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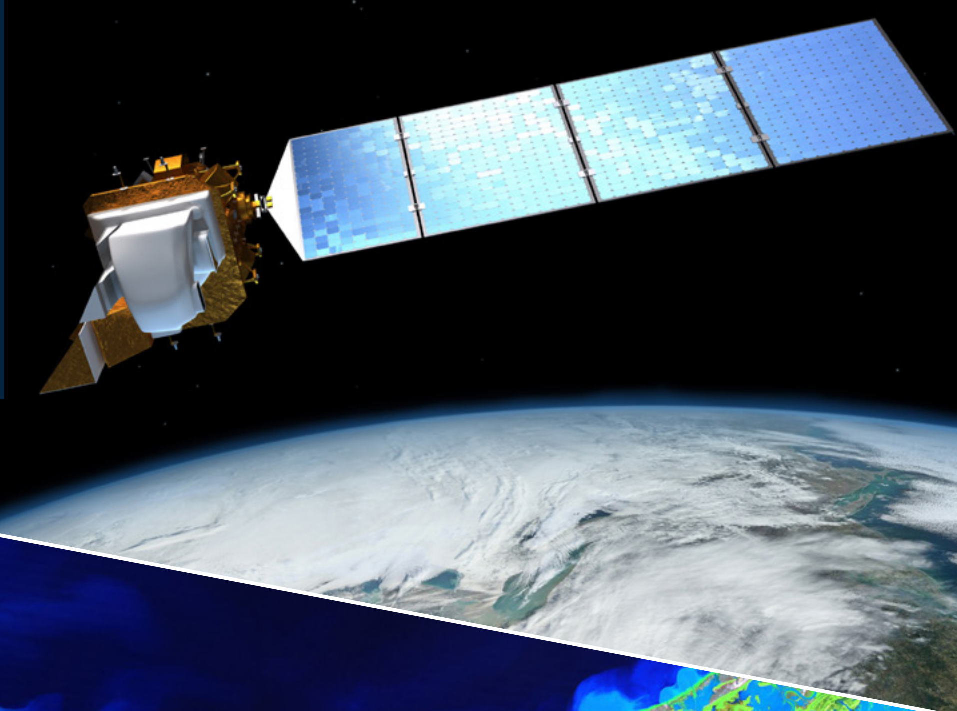
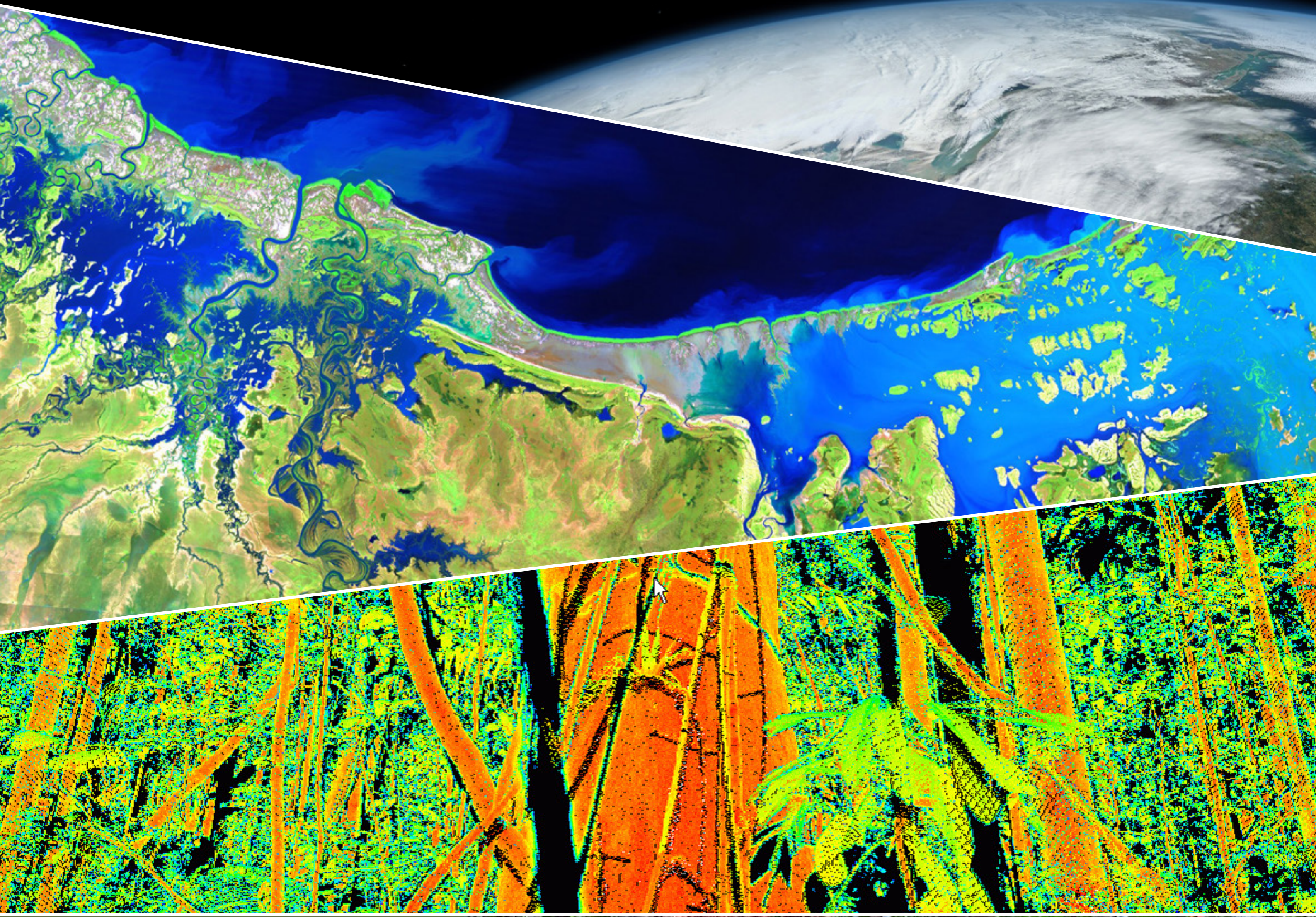
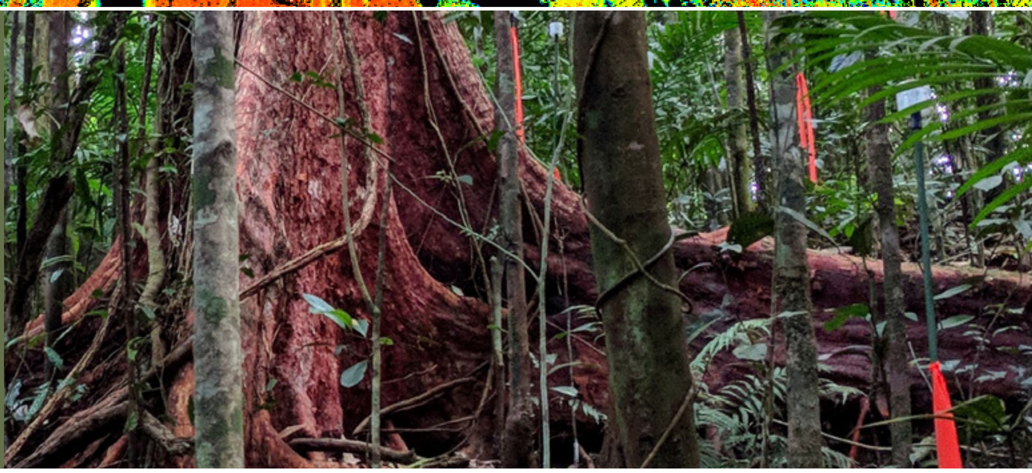
ESTABLISHING AUSTRALIA AS A GLOBAL LEADER IN DELIVERING QUALITY ASSURED SATELLITE EARTH OBSERVATION DATA







AN INITIATIVE OF THE AUSTRALIAN EARTH OBSERVATION COMMUNITY
27 MAY 2021

EOA Earth Observation Australia

FRONTIER SI

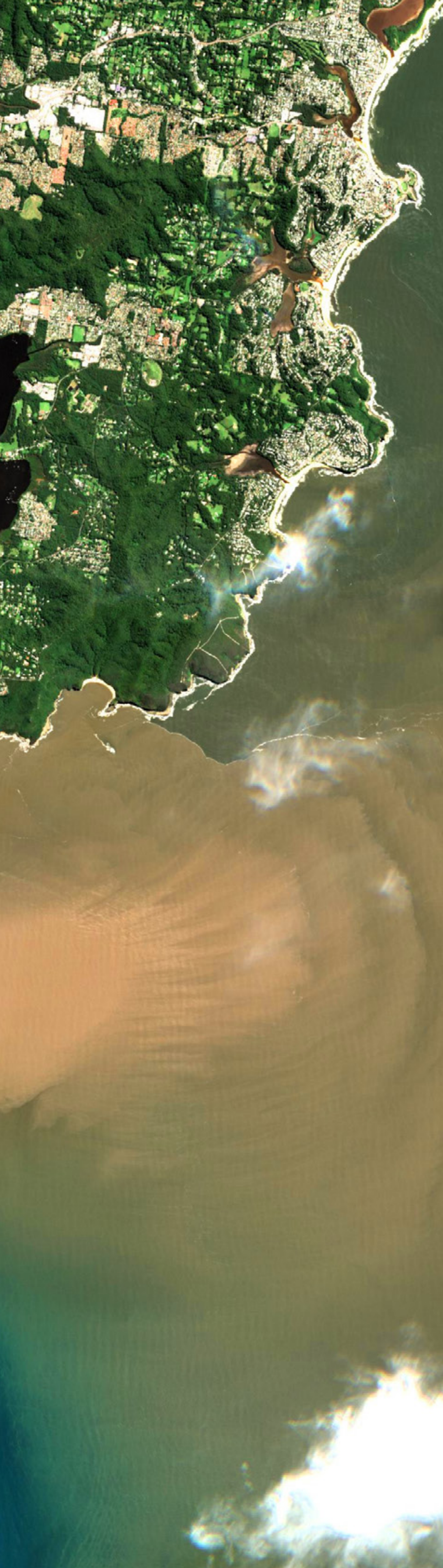
SMARTSAT Cooperative Research Centre

This report was commissioned by Geoscience Australia in consultation with the Australian Space Agency, Bureau of Meteorology, and CSIRO. The report forms part of a series of studies undertaken in support of the development of the Australian Space Agency's Earth Observations from Space Technology Roadmap. The contents of the report do not represent the position of the Australian Government.

