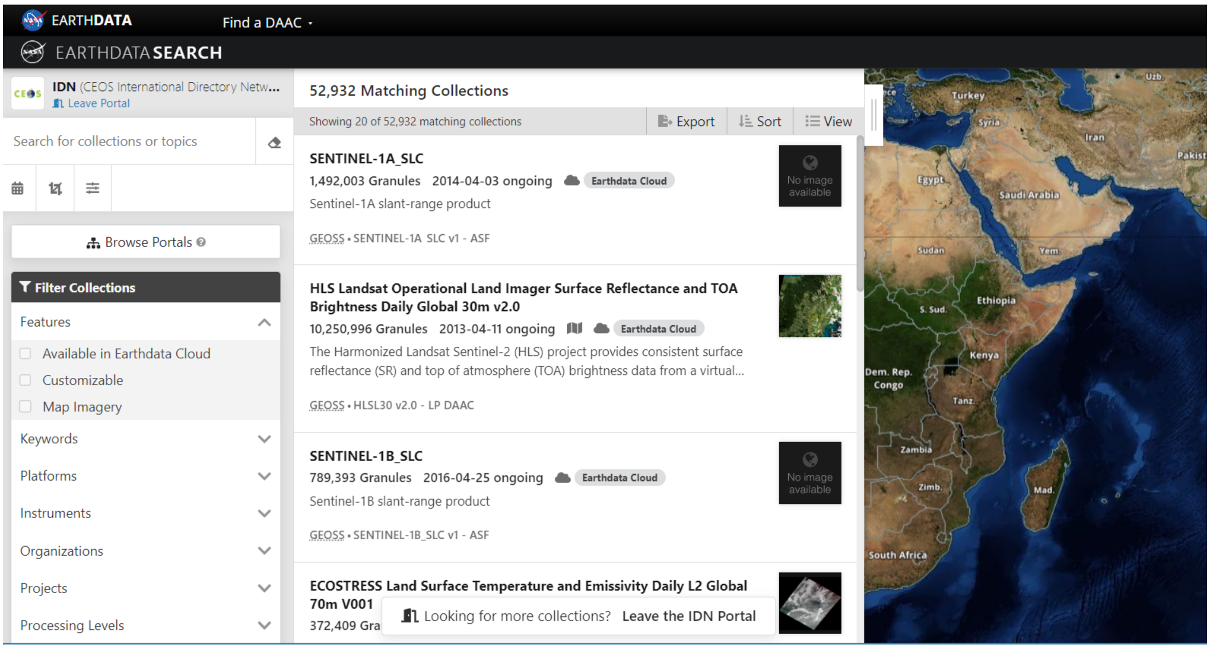

Figure 2: CEOS International Directory Network

As the volume of data and complexity of processing to produce science increases, the traditional workflow of downloading data to local computers and performing analysis is becoming increasingly impractical. The advent of cloud computing now allows any user access to unbounded compute resources. If archives are placed in the cloud, adjacent to that computer, any user can exploit the kind of environment only available to those with access to High Performance Computing environments. In order to fully exploit this capability, however, archives must provide open, cloud-optimized, analysis-ready data in the cloud accessible through standard-based APIs and open-source tools.

The goal of the CEOS Interoperability Framework is to provide comprehensive guidance for the development of interoperable services and data. The framework comprises five factors: vocabulary (semantics), structure (architecture), interfacing (accessibility), quality, and policy.

Data provision and use, based on guidelines to be developed for those factors, will facilitate compatibility of satellite data provided by CEOS partners and New Space companies, allowing to generate more comprehensive and advanced products and applications, which contribute not only to global issues but also promote the industrial use of satellite data.

5.5. Open Data Cube

The Open Data Cube (ODC), created and facilitated by CEOS, is an open-source software architecture that continues to grow in popularity around the world and is being used by more than 100 countries. The ODC can be equally used to manage CEOS datasets and New Space datasets. To date, there have not been any efforts to integrate and test CEOS data with New Space data in an ODC framework. This concept, strongly supported by the Digital Earth Africa program, would be a valuable effort to evaluate interoperability issues and gain a better understanding of New Space metadata, georegistration, and other data features needed to efficiently use such data in analysis frameworks along with common CEOS data.

5.6. ESA - NASA Earth Observation Mission Quality Assessment Framework

A Framework for EO Product Quality Assurance was developed in collaboration between ESA and NASA, with the National Physical Laboratory.

