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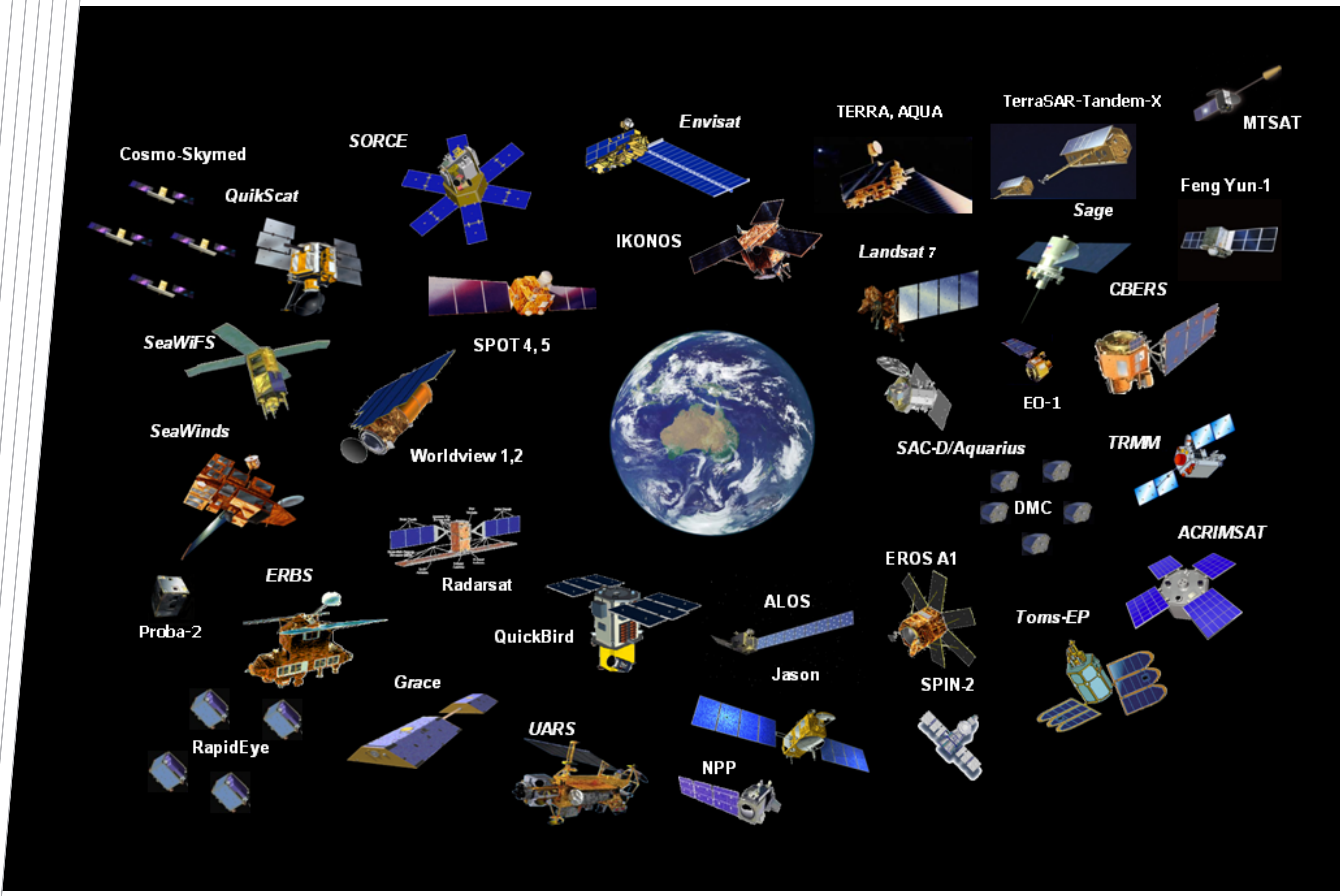

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Continuity of Earth Observation Data for Australia: Research and Development Dependencies to 2020

January 2012

Enquiries

Enquiries should be addressed to:
Dr Kimberley Clayfield
Executive Manager | Space Sciences and Technology
CSIRO Astronomy and Space Science
Email Kimberley.Clayfield@csiro.au

Study Team

Dr A. Alexander Held and Dr Kimberley C. Clayfield, CSIRO
Stephen Ward and George Dyke, Symbios Communications Pty Ltd
Barbara Harrison

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Cover Image

Depiction of the various active geostationary and low Earth orbit Earth observation satellites operating over Australia. Source: Adapted with permission from a graphic by the secretariat of the Group on Earth Observations (GEO) and from various member agencies of the Committee on Earth Observation Satellites (CEOS).