Image (Cover - top to bottom):

1. Landsat 8 [Image: U.S. Geological Survey]
2. Landsat 8 false colour image of flooding in the Gulf of Carpentaria captured on unknown date. [Image: Produced from remote sensing data by the U.S. Geological Survey, processed by Digital Earth Australia, Geoscience Australia]
3. Terrestrial LiDAR Robson Rainforest TERN Supersite. Provided by TERN. [Image: Peter Scarth]
4. Robson Rainforest TERN Supersite. Provided by TERN. [Image: Joint Remote Sensing Research Program]

Image (this page):
Sentinel-2A image from 25/03/2021. True colour view of sediment emerging from the Hawkesbury River during the NSW Floods. Produced from remote sensing data by the European Commission, processed by Digital Earth Australia, Geoscience Australia.



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EXECUTIVE SUMMARY

- Satellite Earth observations and other forms of remote sensing contribute over $5 billion annually to Australian GDP and $543 billion to APEC economies, and provide essential data to sectors representing approximately 75% of global GDP.

- Satellite data are critical for the basic functions of the Bureau of Meteorology. Around 95% of the observations used in weather, hydrological and ocean models come from about 30 international satellites, providing the foundation for all the services delivered by the Bureau, including services to defence, aviation, agriculture sectors and the public. The quality and accuracy of these services relies on satellite data of the highest quality possible.

- Australia's Earth observation application development capabilities are widely regarded as among the best in the world. Our reputation for scientific excellence, decades of experience and advantageous geographic location, along with the availability of in-country infrastructure, mean that Australia is poised to become a global focus for the quality assurance of satellite Earth observation data.

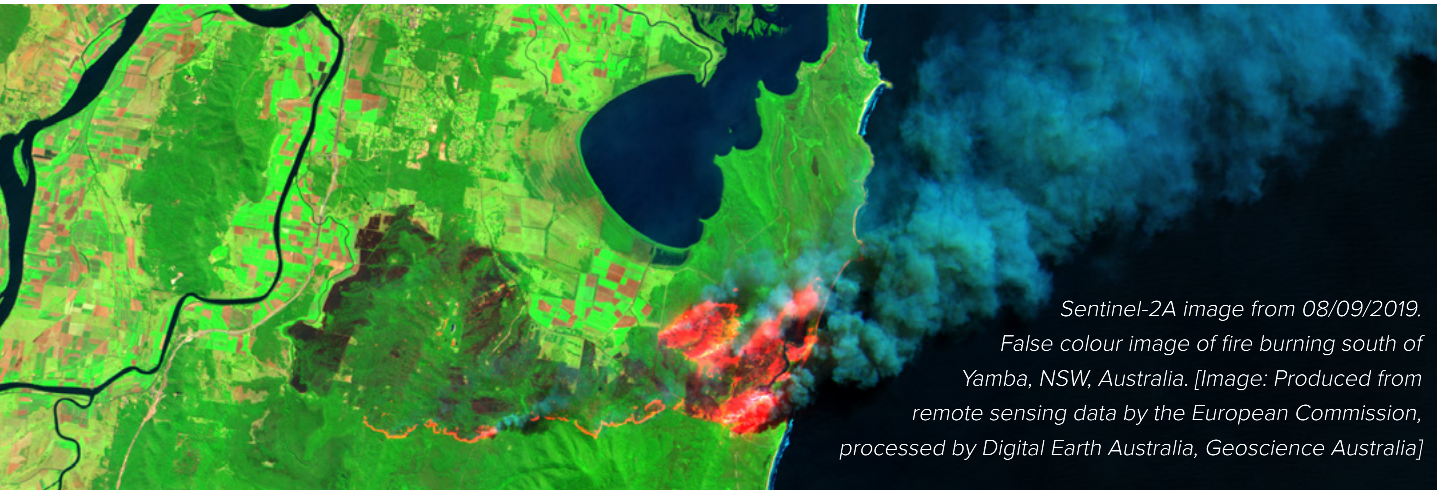
- Quality assurance is essential for satellite operators to produce information to demonstrate their data are fit for use. This builds trust, increases user confidence in the accuracy and reliability of satellite Earth observations, improves weather forecasts, and can drive growth in the global market for spatial information.

- Uplift of Australia's quality assurance infrastructure and capability is required to transition from research to operational capability. Additional investment is required to provide consistent and assured coverage, adequate maintenance, development of skilled personnel and research and private sector opportunities for Government led operational infrastructure.

- A national quality assurance capability for satellite Earth observation instruments and their data is proposed: The Australian Centre for Earth observation Quality Assurance (ACE-QA). The Centre would leverage existing quality assurance infrastructure and bring online new capabilities under one umbrella, providing a centralised access point to grow the Australian satellite Earth observation industry.

- To augment ground-based quality assurance infrastructure, development of a continuous series of *Australian Satellite Cross-Calibration Radiometers* (*SCRs*) should be undertaken. This space-based infrastructure would increase data accuracy and support Australia's international supply relationships, ensuring the long-term supply of critical Earth observation data streams for Australian programs.

- Investing in our sovereign capability through enhanced quality assurance infrastructure and development of a national smallsat program would help build trust in Earth observation data, mitigate long-term Earth observation data supply risks, bolster our growing space sector, and create new job and skill opportunities for all Australians.



Sentinel-2A image from 08/09/2019. False colour image of fire burning south of Yamba, NSW, Australia. [Image: Produced from remote sensing data by the European Commission, processed by Digital Earth Australia, Geoscience Australia]

KEY OPPORTUNITIES

Investment is required to uplift Australian calibration and validation infrastructure and capability to support Australia in becoming a global leader in testing and quality assurance for domestic and foreign satellite earth observation missions, accelerate the growth of the Australian space sector, and create opportunity and resilience for the nation.

To enable Australia to become the leading international provider of quality assurance services for Earth observation satellites and data, the key opportunities are:

1. **Creation of a national capability** (Australian Centre for Earth Observation Quality Assurance (ACE-QA) enabling Australian and International Government, research and industry to perform coordinated quality assurance of Earth observation satellite data and imagery. This facility would leverage existing NCRIS, ASA, CSIRO, GA, BOM, University, industry and Government activities and infrastructure to bring them together under one umbrella.

2. **Coordination of quality assurance infrastructure**, maintenance and research, across Government, research and industry to enable Australia's position as a world-leading provider of modern manufacturing and highly skilled technology services

3. **Provision of the quality assurance infrastructure and quality indicator certification** services required to support advanced satellite Earth observation capabilities for decision-making and resilience across agriculture, extractive industries, defence, environment, and in response to natural disasters.

4. **Creation of a centralised point of access** to data provenance tools for industry and researchers to create new services and products ensuring transparency and traceability of satellite Earth observation data and derived products.

5. **Deployment of a series of Satellite Cross-Calibration Radiometers** to improve accuracy and consistency between optical satellites.

These objectives are designed to:

- Increase international private and Government sector investment in Australia;
- Grow the Australian economy through innovation and entrepreneurship across construction, technology and scientific opportunities;
- Leverage existing investment to promote a sustainable growth model for a new pathway in the Australian space industry;
- Develop infrastructure, research and commercial expertise that can be leveraged to add additional value in other domains and industries;
- Access new Earth observation data that would provide a step change to information production that is relevant for managing Australia's climate, environment and resources;
- Service the multitude of emerging small/micro/mini satellites, particularly from the private sector, that do not have access to pre-flight and/or on-board calibration;
- Enhance Australia's Earth observation satellite development; and,
- Demonstrate Australia's commitment to its international partners by investing in the provision and quality assurance of high value satellite Earth observation data products.

TABLE OF ACRONYMS

Acronym	Definition
ACE-QA	Australian Centre for Earth Observation Quality Assurance
Aeronet	NASA's AErosol RObotic NETwork
ANCDF	Australian National Concurrent Design Facility
API	Application Programming Interface
ASA	Australian Space Agency
BOM	Bureau of Meteorology
CARD4L	CEOS Analysis Ready Data for Land
CEOS	Committee on Earth Observation Satellites
CfAT	Centre for Appropriate Technology
COTS	Commercial Off The Shelf
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EOA	Earth Observation Australia
ESA	European Space Agency
FRM4VEG	Fiducial Reference Measurements for Vegetation
FRP	CEOS Fire Radiative Power network
GA	Geoscience Australia
GNSS	Global Navigation Satellite System
IMOS	Integrated Marine Observing System
IVOS	CEOS Infrared and Visible Optical Sensors subgroup
LPV	CEOS Land Product Validation subgroup
LTER	Long Term Ecological Research Network
MTF	Modulation Transfer Function
NASA	National Aeronautics and Space Administration
NCRIS	National Collaborative Research Infrastructure Strategy
RadCalNet	Radiometric Calibration Network
SNR	Signal-to-Noise Ratio
SIAA	Space Industry Association Australia
SWOT	Surface Water Ocean Topography
TERN	Terrestrial Ecosystem Research Network
TOA	Top-of-Atmosphere
UNSW	University of New South Wales
USGS	United States Geological Survey
VSSEC	Victorian Space Science Education Centre
WGCV	CEOS Working Group on Calibration & Validation
WMO	World Meteorological Organisation

THE AUSTRALIAN CENTRE FOR EARTH OBSERVATION QUALITY ASSURANCE

CONTEXT

GLOBAL OPPORTUNITY

Each day thousands of satellites circle the Earth, collecting data and images depicting the impact of natural and human activities in the atmosphere, on the ground, and in the oceans. These data are critical to inform decision making for **government** (e.g., weather, disasters, food security, natural resource management, planning), **industry** (e.g., operations, mining, and exploration), and **national security**, either through the direct use of satellite products or the analysis of weather forecasts assimilating satellite observations. To establish trust and to optimise their impact on decision making, satellite Earth observations, need to be consistent, of high quality, reliable, and repeatable over time.