The assessment framework is aimed at verifying claimed mission performance and adheres, where applicable, to community best practices to an extent that is "fit for purpose". The assessment is divided into two parts: a review of the mission's quality as evidenced by its documentation, and a validation analysis performed by a mission quality assessor. Please note that the following Cal/Val Maturity Matrix can be customized per-domain basis (e.g., new guidelines have been issued, customised for the atmospheric domain) and to being constantly updated to cope with new domains such as RF (Radio Frequency) and AIS (Automatic Identification System).

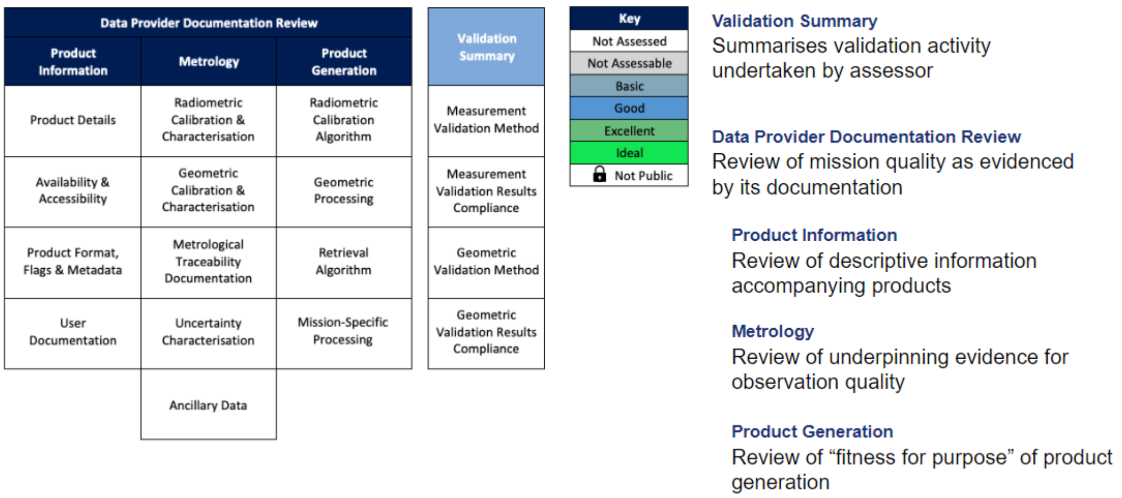

Figure 3: Outline of the ESA/NASA Framework for EO Product Quality Assurance

NASA and ESA are working toward a comprehensive ESA-NASA Evaluation Framework. The ESA Earthnet Data Assessment Project (EDAP) and the NASA Commercial Smallsat Data Acquisition (CSDA) programme are intended to perform quality assessment for various EO missions in the New Space context following the QA4EO principles. The common approach aims to define a mission quality Cal/Val Maturity Matrix, which provides input for quality aspects to the CEOS WGISS Data Management and Stewardship Maturity Matrix. The assessment provides an opportunity to communicate between CEOS Agencies and New Space companies. The Cal/Val Maturity Matrix is done following the EDAP common guidelines and procedures.

5.7. CEOS Engagement with Standards Organisations

CEOS is represented in standards body discussions in an *ad hoc* fashion, mostly through individuals' own representation on behalf of their agency or country. There is currently no mechanism for collective oversight of the status of CEOS engagement with standards processes. CEOS input relies upon individuals raising opportunities via CEOS Working Groups, Virtual Constellations, etc.

While engagement at the working level is certainly the correct approach, consultation with the CEOS community at a 2022 SIT Technical Workshop side meeting found that more coordination and a better understanding of the current engagements that CEOS has with standards organisations would be beneficial to the organisation.

In the past we have seen that a lack of top-level coordination can lead to multiple CEOS groups establishing dialogues with external stakeholders on the same topic yielding the risk that different CEOS groups and member agencies might put forward inconsistent or conflicting opinions. This was the case with the early stages of the OGC Analysis-Ready Data Standards Working Group, where discussions were taking place in both LSI-VC and WGISS, with cross-coordination only later established by the CEOS-ARD Oversight Group. CEOS has since been nominated as a co-chair of the OGC ARD SWG, which will likely be a critical forum for engagement with New Space and for adoption of the concepts behind CEOS-ARD.