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Important Disclaimer

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KEY FINDINGS

- Australian Earth observation (EO) research and development (R&D) is fragmented and underpinned by data from over 40 foreign owned and operated satellites that have been identified as important for the continuity of EO data supply for Australia. Australia is one of the largest users world-wide (by volume and variety) of EOS data provided by foreign satellites.

- The majority of Australian EO research projects surveyed in detail, support and provide continuous improvement to at least 60 current operational EO programs in Federal and State governments, leading to improved weather forecasting and public safety warnings, improved environmental monitoring and informed climate policy, effective surveillance and defence of territorial waters, improved disaster prediction and response, informed resource exploration and management, and improved agricultural and water management capabilities. This support underpins Earth observation dependencies within currently active Federal and State government programs estimated to be worth approximately $950 million (Geoscience Australia, 2010).

- The primary sources of EO data for Australian researchers are NASA and NOAA satellites (USA), even though these are not always optimal for some Australian requirements. The European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA) are rapidly emerging as key future suppliers of multiple data streams needed for Australian R&D, with several other future data sources also likely to include Germany, India, China, Korea, Italy and France.

- The Australian research community, as well as operational agencies, contribute to overseas EO programs through participation in global satellite calibration programs and the direct downlink and return of data back to owner countries, as well as participating in international science teams for selected missions, developing new applications for these data.

- Every year, over 100 TB of Earth observation data (satellite and airborne) are obtained by more than 200 research projects across Australia, and either downloaded directly over the Internet for free or purchased from data suppliers. Assuming that data volumes double each year, it is conservatively estimated that the volume of data downloaded will exceed 1 PB per year by 2016.

- Free and open data policies for access to real-time broadcast data and associated historical archives, combined with routine production of over 40 standard products in the case of the US MODIS program, have made data from the USGS Landsat satellite series, the NOAA AVHRR and NASA MODIS sensors by far the most widely used data across the EO R&D sector in Australia, with almost 60% of surveyed projects using data from one or more of these three data sources. However, these systems are not well designed for Australia's requirements, given our landscapes are dominated by soils, rocks and dry vegetation.

- Eleven of the 25 R&D projects surveyed that rely on MODIS data currently maintain their own MODIS data archives of more than 30 TB, and individually acquire over 1 TB of MODIS data per year. Four of the 12 projects using AVHRR store more than 10 TB of historical imagery each, and also acquire over 1 TB annually.

- Current satellite data continuity issues for Landsat data, ALOS L-band SAR data, and EO data from other science missions with limited, uncertain or broken continuity (*e.g.* CALIPSO, OCO, ASTER, GRACE), as well as uncertainties around the quality of the new VIIRS sensors which are to replace the ageing MODIS sensors, may create potentially serious data gaps across multiple R&D programs and associated operational government mapping programs. The risk associated with such data gaps will depend heavily on contingency planning by the various user groups, and the sourcing of alternative data streams of adequate quality and accessibility.

KEY RECOMMENDATIONS

- Nine Priority Data Types[1] for Australian research projects were identified in this study, based on the number of surveyed R&D projects relying on these datasets. Of the top four Priority Data Types identified, there is one actual and current data gap for L-band Synthetic Aperture Radar (SAR), and a very high risk of a data gap for Medium Resolution Optical data, given the suspension of operation of the Landsat-5 mission in late 2011. A formal coordinated national approach to ensure continuity and evaluate alternative data sources for critical data supplies for Australian researchers, particularly Medium Resolution Optical data, is strongly recommended as a matter of priority, both with regard to international agreements (particularly with NASA/USGS, ESA, JAXA and other priority countries), as well as nationally coordinated EO infrastructure planning.
- Government-funded research infrastructure programs and multi-agency research networks such as the Terrestrial Ecosystem Research Network (TERN), the Integrated Marine Observing System (IMOS), the WA Centre of Excellence for 3D Mineral Mapping (C3DMM) and AuScope, lead the way in demonstrating the effectiveness of coordination of participation in international networks, and coordination of production, standardisation, inter-operability and open access to key EO-derived datasets for use by Australian researchers. Consistent with the *2011 Strategic Roadmap for Australian Research Infrastructure* (DIISR), these facilities and coordination approaches should be expanded where possible to other critical EO application areas (*e.g.* soils, atmospheric observations), and these data services should continue to receive ongoing central support.
- As data supply agencies world-wide move increasingly towards centralised, Internet-based data distribution models, more concerted national coordination will be required to ensure current investments into broadband networks and associated infrastructure can be efficiently and effectively utilised to improve access to and management of the various EO data streams used by R&D and operational users in Australia.
- A small but innovative and dynamic airborne remote sensing R&D and commercial data supply sector underpins much of the EOS R&D community in Australia and should continue to be supported where applicable.
- Several relatively new sensor systems, which may not be widely used currently, merit more attention in terms of continuity and critical data gaps across a range of new science and application fields important to Australia. These have strong potential to provide valuable new information for key essential variables important, for example, to hydrological, Antarctic and marine studies, and for monitoring terrestrial dynamics, and atmospheric gas and aerosol climatologies. These sensor systems include GPS occultation, AMSR-E, OCO-ACE, GRACE, GOSAT, CALIPSO, and ESA Biomass. Key Australian organisations and researchers will need to monitor these systems on an ongoing basis, and the CEODA-R&D survey should be updated on a regular basis.
- The Australian R&D community has tended to use 'whatever free data are available', provided it offers suitable data quality, continuity, coverage and access arrangements. International space agencies should continue to be encouraged and supported as they move towards free and open data access policies.