Trust and quality assurance underpin a high functioning Earth observation sector and are essential to industry, government, and national security programs.

Earth observation contributes over $5 billion annually to Australia's GDP[1] through applications in industries as diverse as weather prediction, agricultural production, mining and extractive technologies, financial services, infrastructure development, and environmental monitoring. In 2020, a report commissioned by the Australian Government[2] found that combined Earth and marine observing is currently worth $29 billion to the Australian economy and $543 billion to APEC economies each year. The 2020 report also suggests that with effective investment in national Earth observation infrastructure and capability, the value of Earth observation to Australia could increase by more than three times to $96 billion by 2030.

In order to fully realise these benefits, users must be able to trust the accuracy of the data and information provided by satellite Earth observations. Data quality assurance is therefore of significant interest to satellite operators, application developers and end users, particularly in the rapidly developing commercial small satellite sector.

Both internationally and domestically, there has been an explosion in the number of satellites launched and slated for launch over the coming years – driven by smallsats (500kg or less) and constellations of 10's to 100's of satellites launched by a broad range of companies from start-ups to established data providers, and national governments. For quality assurance, these small, low-cost platforms tend to rely on high quality 'gold standard' government backed satellites and quality assurance services and infrastructure. Australian quality assurance infrastructure requires further investment and coordination, such as proposed in this report, to meet smallsat operational needs.

AUSTRALIAN SOLUTION

Australia's southern position and unique and diverse range of environments make it ideal for the quality assurance of data from international and domestic satellite Earth observation missions. These environments include arid and semi-arid biomes, large cropping areas, forests and tropical rainforests, coastal and aquatic areas, alpine regions, vast tracts of ocean, and via Antarctic facilities, access to polar environments, glaciers, and ice sheets. Quality assurance infrastructure in Australia across these different environments is relied on by the international community for the calibration and validation of satellite earth observation sensors, data and products in the southern hemisphere. The quality of weather forecasts is also highly dependent on the assimilation of satellite observations in the Southern hemisphere, given the scarcity of land masses to collect ground observations. Australia has a collection of existing facilities based both on our technical heritage and a distributed and diverse range of government, industrial, and academic efforts. However, to build a modern world-class service

1 *2015. The Value of Earth Observations from Space to Australia. ACIL Allen Consulting Pty. Ltd.*
2 *2020. Current and future value of earth and marine observing to the Asia-Pacific region. Nous Group for the Australian Government.*

offering, investment to lift these facilities on to an operational footing is required.

These investments can complement broader investment in advanced manufacturing capability, supporting return on that investment by building a service offering new facilities. In addition, this investment can support ambitions for Australian industry, government, and the defence sector to build its own satellite missions.

This presents a potentially lucrative opportunity to create a new space-based industry that attracts investment in onshore facilities and services from international satellite owners and builders. These advantages and existing infrastructure, coupled with Australia's reputation for scientific excellence mean Australia is perfectly poised to become a calibration and validation focus and growth centre for global satellite Earth observation sensors and their data.

This report outlines quality assurance requirements from across the Australian space sector and highlights key areas in which Australia can capitalise on the opportunity to become a world-leading provider of Earth observation services, while delivering substantial benefits to the economy and people of Australia. It proposes investment to uplift Australian calibration and validation infrastructure and capability, and the establishment of a new coordinating mechanism, the *Australian Centre for Earth observation Quality Assurance* (*ACE-QA*).

The proposed Centre would transform access to data quality and provenance information through a consolidated suite of cloud computing based services, allowing harmonised and rapid access via a single entry point. It would leverage existing quality assurance infrastructure from BOM, NCRIS (TERN, IMOS, Auscope), CSIRO, GA, universities, and state and federal government using one operational model to increase interactions between groups. This would support planned upstream missions across government, research, and industry, as well as enable a suite of opportunities in downstream application for the private sector to leverage as a new Australian industry.

The Centre would act to co-ordinate, maintain and grow the quality assurance capabilities of Australia. In addition, it would provide access to infrastructure and services, and the necessary skilled personnel. Additional investment targeting quality assurance of satellite Earth observation sensors and data, would enable satellite operators to calibrate their earth observing sensors post-launch, and verify the fidelity and quality of their data products, optimise their performance, and increase trust in the accuracy and reliability of Earth observation. By enabling operators of satellite earth observing systems to perform quality assurance, along with the industries that transform data from these sensors into information products and services, this would drive growth in the global market for spatial information.

IMPACTS AND OUTCOMES

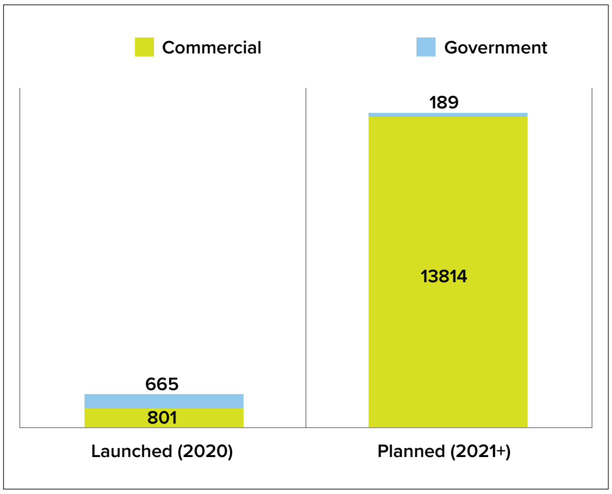
Existing and proposed ACE-QA facilities are already distributed across the country. Increased activity at these facilities, as well as the establishment of proposed new facilities, would add new jobs in a range of sectors from construction through to highly paid technical roles in rural and remote areas. Investing in Earth observation satellite ground infrastructure would benefit the economy and demonstrate the benefits of science and advanced manufacturing as a pillar of the Government's National Economic Recovery Plan from the COVID recession. Investment in quality assurance would support major scientific breakthroughs for Australia's manufacturing and commodity sectors, paving the way for them to lead the world in resilience and production.

Investing in satellite Earth observation data quality assurance infrastructure provides the means to increase the accuracy and fidelity of satellite data, grow the market for satellite data and information products, and open new and trusted information sources for Australian governments and industry. Investment in quality assurance infrastructure would also contribute to Australia's data security, ensuring that critical data streams of Earth observation remain open and available.

Having no Earth observing satellites of its own, Australia relies on partnerships with international satellite operators and space agencies to meet its Earth observation needs. Partners such as the United States Geological Survey (USGS), National Aeronautics and Space Administration (NASA) and European Space Agency (ESA) operate satellites providing essential data to sectors representing approximately 75% of global GDP[3]. Furthermore, around 70% of the Bureau's forecast accuracy can be attributed to the use of satellite data from these partners. Important partners in our region such as the Japan Meteorological Agency and the Korea Meteorological Administration provide essential real time data for bushfires and other high impact weather events, and JAXA provides data for monitoring sea surface temperatures. These global partnerships are built on a foundation of bi- and multi-lateral agreements, and a long-standing practice of collaboration. Quality assurance infrastructure and data provision by Australia, would underscore our commitment to these partnerships,

Number of launched and planned satellites

and is a key link in the international Earth observation satellite pipeline.



The number of launched and planned commercial[4] and government[5] satellites for earth observation (commercial numbers include earth observation, SAR, weather and radio frequency monitoring)

ALIGNMENT WITH CONCURRENT INITIATIVES

The Australian Government Satellite Earth Observation Roadmap is currently being developed by the Australian Space Agency (ASA), the Bureau of Meteorology (BoM), CSIRO, the Department of Defence and Geoscience Australia (GA), in close partnership with the Australian Earth observation community. A series of complementary reports are published or planned, to explain the critical components required to be in place for the Australian Earth Observation Roadmap to succeed.

This report covers the quality assurance facilities, infrastructure and governance arrangements required to ensure the success of Earth observation missions for government, research, commercial, and restricted Defence missions. It complements the Australian Government's Modern Manufacturing Initiative and the broader drive toward Industry 4.0. The quality assurance requirements encompass needs from across the Australian space sector, with this report being built on a public consultation process led by Earth Observation Australia, FrontierSI, Smartsat CRC and Symbios Communications.

Additional reports on the design requirements for Australia's first national Earth observation satellites are to be published by the University of New South Wales (UNSW) Canberra Space's Australian National Concurrent Design Facility (ANCDF).

A study into an Australian continuous launch program for small Earth observation satellite exploring the economic impact of inaction and action is also planned.

In addition, the SmartSat Cooperative Research Centre (CRC) is undertaking a scoping study to understand private space sector requirements for quality assurance for Earth observation satellites.

3 2016. The Economic Impact of Geospatial Services. Alpha Beta Strategy & Economics.
4 2021. Kulu, E. NewSpace Index. NewSpace Index https://www.newspace.im/
5 2020. Symbios. CEOS Missions, Instruments, Measurements and Datasets. The CEOS Database http://database.eohandbook.com/about.aspx

WHY IS QUALITY ASSURANCE FOR SATELLITE EARTH OBSERVATION IMPORTANT?