At the 2022 CEOS Plenary, it was suggested that CEOS could establish a regular reporting opportunity during the Plenary and/or SIT Technical Workshop meetings to raise awareness and ensure that CEOS agencies are all informed on current relevant standards activities, and that CEOS agencies do not miss out on opportunities to agree on common approaches and jointly contribute to community standards. Standards will impact agencies, so they should be aware of what is happening at the working levels of CEOS to give them an opportunity to engage their experts in the relevant teams and discussions.

Additionally, if CEOS considers the definition of standards to be one of its roles in supporting the New Space sector, additional coordination is necessary. In fact, recently the opposite has been true, with CEOS needing to be reactive to the work of the 'New Space' community with the Spatio-Temporal Access Catalog (STAC) specification.

The STAC provides a community based specification of a catalog, which enables Spatio-Temporal Assets to be findable with a web browser, and spreading to be used not only for satellite data but also other spatio-temporal items as a de facto standard owing to its easiness. However, many extensions have been proposed to make it adjust to a specific use and the specification has started to be scattered. WGISS is now reacting and developing STAC best practices to develop a common specification for STAC focusing on Earth observation data (STAC Items) and services (STAC APIs).

When some specifications like CEOS-ARD, STAC, etc. might be identified as those to be standardized as results of the activities of Analysis Ready Data (9.3.), CEOS

Interoperability Framework (9.4.), Open Data Cube (9.5.), those will be standardized by cooperating with OGC and ISO-TC211.

Data provision of satellite data and services is expected to promote the interoperability of data and exchange between CEOS agencies and New Space.

5.8. CEOS Missions, Instruments & Measurements Database

The overarching objective of the CEOS Missions, Instruments, and Measurements Database is to provide a planning resource for CEOS activities, leadership, and groups. This information on past, current, and planned missions and instruments seeks to provide a shared factual basis for awareness and coordination. The Database is captured in the CEOS Three Year Work Plan (2023-2025 Work Plan) as a 'CEOS Service' supported by ESA and the CEOS SEO.

> *The CEOS Database (a.k.a., the Missions, Instruments and Measurements Database, or MIM) is the only official consolidated statement of CEOS Agency programs and plans. Each year, the database will be updated based on survey inputs provided by all CEOS Agencies to reflect the current status of CEOS Agency missions and instruments. - CEOS 2023-2025 Work Plan*

The Database compiles information on CEOS Agency missions, and information on these missions is displayed on the web portal (database.eohandbook.com). However, for some time now the Database team have been adding records on an *ad hoc* basis describing non-CEOS missions, with that information not appearing in the CEOS Database tables and indexes. This information has been added opportunistically, and also via monitoring of launch activity and NORAD tracking information. There are some challenges in collecting this information, in particular from commercial entities, including:

- missions operated by commercial entities tend to have less publicly open planning processes, often for commercial in confidence reasons;
- the time horizons for non-governmental mission planning tend to be shorter, and based more on launcher availability than longer-lead governmental programs;
- representation of constellation architectures in the CEOS DB will need to be considered and optimised; and,
- there is no consolidated set of contacts for non-CEOS entities to provide inputs to the CEOS Database which impacts the efficiency of information collection.

Despite these limitations, the Database now contains a reasonably good set of information on non-CEOS missions. This information is used to support adjacent resources such as the EO Portal (eoportal.org), and is also used for gap analyses.

In the follow-up to the work of the New Space Task Team (NSTT), CEOS could consider further inclusion of non-CEOS missions in the CEOS Database. This would require clarity around the limitations of the information, but may help contribute to CEOS understanding of the full mission and instrument landscape, provide an aid to planning, and a basis for interaction with the community.

5.9. Combined and harmonised data streams

CEOS agencies are engaging in multiple frameworks and applications where data from New Space company missions are already making a valuable contribution or where companies are positioning themselves to make future contributions. These span the full thematic spectrum of CEOS activities and working teams and reflect the significant diversity in the industrial sector for EO missions in definition and development. Undoubtedly a fair proportion of these missions will never fly, with the availability of space startup funding being reduced very substantially during 2022 and 2023 as interest rates have risen globally and capital-raising has become much more difficult. Yet even a small proportion of the thousands of planned missions from industry would represent a much larger number of missions than those planned by public agencies, which tend to be larger, longer-lasting and better characterised. Some CEOS agencies are already adapting to a world where New Space principles are being applied to their system architectures - featuring more but smaller and shorter-lived missions, developed at less cost. These new architectures have the benefit of quicker deployment, and greater resilience and redundancy; and the disadvantages of more complex data architectures that must deal with inputs from multiple systems and sensors and the challenges of interoperability and standardisation.