[1] Priority Data Types ranked by frequency of usage across surveyed projects (no weighting applied for data volumes): Low Resolution Optical; Medium Resolution Optical; High Resolution Optical; Synthetic Aperture Radar (SAR) (C-, L- and X-band); Passive Microwave Radiometry; Radar Altimetry; Hyperspectral Imagery; Lidar; Ocean Colour.

- Coordinated Australian participation in regional and global EOS coordination bodies, such as the Committee on Earth Observation Satellites (CEOS), the Group on Earth Observations (GEO), the Coordination Group for Meteorological Satellites (CGMS) and the Asia Pacific Regional Space Agency Forum, as well as negotiation of new data agreements with emerging suppliers of public good EO data, will therefore help secure current and future data access to critical EO datasets.
- To continue to realise the great benefits that EO data increasingly provide, Australia's modest contribution towards international EO programs should be more closely integrated and coordinated across research facilities, R&D agencies and university groups, and expanded to include better support for satellite calibration/validation, international science team membership, data downlink – as a Southern Hemisphere and regional 'data node', regional development assistance, and scientific collaborations on the development of new applications.
- US and European financial pressures are likely to cause shifts in large new Earth observation investments and associated R&D programs. Asia and South America are likely new growth regions, presenting Australia with significant opportunities for increased engagement with, and enhancement of R&D collaborations and technical development assistance for, emerging space nations.
- Australia's EO R&D and operational user community should undertake a detailed study of the relative merits of increased national investment into EO space segment infrastructure development (for example, niche sensor technologies, hosted payloads, co-investment in joint space missions with other space-capable nations, or alternatively, high altitude unmanned aerial platforms), as an avenue towards future self-reliance, securing future data streams, and to help grow Australia's research, international collaborations and industrial development in the field of Earth observation. Three high priority candidate areas for further exploration are: SAR, Hyperspectral imagery, and Short Wave and Thermal Infrared. Cost-effective contributions could be made through international virtual constellations.

EXECUTIVE SUMMARY

Scope

The Space Policy Unit (SPU) within the Department of Industry, Innovation, Science, Research and Tertiary Education (DIISRTE, formerly DIISR) engaged CSIRO to survey the key dependencies and future priorities for EO data (space and airborne) used by the Australian research community. A recent companion report, entitled *Continuity of Earth Observation Data for Australia: Operational Requirements to 2015 for Lands, Coasts and Oceans (CEODA-Ops)* (Geoscience Australia, 2011), detailed the projected EOS data requirements for Australian Government agencies in 2015, and assessed the expected availability of EOS data in Australia to 2020. A third report focusing on operational meteorological Earth Observation (EO) data needs is in preparation by the Bureau of Meteorology (BoM).

Survey Population

Nearly 200 significant and representative Australian R&D projects requiring EO data were identified from research teams within CSIRO, Cooperative Research Centres (CRCs), universities, and Federal and State government agencies. National benefits from this research are many and varied, including improved weather forecasting and public safety warnings, improved environmental monitoring and informed climate policy, effective surveillance and defence of territorial waters, improved disaster prediction and response, informed resource exploration and management, and improved agricultural and water management capabilities.

From these projects, 56 projects from 31 organisations were selected as a representative sample set of the wide variety of EO-related R&D activities in Australia, and include the majority of the prominent research groups. These 56 projects (with a total annual budget of approximately $35 million and employment of over 190 full time equivalents, in both civil and defence organisations) were surveyed in more detail in terms of their current and future EO data requirements, their current and future data supply preferences, and their linkages to national and international programs, both research and operational. Over 70% of the projects surveyed in detail are linked to current operational EO-dependent programs in Australia, as reported in *CEODA-Ops*.