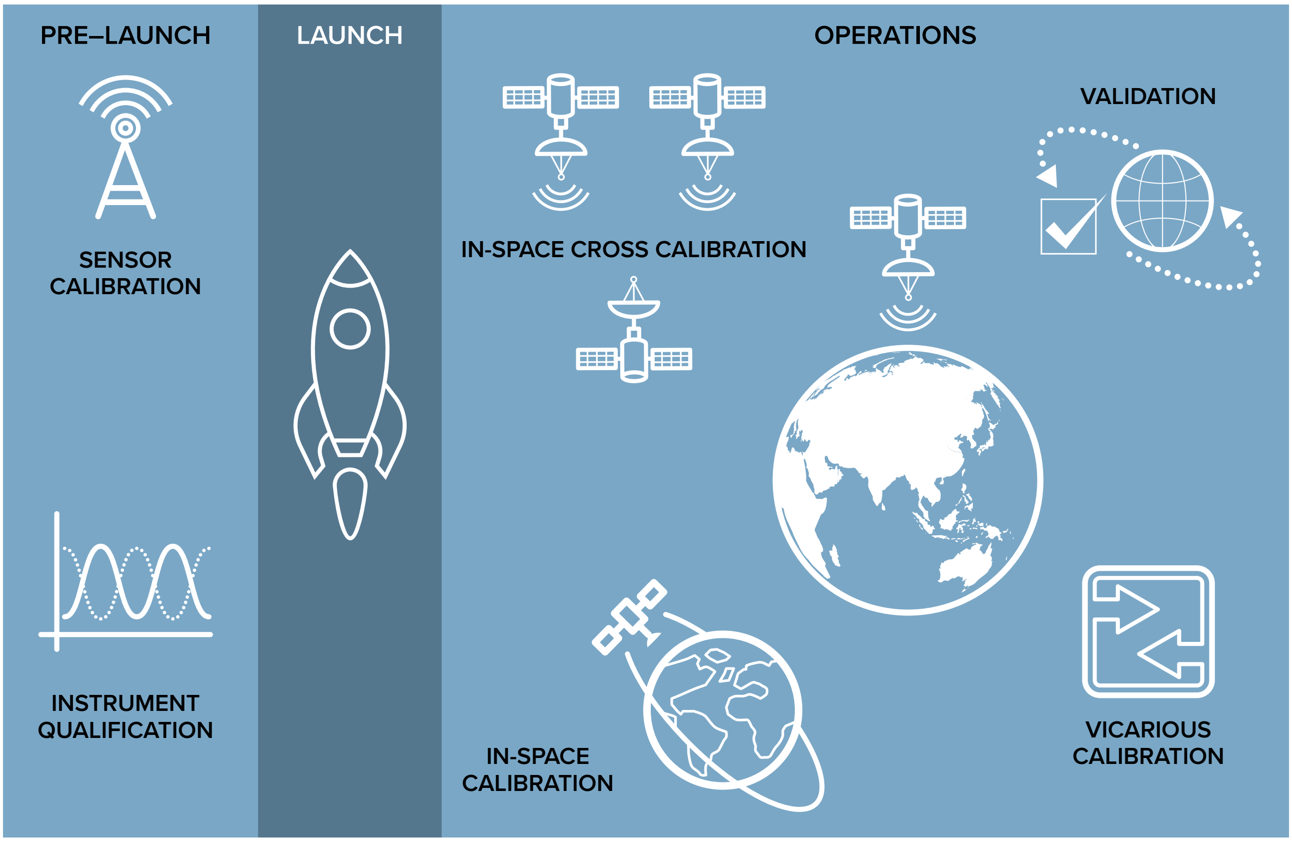
The process of quality assurance can be thought of as similar to a financial audit process or quality control on a production line. It provides a check on satellite instrument performance and the resulting data quality. It is particularly important in enabling comparability over long historical records (time-series) that increasingly rely on information from multiple satellites from multiple countries and providers. With proper quality assurance, the value of time-series data can be seen in applications such as the production of weather forecasts, the long-term monitoring of land use, agricultural productivity, wetland health, and water availability. Without appropriate quality assurance, uptake of applications and trust in decisions based on Earth observation satellite data may be eroded or lead to sub-optimal outcomes[6].

Quality assurance is required at all stages of an Earth observation satellite's development, from pre-launch to end of life, and should be viewed as two separate processes: instrument **calibration** pre-launch and during operations (post-launch), and **product validation**.

Pre-Launch is the period during which the satellite and its instruments are being built, tested, assembled, and integrated onto the spacecraft on the ground. During pre-launch there are two key instrument quality assurance functions that are required.

Instrument qualification includes testing, evaluation, and hardening of the instrument for the space environment. For example, putting the instrument in a thermal-vacuum chamber to ensure it can maintain its performance in the harsh environment of space, or exposing the instrument to significant vibrations to ensure it can survive launch.

QUALITY ASSURANCE FOR EARTH OBSERVATION SATELLITES



6 2018. Ernst & Young. *Assurance in the age of AI. https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/digital/ey-assurance-in-the-age-of-ai.pdf*

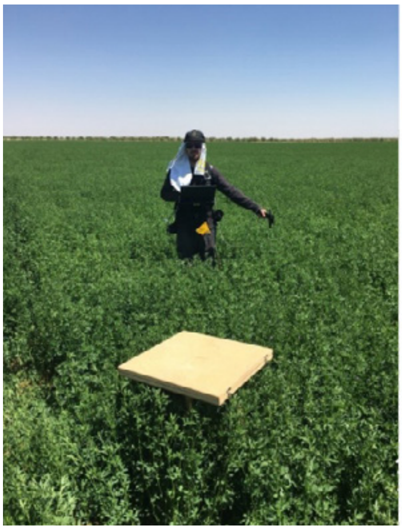
Sensor calibration is the process of quantitatively defining an instrument's response to known and controlled signal inputs under laboratory conditions to characterise its performance. For example, testing the red, green and blue bands of the instrument against known samples of these colours to characterise the observations of the instrument.

Operations (post-launch) is the period during which the satellite and its instruments are in space collecting and downlinking measurements and observations.

In-space calibration is checking a satellite instrument's measurements against input signals from a known reference. This includes both *calibration* by imaging purpose-built targets such as well characterised coloured shapes painted on the surface or a structure (for optical instruments), or a corner reflector with precisely known location, size and geometry (for radar instruments). *In space calibration* also commonly includes *vicarious calibration* which makes use of natural or artificial sites. For example, for optical instruments a dry salt lake (bright) or a deep body of water (dark). It is essential that these calibration targets remain consistent over time as they need to be observed repeatedly from space to characterise changes in the instrument as it ages. (e.g. stability, noise, performance) For all calibration sites, periodic in-place observations are required to ensure this consistency and for comparison.

In-space cross calibration involves the collection of images over *calibration* or *vicarious calibration* sites by multiple satellite instruments at a very close time interval (e.g. minutes to hours) to enable cross-comparison. For example, the *Satellite Cross-Calibration Radiometer* (*SCR*) study mission would aim to collect coincident observations with the likes

Aboriginal Australian and Native American artwork adorn two satellite dishes at a Landsat International Cooperator Ground Station in Alice Springs, Austalia. [Image: Provided by Geoscience Australia] of Landsat, Sentinel-2, and commercial Earth observation satellites, providing a basis to intercompare data, and provide a standard measure to improve the cross-calibration and interoperability of images from these missions.



Calibration measurements of alfalfa and bare soil sites using the portable Analytical Spectral Devices (ASD) FieldSpec 4 instrument. [Image: FRM4VEG]

Validation (or product validation) is the process of assessing, by independent means, the quality of the data products derived from satellite observations. Examples include:

- assessing a map of crop area or crop type derived from satellite images against independently collected ground reference measurements as part of a coordinated campaign[7];

- checking the record of sea level derived from satellite instrument observations against the record of measurements of sea level from in-place instruments taken from a jetty in northern Tasmania; and,

- the Fiducial Reference Measurements for Vegetation (FRM4VEG) project (https://frm4veg.org/), managed by ESA focused on traceable local measurements of vegetation-related parameters, to support the validation of products from Sentinel-2, Sentinel-3, and PROBA-V.

Several types of ocean platforms are also used for satellite sea surface temperature (SST) validation, including ships, drifting buoys, moorings, Argo floats and Saildrones. All platform types are valuable for satellite SST validation, because they provide unique benefits. For example, the International Sea Surface Temperature (SST) Fiducial Reference Measurement (FRM) Radiometer Network (ISFRN; https://www.ships4sst.org/) sets out to improve the use of shipborne infrared radiometers for measuring skin SST at the surface of the ocean, essential for accurately validating skin SST measurements from satellite infrared radiometers. Australia (through CSIRO, BoM and IMOS), contributes data to this international effort.

WHAT IS REQUIRED FOR QUALITY ASSURANCE?

Quality assurance for Earth observation satellite data requires infrastructure, highly skilled personnel and operational programs, combined with dedicated and sustained field data collection campaigns. Infrastructure is established at permanent natural or artificial sites on the Earth's surface to verify the accuracy of the measurements made by satellite sensors.

These sites can feature a range of constructed reflectors, geometric shapes, or natural features, which are used to calibrate the on-board instrument as the satellite passes overhead.

The sites may make use of natural features, for example deep water lakes which appear black on a satellite image. They may also make use of human built fiducial markers setup to serve as known and well characterised references.

Product validation requires additional infrastructure, combined with both periodic and sustained field data collection, for example the FRM4VEG project. For cross-calibration of satellite sensors, it is necessary for satellite overpasses to be close as possible both between satellites (such as the Copernicus Sentinel satellites) and to the recorded ground measurements.

The characterisation of error and uncertainty is essential for all quality assurance (including

7 2021. CEOS. CEOS Working Group on Calibration & Validation. https://ceos.org/ourwork/workinggroups/wgcv/

calibration and validation). While the overall aim of this assessment is to minimise uncertainty, reporting enables users to determine if the data are fit-for-purpose. Understanding quality tolerances also enables manufacturers to make essential cost-benefit decisions between increased accuracy and the cost of more precise instruments. Transparency around the quality and accuracy of the data also aids in building trust with users.

BENEFITS TO THE NATION

Our national advantages in providing satellite quality assurance observations – southern position, diverse environments, broad sampling of surrounding oceans, technical capability, and international engagement – mean that Australia contributes disproportionately to global calibration and validation efforts.

Our capabilities are widely regarded as some of the best in the world, with Australia having seven of the top 10 quality assurance supersites worldwide as ranked by the Committee on Earth Observation Satellites' (CEOS) Working Group on Calibration and Validation (WGCV[8]).