These same challenges are at the heart of a future for Earth observation broadly where more providers offering more data sources, with more diversity in approach, quality, characterisation, calibration and validation etc, are engaged in the various thematic sectors in which CEOS agencies operate. A number of CEOS agencies have already recognised the opportunity for the better characterised and longer-lived public systems to be deployed for calibration transfer purposes so that more new space systems can be fit for more purposes and contribute to some of our information challenges with faster coverage, quicker repeat, gap-filling etc.

Even within the pool of public data providers of CEOS, it has proven extremely difficult to attempt to harmonise different datasets from different missions. A dedicated CEOS biomass harmonisation team was established for just this purpose, seeking to reconcile significant differences in what users were being provided for the same parameters from different agencies (JPL, ESA CCI, GEDI etc). The team has decided on a different tack that seeks to promote more consistency in the way in which space agency data sets are communicated to the user, how they are characterised, made available, and the nature of the tools provided. And the same challenges apply to all sectors and all datasets with each new mission and new technology adding to the confusion of the user as to which to use and why.

Generally the issue of pixel mixing of sensor data from a variety of sources will become more important, and the groundwork that CEOS has initiated for many years in standards for Analysis Ready Data will hopefully pay off, such that users can worry less about the provenance of the particular pixels they are mixing for their particular application.

CEOS agencies retain world-leading expertise in the calibration and validation of satellite EO instrumentation and this expertise is needed to help all potential data contributors rise to the common information challenges, be that in relation to detecting methane emissions, or decadal trends in the surface temperature of the land or ocean. There is a need to establish best practices for all aspiring data providers so that new space investments can be intelligently directed and so that all potential contributors can optimise their offering to be fit for purpose. The groundwork of WGCV over the years should help in this regard, as will the Best Practices activity underway between CEOS and IMEO.

6. Conclusion and Recommendations

The determining factor for the New Space economy has been new motivations for entering the space domain. While the logic of public engagement in the space market has historically been linked to issues of security and defence, economic growth, national prestige and benefits at the service of citizens in areas such as environmental monitoring, climate change, etc, the interests of new entrants are driven by business models aimed at profit, which exploit new market niches by striving to offer better services than those of their competitors. Concrete profitable markets entail national security (e.g., VHR, SAR and optical) and contributions to meteorology (e.g., radio-occultation), which are clear cases of Business to Government. Business to Business activities, i.e., purely commercial, are progressively rising (e.g., insurance, oil and gas, etc.) but, alone, have not yet proven to be sufficient to guarantee the enterprise sustainability.

So far, EO New Space's ventures have tended to see stable growth when they have been granted explicit public support. Considering this situation, many New Space EO companies have started to re-structure their businesses with government/public customers in mind. The demand does not appear to be consolidated outside the niches of competence, so it would be necessary to expand the customer base to make it self-sustainable. Until this is achieved, institutional anchor clients will play an essential role in creating the demand to underpin their business models.

In general, it is too early to assess the maturity of the commercial space market for EO and the definition of its priorities are still with public entities. Early-stage start-ups with optimistic business plans requiring significant technology development are already facing challenges with unproven business models, to create new markets and to ensure their customer base. Therefore, not all the current start-ups and early-stage companies may survive. However, the global volume of public and private investments is such that the trend of co-investments and applications is expected to continue, and a natural selection of commercial companies will occur.

This new paradigm is expected to yield medium- to long-term benefits and, in particular, the diversification of technical and industrial responses. It could enable:

- Increased innovation in industrial processes.
- Increased innovation in infrastructure and systems.

- The emergence of new players attracted by less risky market prospects.
- The emergence of new markets for services.