These sites underpin the long-term accuracy and consistency of data from large, reference Earth observation missions run by international space agencies.

Leveraging these national advantages holds the potential for Australia to become the recognised "go-to" for quality assurance of Earth observation satellite data globally. This offers several important potential benefits:

- **Economic growth** as trusted, quality assured satellite Earth observation data are used to inform better investment and environmental management decisions across the entire economy.

- **New jobs and skills** in sectors supporting the development and maintenance of quality assurance infrastructure, including instrument design and manufacture, satellite development and launch, facilities construction and maintenance in rural areas, and application development.

- **Data supply assurance** as international satellite operators come to rely on Australian quality assurance infrastructure, thus cementing our contribution to the international Earth observation community and ensuring the long-term supply of satellite data for Australia.

- **Data sovereignty** as Australia develops and builds domestic satellite construction and launch capabilities.

Robson Rainforest TERN Supersite. [Image: Joint Remote Sensing Research Program.]

8 2021. CEOS. CEOS Working Group on Calibration & Validation. https://ceos.org/ourwork/workinggroups/wgcv/

DELIVERY OF QUALITY ASSURANCE FOR SATELLITE EARTH OBSERVATION DATA

The concept of establishing a centrally coordinated network of quality assurance sites across Australia's terrestrial, aquatic (freshwater, coastal, oceanic), and atmospheric environments has long attracted strong community support. Such a network has been identified as a capability gap by Australian Government and research groups[9], was the subject of a previous unfunded NCRIS facility bid in 2017, and is one of the five national priorities in the Australian Earth Observation Community's 10-year plan 2016-2026 (www.eoa.org.au/aeocp-the-plan). It has been discussed internationally within the Committee on Earth Observing Satellites (CEOS) for over a decade and has been addressed in submissions to the 2021 Parliamentary Space Enquiry.

This scoping study builds on the acknowledged need for a coordinated site network and proposes the development of an internationally recognised facility for the calibration and validation of Earth observation sensors and their data, comprised of:

- a coordination body to oversee operations, communication and access to data, facilities and expertise – the Australian Centre for Earth observation Quality Assurance (ACE-QA);
- a comprehensive, operational and research network of calibration and validation facilities across Australia;
- a suite of tools and support provided via a unified service access point to enable national and international satellite operators to use the infrastructure and data collected for quality assurance; and,
- an Australian owned and operated series of Satellite Cross-Calibration Radiometers to provide improved accuracy and consistency between optical satellites, e.g. domestic, international, and commercial operators.

Establishment of the Centre would help address scientific and operational drivers for improved data quality and enable Australia to respond to emerging strategic issues such as:

- Accessing new sources and emerging types of satellite data that are expected to enable new and innovative services.
- Engagement with the rapidly growing commercial small satellite sector by providing calibration services which reduce their operating costs and add value to their end products.
- Investing in building Australia's reputation as a calibration and validation leader by enhancing global calibration and validation networks.
- Increasing trust in and use of satellite Earth observations for critical applications such as environmental and resource management and hazard monitoring.
- Streamlining service access and driving uptake by improving tools for data quality and fidelity.
- Participating in and helping lead and shape the international evolution of tools and best practice.

GOVERNANCE FRAMEWORK

It is proposed that ACE-QA operations be coordinated by a dedicated governance board comprised of representatives from government, research, industry and NGOs. The Centre would operate as a government co-funded entity, enabling it to accept government funding and leverage existing governmental operational budgets for maintenance and running of quality assurance facilities. It would require an Earth observation operations/mission centre with adequate staffing and technical expertise to coordinate and maintain relevant permanent sites, calibration laboratories and occasional field campaigns required for calibration and validation of key satellites.

Centre functions would include:

1. **National communication, collaboration, coordination and advocacy** of activities related to calibration and validation of Earth observation satellites under a commonly agreed framework for the operation and partnership among all relevant organisations undertaking such activities.

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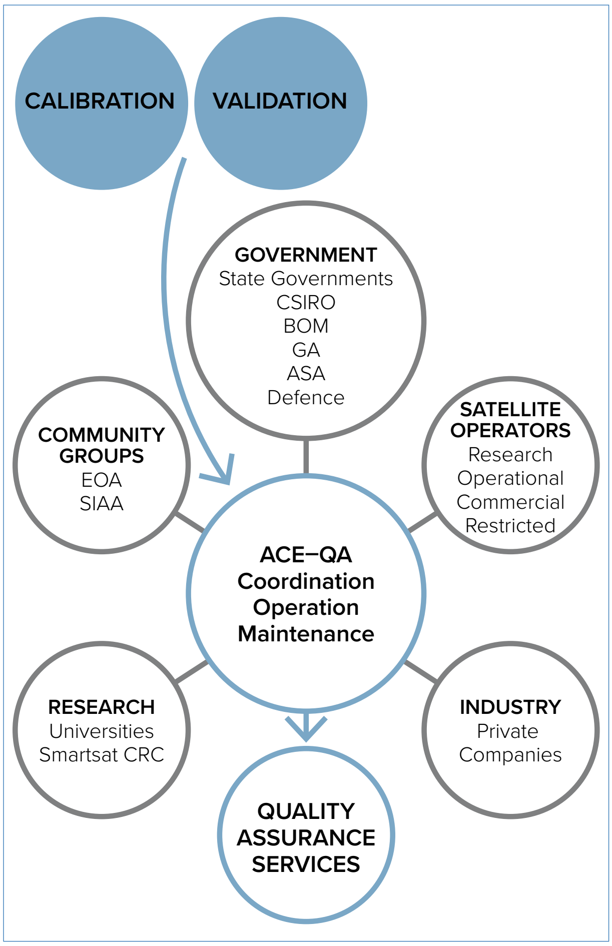
2. **Working with existing infrastructure providers to maintain key operational networks of sites** and associated calibration laboratories and staff, essential for the calibration and validation of Earth observation satellites through working with existing infrastructure providers. This would include the development of guidelines, protocols, verification of associate procedures for such activities.

3. **Ongoing review and development of new calibration and validation activities** that would contribute towards access of new and operational foreign satellite data essential for Australia's ongoing science and operational requirements.

CALIBRATION AND VALIDATION INFRASTRUCTURE, DATA AND EXPERTISE



Proposed structure of ACE-QA for co-ordinating access to calibration and validation infrastructure, data and expertise from participating partner organisations.

4. **Providing a viable process to access** all current and historical calibration and validation data collected at any site in the network.

5. **Performing live and public quality and latency testing** on every sensor in the network for reporting on the reliability of the network.

6. **Specialist consulting** advisory and services.

7. **Private Sector** provision of value-added data and tools.

EXISTING QUALITY ASSURANCE INFRASTRUCTURE

Existing Australian calibration and validation facilities are among the best in the world and represent a national competitive advantage. These facilities feature a mixture of targets (natural and artificial) and on-site reference instrumentation, and enable operators to calibrate instruments as the satellite passes overhead. The existing facilities are primarily operated and maintained by the BOM, CSIRO, and GA. Some smaller, calibration and validation sites are maintained by academic and research institutions and industry (see Appendix B for a summary).

The facilities are spread across the continent (and research vessels) and form an integral part of national and international calibration networks such as Australia's Terrestrial Ecosystem Research Network (TERN), Integrated Marine Observing System (IMOS) and AusSCOPE, the WMO Global Observing System, the CEOS RadCalNet, the Global Atmospheric Watch (GAW) and NASA's Land Product Validation network. However, despite the world-leading quality of Australia's calibration and validation facilities, the current sites only provide suitable infrastructure for a small proportion of the Earth observation satellites currently in service. This is due in part to the range of calibration and validation "targets" required for use, as different sensors require different target types and instruments (see table below). It is also due in part to the *ad hoc* nature of numerous sites and the fact that they do not comprise a single integrated and operational network. This decentralised approach requires each user to collate data from multiple sites and develop custom solutions at considerable cost, creating a barrier to uptake.

Enhancing the network through improved communication, coordination of existing sites, and the development of new facilities with a wider variety of natural and artificial targets would dramatically increase the range of instruments that can be calibrated and validated. Investing in a unified approach to data access would enhance the value of existing facilities and reduce the costs faced by users when integrating data from multiple sites. It would also establish a base for future scaling by streamlining the addition of new sites, data types, and locations (including space-based), as well as allowing existing users to access these new calibration and validation data flows without having to build additional new interfaces into their workflows.

On behalf of the Commonwealth, CSIRO currently operates a number of national facilities[10] and collections in the form of specialised laboratories that are available to both international and Australian users from industry and research. In addition, in 2019 CSIRO acquired and now operates a 10% share of the UK's NovaSAR satellite. This investment is the first in an anticipated series of CSIRO-lead Earth observation missions, and as such the program has included the implementation of a satellite ground segment, and the utilisation of existing quality assurance infrastructure. This represents the early stages of an indigenous Australian space-to-ground capability, and it is expected synergies may exist and should be explored.

SELECTED INFRASTRUCTURE / SENSOR BY SITE; * WATER MEASUREMENTS (OCEAN, INLAND)

Infrastructure or Sensor	Type	Purpose	Existing Site(s)	New Site(s)
Corner Reflector Array/Network	Radar Calibration	Used to geometrically align and calibrate radar intensity (backscatter)	1	2
Sun Photometer	Optical Calibration or Validation	Measures direct solar radiation	4, 9*, 14	3
Laboratory	Optical Instrument Calibration	Calibration of sensors to be used on site	5	
Spectral Radiometer	Optical Calibration or Validation	Measures aerosols and solar radiation		6, 7, 11*
Multiple Sized Painted Targets	Optical Calibration	Used to geometrically align optical data		8
WETLabs Thetis moored profile	Validation	Profile of the water column including environmental parameters and phytoplankton characteristics	13*	
High resolution solar Fourier transform infrared spectroscopy	Validation	Spectra are analysed to provide total column amounts of over 40 trace gases in the atmosphere for greenhouse gas measurements	15	
Cosmic ray sensors	Validation Radar and Optical	Measures soil moisture for validation	18	
Micrometeoro-logical flux stations	Validation	Measures of energy, carbon and water exchange between the atmosphere and key Australian and New Zealand ecosystems	19	
Various Sensors	Calibration and Validation Optical and Radar	Various sensors with continuous measurement or specific field validation campaigns to collect measurements	16, 17, 20, 21, 22, 23, 25	10*, 11*, 12*, 24,

10 *2021. CSIRO. Facilities and collections. https://www.csiro.au/en/about/facilities-collections*

Field work using terrestrial LiDAR at Karawatha Forest, Brisbane, QLD, Australia. [Image: Mark Grant, provided by TERN.]

PROPOSED NEW QUALITY ASSURANCE GROUND INFRASTRUCTURE

This report proposes the development of new infrastructure, along with the coordination of Australia's existing sites into permanent facilities suitable for routine, automated calibration, and validation, and the establishment of a standards-based approach that would meet the requirements of global satellite operators and international calibration and validation networks.

The expansion of the existing network would provide opportunities for Australian industry to both develop and coordinate new sites, leading to investment in the manufacturing, space ground segment, and facilities management sectors. The expansion would also address a currently unmet international need for robust calibration and validation infrastructure. Further, if carried out as a part of an integrated service offering, each new site would increase the attractiveness

EXISTING AND PROPOSED CALIBRATION AND VALIDATION SITES

Type	Existing site	New site
Radar sensors	Site 1: QLD Corner Reflector Array	Site 2: NT Alice Springs or Woomera corner reflector network
Optical sensors	Site 3: WA Pinnacles Medium Spatial Resolution Bright Optical Vicarious Calibration Site 4: WA Lake Lefroy Medium Resolution Bright Optical Vicarious Calibration Site Site 5: National Optical Calibration Laboratory Facility	Site 6: Optical Coarse Spatial Resolution Vicarious Calibration Site Site 7: CORIO: Cotter Reservoir Inland Observatory (optical dark target)
Geometric calibration		Site 8: NT Alice Springs geometric calibration facility
Above and in-water biophysical properties	Site 9: QLD Lucinda Jetty Coastal Observatory	Site 10: TAS Bruny Island Aquatic Target Site 11: AquaWatch In-Situ Sensor Network Site 12: NT Darwin Harbour Aquatic Target Site 13: Rottnest Island blue water site
Atmospheric Composition	Site 14: AeroSpan Network (Internationally AERONET) Site 15: Total Carbon Column Observing Network TCCON	Site 16: Terrestrial Numerical Weather Prediction validation
Terrestrial landscapes/ vegetation	Site 17: Terrestrial Ecosystem Research Network (TERN) SuperSites and associated sites Site 18: Cosmic Probe (CosmOz) Network Site 19: OzFlux Network Site 20: Endorsement of Australian sites for the Global Forest Biomass Reference System	
Ocean	Site 21: IMOS Site 22: SWOT (Bass Strait) Site 23: Ocean Numerical Weather Prediction validation Site 24: SWOT (GBR/SOFS/Albany) Site 25: SWOT (Mawson)	

of the overall offering, providing access to new sources of calibration and validation information via a single interface.

COORDINATED FIELD CAMPAIGNS

Validation field data collection through both *ad hoc* and ongoing field campaigns are also required and would need to be budgeted and planned as part of the proposed Centre operations. Ongoing campaigns are essential to the validation of Earth observation products in relation to land, ocean, atmosphere, and meteorological attributes that are measured by satellite missions. The existing TERN data collection campaigns for vegetation biomass and ground cover mapping represent one example. These campaigns require dedicated technical staff to collect the measurements. The Centre can provide the scope, training and coordination of private sector and university research groups to facilitate the collection of this data.

PROPOSED NEW QUALITY ASSURANCE SPACE INFRASTRUCTURE: SATELLITE CROSS-CALIBRATION RADIOMETERS

To date, Australia has focused on ground-based quality assurance infrastructure, however these approaches have limitations. To overcome these limitations, a conceptual Phase-A study of a continuous series of Australian Satellite Cross-Calibration Radiometers (SCRs) has been undertaken. This smallsat program would aim to improve the calibration of satellite Earth observation data's radiometric accuracy to within 1% of actual values. Among other applications, this increase in accuracy would enable the identification of specific crop types where before it was only possible to identify generic agricultural activity. The SCRs would also improve the ability to cross-calibrate between key international missions (e.g., Landsat, Sentinel-2), as well as commercial and other satellites.

SCRs are small (~50kg), sun-synchronous orbiting satellites that collect images using optical hyperspectral sensors. Designed to "under-fly" other optical satellites (e.g., Landsat), SCRs provide calibration data that aids in the improvement of the radiometric accuracy of Earth observation data.

ALICE SPRING SPACE PARK – AN EXEMPLAR FOR COLOCATION

In developing this scoping study, Alice Springs was identified as the ideal location for two new facilities:

- NT Alice Springs corner reflector network (A linearly arranged pointable reflector network of 25 sites around 10 km apart with two reflectors at each site)

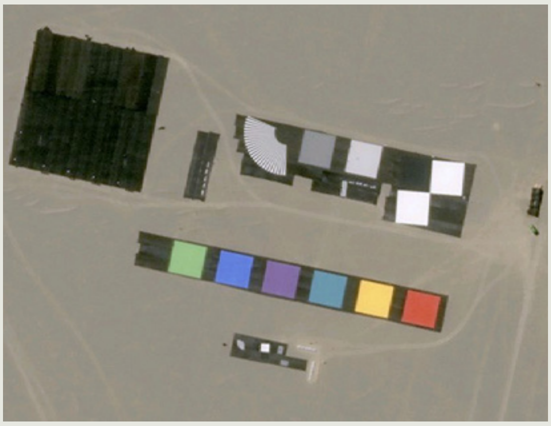
- NT Alice Springs geometric calibration facility (Two sets of shapes to support moderate and high-resolution sensors and a series of colours)

A variety of existing facilities capable of being collocated with this site were also identified:

- Central Australian ground station space park (Space Parks provide ground station operators with access to land and assurance of access to radio spectrum with streamlined processes for establishment of new facilities, while also making it easier to manage a range of risks)

- Commonwealth government observatories (Weather, seismic, geophysical, GNSS)

Collocation of sites offers numerous benefits. Operating and maintenance costs are generally lower, opportunities for training and employment in remote areas and among Aboriginal and Torres Strait Islander communities are greater, and student education and tourism opportunities can be created with the establishment of visitor centres such as the Victorian Space Education Centre. Furthermore, collocation of different types of scientific observatories has historically opened new lines of scientific inquiry and led to new insights.



Example of a geometric calibration facility

The proposed SCR program would launch two satellites every two years starting with a pair of pathfinder missions in Q4 2023 followed by the full operational capability (FOC) as of Q4 2025. The pathfinder missions, while technically aligned, pursue complimentary purposes:

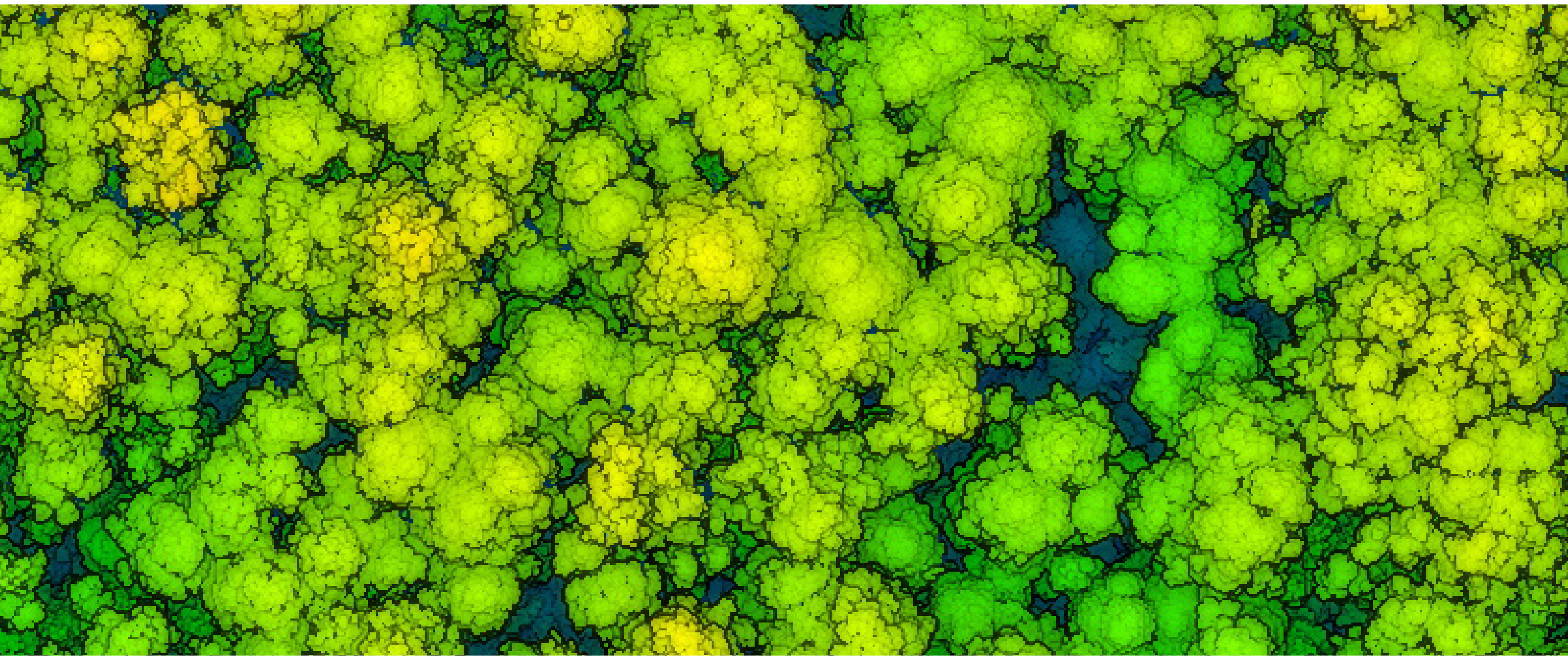
- SCR 1 is a low-risk version relying on commercial off the shelf (COTS) elements as far as possible to ensure a launch at the same time as NASA's CLARREO-Pathfinder mission in Q4 2023; and,
- SCR 2 is the opportunity for Australian industry to ramp up its manufacturing capability so that the operational satellites can benefit from significant Australian manufacturing content.