Whilst the responsibility for many of the points outlined in this paper lie with individual Space Agencies, a cooperative effort for CEOS has been identified in areas where the sovereignty interests of individual member countries are unaffected yet where common benefits among the CEOS membership exists. CEOS is the right forum to exchange information and experiences in the satellite EO domain at a global level and, in particular, the approach to foster relationships with commercial entities. Of course, the user should be the ultimate beneficiary of any partnership between CEOS and the New Space sector. New Space, by its very nature, is driven by commercial economics and profit, whilst CEOS seeks to prioritise the public good in its endeavours regardless of financial gain. Even though the overarching priorities are different, there are commonalities in approach, and each can find ways to support the other. Indeed, collaborative initiatives between the commercial and public EO sectors have been going on for many years already. What is different now is the rapid recent expansion of the New Space sector and CEOS should consider its position as a supporting friend, collaborative partner, and potential customer.

In line with the CEOS mission, CEOS has a supporting role to play within the commercial EO community as the long-established community-led international forum for all civil space-based EO matters. CEOS has a long history of developing common methodologies and best practices for EO data acquisition, handling and use, and this has always been of relevance to both public and commercially funded missions. This role will continue with a specific reliance on the expertise and the activities of the CEOS entities. The CEOS Working Group on Calibration and Validation (WGCV) provides calibration and validation procedural advice and references, and facilitates the sharing of ground truth data for commercial data evaluation alongside their well-established support to publicly-funded missions. The CEOS Working Group on Information Systems and Services (WGISS) provides an expert advisory role for all matters pertaining to the development of systems and services that manage and supply EO data. The CEOS Working Group on Capacity Development and Data Democracy (WGCapD) focuses and unifies CEOS efforts toward providing wider and easier access to EO data, increasing the sharing of software tools such as the use of open-source software and open systems interface, increasing data dissemination capabilities, transferring relevant technologies to end users, and providing intensive capacity building, education, and training. This is of potential huge support to an emerging and rapidly expanding industry in New Space. These three CEOS entities are key to our engagement in New Space, but they do not act alone, the rapidly expanding magnitude and reach of the commercial sector and their interests also touch many if not all CEOS entities and CEOS activities in some way.

New Space is going to be an important component for the future EO ecosystem. As shown in previous sections of this paper, the commercial sector can bring new and innovative satellite data and EO-derived solutions in a cost-effective manner that fills current gaps in observations, but their role goes much further than this. The added value of New Space companies to CEOS translates into improved information and services to society, which is entirely aligned to CEOS priorities and mission.

Industry is a key player in EO and CEOS should listen to its voice. It is CEOS's responsibility to:

- act as an observer as New Space evolves within the various national ecosystems.
- be a catalyst and create homogeneity across the CEOS entities for the commercial industry
- address specific methodological tools to assess the data and the service quality, including cal/val and ARD
- address methods to assess the quality of constellation data as a whole rather than for individual satellites for emerging areas (e.g. hyperspectral and high-resolution).
- provide intercomparison opportunities for CEOS and New Space datasets.

CEOS, both as a collective and as individual agencies, should continue to engage with commercial EO companies and industries where appropriate and where priorities align. Together with partners in EO such as the Group on Earth Observations (GEO, who regularly host an industry track at their annual Plenary meeting) and others, CEOS can more effectively engage with EO industries at a corporate level. As individual CEOS Members and Associates, country properties often drive action to support the commercial sector, so CEOS needs to remain mindful of these aspects as it moves forwards.

It is recommended that the work of the New Space Task Team (NSTT), who brought together this body of work, has completed its task and there are no new activities foreseen in the immediate term that warrants its continuation beyond its one-year remit. The NSTT has very effectively brought Members and Associates together for active and fruitful discussion and information sharing, the results of which are outlined in this paper. These active discussions will guide CEOS as it moves forward on this important topic. Whilst the need for the continuation of a dedicated Task Team is not foreseen beyond the end of 2023, CEOS should act upon the recommendations highlighted in this paper. Specifically, that CEOS entities should maintain a watching brief on the progress of New Space within their realm of expertise and should use the CEOS Secretariat telecons, CEOS Strategic Implementation Team and Technical Workshop meetings, and the annual CEOS Plenary sessions to bring any issues of potential collaborative benefit to the attention of CEOS Principals. Complimentary to this, individual Members and Associates are encouraged to use CEOS as a forum for discussion and information sharing where appropriate in the spirit of CEOS's principles of openness and collaboration.

Appendix A - Recommendations to CEOS Plenary

	Recommendation	Responsible Group
R1	In view of augmenting the scientific and operational potential of long-term, institutional programmes, CEOS Members and Associates should act collectively in **using the CEOS mechanisms to identify and support potential complementary capabilities enabled by New Space and other commercial actors**.	All CEOS Members and Associates
R2	CEOS Members and Associates should strive to continue to **share information on relevant events and activities related to New Space**, including commercial data evaluation results when possible. CEOS Agencies should also investigate ways to work together on cooperation agreements with New Space actors possibly including common lines to take on end-user licence agreements and IPR issues.	All CEOS Members and Associates
R3	Cooperation and collaboration opportunities should be sought with to **facilitate interoperability between private and public sector data** and future CEOS SIT Chairs are encouraged to routinely provide the opportunity for CEOS Members and Associates to report on developments in the standards domain, be they from public or private sources, at future SIT Technical Workshops.	SIT Chair

Appendix B - Recommended Deliverables for inclusion in the CEOS Work Plan

	Recommended Deliverable	Responsible Group
D1	To ensure users can benefit from increased complementarity and interoperability of CEOS Agency and New Space datasets, the **CEOS-ARD initiative should identify and implement mechanisms to deepen engagement with the New Space sector,** consistent with CEOS Governing Documents. Examples include establishing a mechanism to consult the New Space sector during the development and review of CEOS-ARD Product Family Specifications (PFS), encouraging commercial sector participation in the ISO-AGC ARD Standards Working Group, and encouraging and assisting New Space entities to undertake self-assessments of their datasets against CEOS-ARD PFSs.	CEOS-ARD Oversight Group and Virtual Constellations
D2	CEOS Members and Associates should continue unified engagement with New Space actors on key topics such as ARD, Cal/Val and data quality via **CEOS representation at key meetings** including VH-RODA, JACIE, IGARSS, Living Planet Symposium and ARD2x.	CEOS-ARD Oversight Group, WGCV, WGISS
D3	A **revision of CEOS-ARD Industry Engagement Strategy** should include consideration of aspects of specific relevance to the New Space sector, and the CEOS-ARD Oversight Group should consider the merits of organising a dedicated New Space workshop.	CEOS-ARD Oversight Group
D4	The CEOS Interoperability Roadmap will **ensure that legacy and new public and commercial datasets can be used more interoperably** to generate advanced decision-support products and new research applications. As such, adequate resources should be made available to complete its development and maturation.	WGISS
D5	The CEOS Systems Engineering Office should **demonstrate the integration of New Space data into the CEOS Analytics Lab** and evaluate its interoperability with common CEOS datasets..	CEOS Systems Engineering Office (SEO)

Appendix C - Task Team Membership

Members of the task team are listed below.

Name	Affiliation
Adan Salazar	AEM
Alexis Sarraute	ESA, SIT Chair Team
Andreia Siqueira	Geoscience Australia, LSI-VC Co-Lead
Antonio Ciccolella	ESA, SIT Chair Team
Astrid-Christina Koch	European Commission
Atipat Wattanuntachai	GISTDA
Aurelien Sacotte	CNES
Beth Greenaway	UKSA
Catharina Bamps	European Commission
Charles Wooldridge	NOAA
Chris Kidd	NASA, P-VC Co-Lead
Cody Anderson	USGS, WGCV Vice Chair
David Borges	NASA, SEO
Eleni Paliouras	ESA, SIT Chair Team
Eric Laliberte	CSA
Frederick Policelli	NASA
George Dyke	SIT Chair Team
Heikki Pohjola	WMO
Helene Deboissezon	CNES, WGDisasters Chair
Hugo Costa	PT Space
Ivan Petiteville	ESA, SIT Chair Team
Jeff Privette	NOAA, WGClimate Chair
Joan Alabart	PT Space
John Moores	CSA
Joost Carpay	NSO
Jorge Del Rio Vera	UNOOSA, WGCapD Chair
Kelly Turner	NOAA
Laura Frulla	CONAE, WGDisasters Vice Chair
Libby Rose	SIT Chair Team
Makoto Natsuisaka	JAXA, WGISS Chair
Marc Beaudry	CSIRO
Marie-Claire Greening	ESA, CEOS Executive Officer

Matt Steventon	SIT Chair Team
Michael Nyenhuis	DLR
Paolo Castracane	ESA, WGCV Chair Team
Paul Counet	EUMETSAT
Philippe Goryl	ESA, WGCV Chair
Riza Singh	SIT Chair Team
Satoshi Uenuma	JAXA
Stephen Briggs	SIT Chair Team
Stephen Ward	SIT Chair Team
Steven Labhan	USGS, LSI-VC Co-Lead
Tom Sohre	USGS, WGISS Vice Chair
Yuko Nakamura	JAXA