Development of the SCRs would be a major investment in the Australian space sector providing significant opportunities for local manufacturers and small, medium and micro enterprises (SMMEs). For further information on the proposed SCR program refer to *Technical Feasibility Study into Australian Development of a Satellite Cross-Calibration Radiometer (SCR) series including potential to support partner land imaging programs* (2021, University of New South Wales Canberra Space).

PROPOSED NEW QUALITY ASSURANCE SERVICES

Calibration and validation remain highly technical and costly processes that routinely require-specialised infrastructure and highly trained personnel to complete. Satellite operators, governments and the commercial sector invest significant effort, time, and money to ensure the data coming from Earth observing satellites, and information products and service developed from these, are sufficiently accurate and can be relied upon to make defensible and informed environmental and infrastructure management and investment decisions.

Currently, it is difficult for individuals and organisations to access the resources to obtain quality assurance reference data in Australia, held by multiple different organisations. The Centre could coordinate access to these data sets and the government and industry organisations that provide these data and services, through a central point allowing streamlined access. At its core, this could include a machine-to-machine application programming interface (API) to provide standardised access, built using open standards. On top of the API a suite of tools could be developed by individual groups such as satellite



Produced from LiDAR captured by Airborne Research Australia (ARA) at Warra Tall Eucalypt TERN SuperSite in May 2014. [Image: Arko Lucieer, provided by TERN.]

operators or Earth observation data product producers. Access to quality assurance reference data would allow quality indicators to be provided alongside satellite earth observation data and products, enabling decisions on using the data for the purpose at hand. It is anticipated that future demand from private and public sectors may require reporting of quality indicators in the form of sensor or data certification. The Centre could perform this function, as well as offering access to specialist staff, through participating partners, to complete one-off and routine quality assurance services and provide technical expertise.

ENDURING SERVICE OFFERING AND THE POTENTIAL FOR GLOBAL LINKAGES

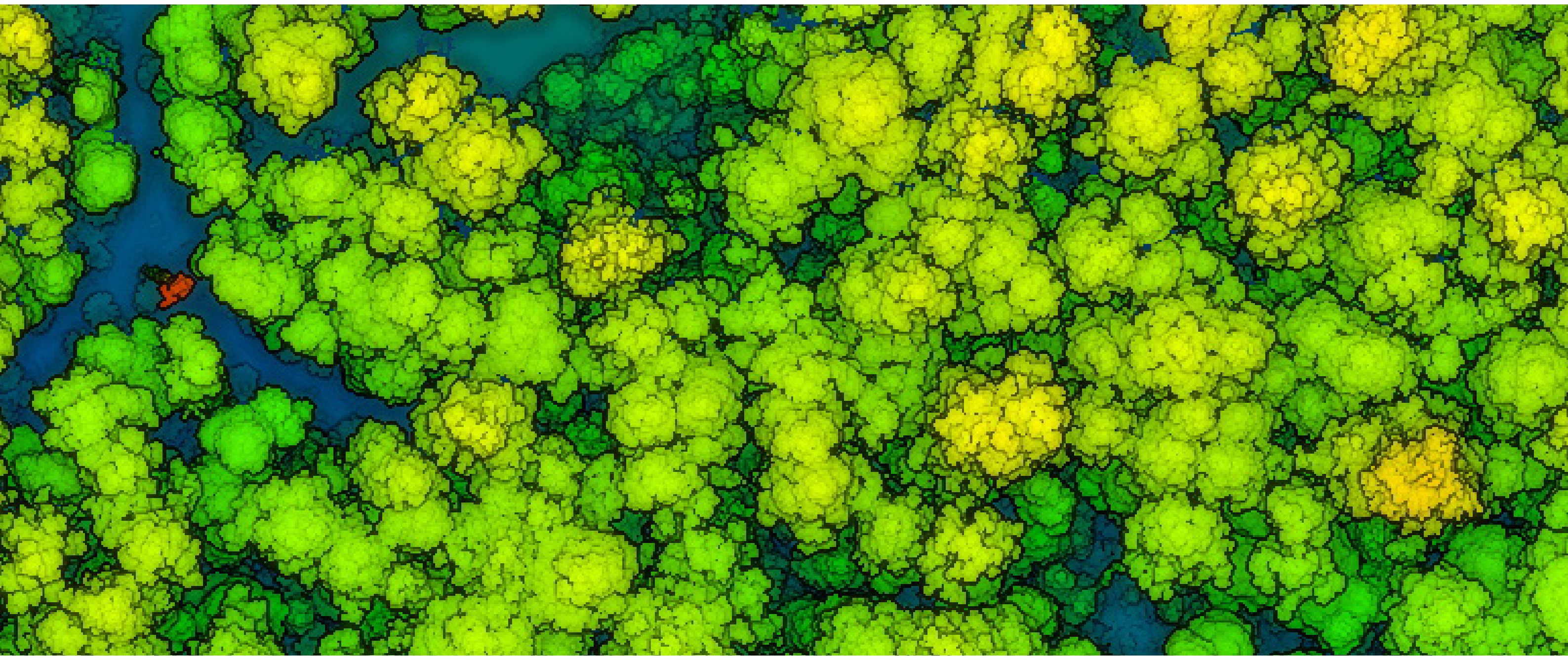
A quality assurance service offering based on coordinated and sustained investment in Australian ground and space infrastructure has the potential to carve out a unique international niche. By packaging access to Australian quality assurance infrastructure and providing it to the international community, we would engage in meaningful ways with our data supply partners, and build a platform from which we can grow and strengthen our interactions. We are a continent scale country with high quality satellite derived national datasets (e.g. produced by CSIRO and GA), and demonstrating quality assurance of those products at this scale would display our national capacity to the international community.

There are a variety of global calibration and validation networks for diverse types of satellite Earth observations data which the Centre could engage with. The CEOS Working Group on Calibration and Validation (WGCV) runs several key networks:

- **RadCalNet or the Radiometric Calibration Network:** The RadCalNet service provides satellite operators with SI-traceable Top-of-Atmosphere (TOA) spectrally resolved reflectance to aid in the post-launch radiometric calibration and validation of optical imaging sensor data.

- **Land Product Validation subgroup (LPV) Supersites:** Super characterised sites useful for the validation of satellite land products.

- **LPV Fire Radiative Power (FRP) network:** Validation network for satellite-derived fire radiative power products.



- **Infrared and Visible Optical Sensors (IVOS) subgroup Modulation Transfer Function (MTF) network:** Geometric accuracy network focused on measuring the Modulation Transfer Function (MTF) along with the signal-to-noise ratio (SNR).

Other networks include:

- **European Copernicus program's Ground-Based Observations for Validation (GBOV) of Copernicus Global Land Products:** The GBOV service provides in-situ measurements to validate 7 core land products (Top-of-canopy reflectance, Surface albedo, fAPAR, LAI, fCover, Land Surface Temperature and Soil Moisture).

- **European HyperNets:** Automated ground hyperspectral radiometers for validating any type of optical mission.

- **US's Long Term Ecological Research Network (LTER):** Monitoring network of diverse ecosystem sites.

- **NASA's AErosol RObotic NETwork (Aeronet):** Is a federation of ground-based remote sensing aerosol networks established by NASA and PHOTONS (PHOtométrie pour le Traitement Opérationnel de Normalisation Satellitaire; Univ. of Lille 1, CNES, and CNRS-INSU) and is greatly expanded by networks (e.g., RIMA, AeroSpan, AEROCAN, and CARSNET) and collaborators from national agencies, institutes, universities, individual scientists, and partners. For more than 25 years, the project has provided long-term, continuous, and readily accessible public domain database of aerosol optical, microphysical, and radiative properties for aerosol research, and validation of satellite retrievals, as well as synergism with other databases.

- **International Sea Surface Temperature (SST) Fiducial Reference Measurement (FRM) Radiometer Network (ISFRN; https://www.ships4sst.org/):** Is a community of in situ radiometer builders, operators and data users who aim to promote good practice in the construction and operation of in situ radiometer, agree and establish protocols, formats and standards for quality assurance of data, provide a single access point for the collection and dissemination of radiometer data, and support satellite radiometer operators in the long-term validation of satellite products. Shipborne radiometers are used to validate satellite measurements of skin SST, which is what satellite infrared SST measurements measure. They provide traceability of measurements to NMI standards (FRM4STS). CSIRO and BoM (through IMOS) contribute RV Investigator skin SST data to the ISFRN and participate in international ship radiometer inter-comparison workshops. These data have been used by JAXA and EUMETSAT to validate satellite SST from Himawari-8, GCOM-C and Sentinel-3. AAD is about to instrument the new icebreaker, RSV Nuyina, with an SST radiometer, but lacks the resources to contribute skin SST data to ISFRN or IMOS.

With the service model, capacity, and international network participation established, we would be on a strong footing to sustain an engagement with space agencies, space data providers, and the commercial sector globally. This could be initiated under Australia's existing participation in CEOS, for example via and Australian hosted office, facility, or function analogous to the NASA-funded CEOS System Engineering Office. Such an office could:

- Maintain a consolidated CEOS service showing the recent calibration performance of key reference satellites;

- Improve efficiency of the quality assurance function by maintaining a focal point for information and tools;

- Offer a free automated system to data providers (public and commercial) based on continuous or episodically observations over global calibration and validation network sites;

- Pursue advocacy via the CEOS community to build trust across the user community about the reliability of Earth observation data, and related Australian capabilities; and,

- Contribute to and lead broader international framework discussions, for example around establishing satellite data provenance and use in formal proceedings.

AN AUSTRALIAN OPPORTUNITY

Satellite Earth observations contribute billions of dollars to the global economy through applications in weather prediction, agricultural production, mining and extractive technologies, financial services, infrastructure development, and environmental monitoring. The opportunity to increase Australia's share in this rapidly expanding applications market is vast, as is the opportunity to participate in and realise the benefits of the global space economy.

To grow the market for Australian-made Earth observation applications users must be able to trust the accuracy of the data and information provided by satellites. Data quality assurance is therefore of significant interest to satellite operators, application developers and end users, particularly in the rapidly developing commercial small satellite sector.

Investment in a coordinated continent-wide calibration and validation site network overseen by a national centre for Australian Earth observation quality assurance, and underpinned by a continuous launch smallsat program of satellite cross calibration radiometers (SCRs), offers not only an opportunity for Australia to become a world leader in quality assurance, but also a chance for the Australian space and spatial industries to take key roles in the global Earth observation community.

Australian instrument technology, manufacturing know-how, and scientific expertise are among the best in the world. Investing in our sovereign capability through enhanced quality assurance infrastructure and development of a national smallsat program would help build trust in Earth observation data, mitigate long-term Earth observation data supply risks, bolster our growing space sector, and create new job and skill opportunities for all Australians.

APPENDIX A: CONTRIBUTIONS

Australian Space Agency

- Arvind Ramana, Office of the CTO
- Reece Biddiscombe, Office of the CTO

Australian Antarctic Division

- Johnathan Kool, Director Science Technical Support

Bureau of Meteorology

- Agnes Lane, Team Leader Data Requirements and Planning
- Helen Beggs, Ocean Remote Sensing Scientist
- Joel Cabrie, Port Meteorological Officer
- Alain Protat, Radar Science and Nowcasting Team Leader

CSIRO

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- Ian C Lau, CSIRO Mineral Resources, Senior Experimental Scientist, Lead of AeroSpan (Aernonet, Australia), Centre for Earth Observation
- Tim Malthus, CSIRO Oceans & Atmosphere, Research Group, Coastal Sensing and Modelling
- Janet Anstee, CSIRO Oceans & Atmosphere, Research Team Leader, Aquatic Remote Sensing
- Thomas Schroeder, CSIRO Oceans & Atmosphere, Senior Research Scientist, Lead of IMOS Ocean Colour Sub-facility, Manager Lucinda Jetty Coastal Observatory
- Aaron Hawdon, CSIRO Land and Water, Senior Experimental Scientist, Lead of Material Fluxes Team (CosmOz, Australian Cosmic-Ray Neutron Soil Moisture Monitoring Network)
- Melita Keywood, CSIRO Oceans & Atmosphere, Co-Research Group Leader, Atmospheric Composition and Chemistry,
- Matt Stenson, CSIRO Land and Water, Environmental Informatics Team Leader.

Earth Observation Australia (Management Committee)

- Stuart Phinn, University of Queensland, Professor, School of Earth and Environmental Sciences; Earth Observation Australia President
- Amy Parker, CSIRO Centre for Earth Observation, Acting Satellite Operations and Data Manager; Earth Observation Australia Vice President
- Sylvia Michael, University of Queensland, Earth Observation Australia Business Manager
- Joanne Edkins, University of Queensland, Research Support Manager, Remote Sensing Research Centre; Earth Observation Australia Treasurer
- Alfredo Huete, University of Technology Sydney, Professor, School of Life Sciences; Earth Observation Australia General Member
- Cindy Ong, CSIRO Energy, Principal Research Scientist, Lead of Calibration and Validation, Centre for Earth observation; Earth Observation Australia General Member*
- Dan Wu, Esri Australia, Junior Project Manager; Earth Observation Australia General Member
- David Antoine, Curtin University, Professor, Remote Sensing & Satellite Research Group, School of Earth & Planetary Sciences; Earth Observation Australia General Member
- Jasmine Muir, FrontierSI, Earth Observation Technical Lead; Earth Observation Australia General Member*
- Megan Lewis, University of Adelaide, Professor, Ecology and Evolutionary Biology; Earth Observation Australia General Member

- Renee Bartolo, Department of Agriculture, Water and the Environment, Principal Research Scientist; Earth Observation Australia General Member

- *Participated as observers only for Earth Observation Australia

FrontierSI
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- Clive Fraser, Defence Program Manager; University of Melbourne, Professorial Fellow, Department of Infrastructure Engineering

- Graeme Kernich, Chief Executive Officer

Geoscience Australia
- David Hudson, Senior Advisor Earth Observation

- Medhavy Thankappan, Director Cal/val and Analysis Ready Data

- Matt Garthwaite, InSAR Team Leader

- Chris Penning, Assistant Director, National Planning and International Relations

- Jonathon Ross, Director National Planning and International Relations

National Collaborative Research Infrastructure Strategy (Including TERN, IMOS)
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- Mirko Karan, James Cook University, TERN, Ecosystem Processes Platform Coordinator

- Peter Brady, University of Queensland, TERN Project Manager

- Ben Sparrow, University of Adelaide, TERN, Ecosystem Surveillance Platform Lead

- David Antoine, Curtin University, Head Remote Sensing & Satellite Research Group, IMOS Science and Technology Advisory Committee

- Shane Keating, University of New South Wales

- Jamie Cleverly, University of Technology Sydney, OzFlux, Associate Director

Symbios
- Stephen Ward, CEO

- Matthew Steventon, Consultant and Analyst

- George Dyke, Consultant and Analyst

APPENDIX B: SITE SUMMARY

The site summary in this appendix reflected the design at the time of writing.

Sites by Global Calibration and Validation Networks

	Existing	New	Total
RadCalNet *Radiometric Calibration Network*	0	3	3
GBOV *Ground-Based Observation for Validation*	3	1	4
LTER *Long Term Ecological Research*	12	0	12
FBR *Global Forest Biomass Reference System*	0	11	11
MTF *Modulation Transfer Function*	0	1	1
HyperNets *Network for Land Surface Reflectance Validation*	0	1	1
Aeronet *Aerosol Robotic Network*	7	5	12
LPV Supersites *Land Product Validation Supersites*	12	0	12
OceanSITES *Long-term, deep water reference stations*	1	0	1
Total	**35**	**22**	**57**

Sites by Sensor Calibration Function and Product Validation Thematic Area

	Existing	New	Total
Satellite Sensor Calibration			
RADAR Sensors	1	2	3
Optical Sensors	2	5	7
Geometric calibration	0	1	1
Total Sensor Calibration	**3**	**8**	**11**
Satellite Product Validation			
Above and in-water biophysical properties	2	4	6
Atmospheric composition	10	2	12
Terrestrial landscapes/ vegetation	43	3	46
Ocean	21	6	27
Weather forecast	18	3	21
Total Product Validation	**94**	**18**	**112**

Sites by State/Territory

Not all sites are represented, in particular networks which are national in scale and potentially involve 10's or 100's of small locations.

	Existing	New	Total
ACT	0	1	1
NSW	11	0	11
NT	7	4	11
QLD	13	1	14
SA	2	1	3
TAS	8	1	8
VIC	4	0	4
WA	11	3	14
Antarctica	1	3*	4
Total	**57**	**14**	**71**

** One of the new Antarctic sites is on the ship the RSV Nuyina.*

Sites by CEOS Data Type

Earth observation data types from the CEOS Earth Observation Handbook (www.eohandbook.com).

	Existing	New	Total
Atmospheric chemistry	11	3	14
Atmospheric temperature and humidity sounders	2	0	2
Cloud profile and rain radars	0	2	2
Earth radiation budget radiometers	0	2	2
Gravity instruments	0	0	0
High resolution optical imagers	30	3	33
Hyperspectral imagers	21	0	21
Imaging microwave radars	37	1	38
Imaging multi-spectral radiometers (passive microwave)	17	0	17
Imaging multi-spectral radiometers(vis/IR)	13	9	22
Lidars	20	0	20
Lightning sensors	0	0	0
Magnetic field	0	0	0
Multiple direction/polarisation radiometers	16	0	16
Ocean colour instruments	2	2	4
Radar altimeters	3	1	4
Scatterometers	16	2	16
Total	**188**	**25**	**213**

APPENDIX C: BUDGET TABLE SUMMARY

Information in this annex contains commercial in confidence information and was provided to the Australian Space Agency, CSIRO, Bureau of Meteorology and Geoscience Australia only.

Landsat 8 image from 29/03/2013. False colour NBAR image showcasing mineralogy at Ashburton River, WA, Australia. [Image: Produced from remote sensing data by the U.S. Geological Survey, processed by Digital Earth Australia, Geoscience Australia]

SUPPORTING ORGANISATIONS

Industry groups

- EOA Earth Observation Australia
- SIBA
- gita Australia and New Zealand
- SSSI Surveying & Spatial Sciences Institute

Industry

- cohga Integration made easy
- Douglas Partners Geotechnics | Environment | Groundwater
- EOS
- Frontierra
- Fugro
- INOVOR Technologies
- MAXAR
- Myriota
- SITAEL Australia
- Symbios Communications

Research

- National Committee for Space and Radio Science – Australian Academy of Science
- AMRF Australian Mountain Research Facility
- Australian National University Institute for Space
- Curtin University
- Frontier SI
- IMOS Integrated Marine Observing System
- tern Ecosystem Research Infrastructure
- NCRIS National Research Infrastructure for Australia – An Australian Government Initiative
- Monash University
- SmartSat Cooperative Research Centre
- The University of Newcastle Australia
- National Committee for Earth Sciences – Australian Academy of Science
- une University of New England
- UNSW Canberra Space
- space UNSW Canberra
- University of Tasmania

Government

- Australian Government – Bureau of Meteorology
- Australian Government – Department of Agriculture, Water and the Environment
- Australian Government – Geoscience Australia
- CSIRO
- Australian Space Agency
- Government of Western Australia
- Landgate
- Northern Territory Government

International partners

- CEOS
- JAXA
- USGS science for a changing world
- VNSC Lift-off your Dream