Appendix D - Further details on Cal/Val References

D.1. RadCalNet

RadCalNet is a CEOS WGCV initiative. RadCalNet is a network of test sites providing, via a common portal, Top Of Atmosphere @ Nadir references with uncertainties in the range of 400 - 2500 nm (10 nm bands) every 30 mins. Test sites have to demonstrate their traceability and uncertainties. RadCalNet processing provides uncertainties for each data point. Several well characterised sensors were used to evaluate RadCalNet sites. SI-traceability allows users to combine data from multiple sites with confidence. There are a large number of possible calibrations that allow evaluation of temporal changes. RadCalNet provides fiducial reference measurements. As of March 2023, the network is composed of five sites and is being extended to seven sites.

D.2. Land Product Validation (LPV) Supersites

CEOS WGCV LPV subgroup has defined sites which are referred to as LPV Supersites. These sites: Follow well-established protocols useful for the validation of satellite land products (at least three types) and for radiative transfer modelling approaches. Have active, long-term operations supported by appropriate funding and infrastructural capacity. Are supported by airborne LiDAR and hyperspectral acquisitions (desirable). Were selected primarily from well known and established networks, and several were nominated by each LPV focus area team, and then all sites were evaluated for their suitability by ranking them first based on the availability of data (active site) and their spatial representation. After this, the variables were ranked based on the number of key variables that could be validated with a given site, whether structural information was available, and if atmospheric and other properties were measured.

There is an ongoing joint CEOS WGCV IVOS/LPV activity on the two rapidly growing domains, LST and Hyperspectral. This is a relevant activity for New Space. Additionally, Hypernet – a network of hyperspectral equipment that will facilitate the cal/val of hyperspectral instruments.

D.3. SARCalnet

There is a demand for well-defined calibration targets for SAR instruments. Fixed targets are used to calibrate data from SAR missions. Traditionally these targets have been defined differently for each SAR mission. There are three main categories of targets

- Natural Targets,
- Artificial Passive Targets, and
- Artificial Active Targets.

The CEOS WGCV SAR subgroup is currently in the early stages of formulating SARCalnet - an established network of calibration sites that would ease mission calibration and facilitate collaboration between sensors by offering a network of consistent and open calibration references.

D.4. Thermal InfraRed Calibration Network (TIRCALNET)

The objective of TIRCALNET is to provide ToA spectra for thermal infrared calibration/validation as an automated network. There are uncertainties arising from challenges related to site heterogeneity and emissivity estimates, with instrument radiometric uncertainty being less significant. The network requirement is to provide a spectrally sampled brightness temperature at ToA to 0.5K (or ToA radiance).

The main customers/users for a ToA service are the space agencies including but not limited to NASA, ESA and CNES with their higher resolution future TIR missions, but also for commercial missions in the TIR domain that are being planned. In any case, the requirements being planned by space agencies should also be more than sufficient for commercial missions.

D.5. GHG Sensor Calibration

CEOS WGCV provides a methodology of vicarious calibration for various size footprint and off-nadir GHG data as well 14-year annual joint campaign data for cal/val including surface albedo, radiosonde data, XCO2, CH4 by EM27-FTS, and alpha jet vertical profiles. Datasets for analysis include solar irradiance and molecule cross sections. In addition, analytical results from various types of spectrometers: GOSAT FTS, OCO and S5P TROPOMI are also available.

D.6. Pseudo-Invariant Calibration Site (PICS)

Terrestrial sites used to monitor the long term in-flight radiometric calibration of Earth Observation optical sensors. They have been used intensively by space agencies and New Space for a long time as they are spatially uniform, spectrally stable and invariant with time. A long list of these sites has been identified. They are mostly located in the Sahara desert and Arabian Peninsula. Among these sites, six have been endorsed by CEOS as standard reference sites for the post-launch calibration of space-based optical imaging sensors. Other methods include the use of Deep Convective Clouds or Rayleigh scattering as a standard approach. CEOS WGCV and LPV (Land Product Validation) provide a set of protocols to correctly validate geo-physical and bio-physical products, e.g., Global Surface Albedo Product Validation Best Practices Protocol and the LAI / FAPAR protocols.

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Section 5.2.1

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