Main Results

The 56 R&D projects studied in detail in this survey demonstrated great ingenuity and diversity in their data access arrangements and their use of EO data across a wide range of application areas, collectively using 59 different satellite EO instruments that are considered essential to research. Of these 59 instruments, 17 are used uniquely by the Centre for Australian Weather and Climate Research (CAWCR) and BoM in support of their National Weather Program (NWP) and application research projects. This highlights the importance of, and Australia's reliance on, EOS data as a key input towards improved understanding of the various physical and biological processes, human impacts and elements that form part of the Earth System, and for underpinning State and Federal programs which ensure improved evidence-based management of essential food-, water-, resources-, environmental- and national security across Australia.

Nine broadly classified "Priority Data Types" have been identified, based upon their criticality in support of research outcomes, and their widespread usage across multiple projects. These are (in decreasing order of usage):

- Low Resolution Optical;
- Medium Resolution Optical;
- High Resolution Optical;
- SAR (C-, L- and X-band);
- Passive Microwave Radiometry;
- Radar Altimetry;
- Hyperspectral Imagery;
- Lidar; and
- Ocean Colour.

While also used extensively in routine operational programs across Australian Government agencies, the Low and Medium Resolution Optical data are also by far the most widely used data types in the R&D sector, with Low Resolution Optical data being used by around half of the surveyed projects. SAR data represent the next most widely used data type, and their use is expected to grow as data streams become more accessible and continuous.

Researchers assessed that their needs for these Priority Data Types will not change significantly over the next five years, although a broadening of the available satellite EO instrument suite and increased use of new EO data sources with higher spatial and spectral resolutions are widely anticipated. Therefore, significant increases in the variety of data streams and in particular in data volumes are envisioned in future.

Survey results highlighted the tendency of the R&D community to historically use 'whatever free data are available', provided it offers suitable data quality, continuity, coverage and access arrangements. The purchase of large volumes of commercial EO data is financially unsustainable for the vast majority of projects surveyed.

Several relatively new sensor systems, which may not be widely used currently, merit more attention in terms of continuity and critical data gaps across a range of new science and application fields important to Australia. These have strong potential to provide valuable new information for key essential variables important, for example, to hydrological, Antarctic and marine studies, and for monitoring terrestrial dynamics, and atmospheric gas and aerosol climatologies. These sensor systems include GPS occultation, AMSR-E, OCO-ACE, GRACE, GOSAT, CALIPSO, and ESA Biomass. Key Australian organisations and researchers will need to monitor these systems on an ongoing basis, and the CEODA-R&D survey should be updated on a regular basis.

Awareness of future international EO satellite program plans, data contingency planning, radio-frequency protection issues, and the need to strengthen international partnerships with additional supplier agencies, varied significantly among individual researchers but was generally low, with few researchers following global developments closely. This suggests that the R&D community may need to be better informed of future opportunities before national priorities can be established.

Data Continuity Risks

Of the top four Priority Data Types listed above, there is one current data gap for L-band SAR, and a significant risk of a data gap for Medium Resolution Optical data (see Table ES-1). Numerous operational national programs and legislated monitoring activities could be delayed or otherwise affected by loss of L-band SAR data, Landsat and MODIS data in particular, due to the significant cost and effort associated with changing data processing protocols and negotiating data access, as programs transition to alternative data sources.

Landsat data continuity had been dependent on the ongoing health of the ageing Landsat-5 satellite (suspended in November 2011, possibly at end of life) and the relative utility of a malfunctioning Landsat-7 satellite, and is the subject of some anxiety in the relevant user communities. In the short-term, the economic impact to Australia of losing access to Landsat data has been assessed as $100 million in the first year of a data gap, with a flow-on effect in subsequent years for the duration of that gap (ACIL Tasman, 2010).

NASA's replacement mission, the Landsat Data Continuity Mission (LDCM, Landsat-8), is not expected to be operational until mid-2013. Beyond 2013, the European Space Agency/European Commission's (ESA/EC) Sentinel-2 mission (part of Europe's Global Monitoring for Environment and Security/GMES satellite program) should also provide ample Medium Resolution Optical data.

Similarly, due in part to free access to over 40 derived products, use of MODIS data is so widespread in Australian research and government programs that inevitably a very significant financial and technical cost will be incurred across several national and regional programs in the event that this sensor becomes unreliable or unavailable, forcing R&D and operations sectors to transition to other sensors and information products derived from new sensors such as VIIRS or Sentinel-3.

A gap in new acquisitions of L-band SAR data has existed since the failure of Japan's ALOS mission in March 2011 and has significantly impacted the research community, including those supporting routine national and international forest carbon, vegetation mapping and disaster monitoring programs using this type of radar imaging.

Critical Relationships

The current financial crises in the US and Europe could have significant implications for continuity of EO data supply to Australia. NASA and NOAA have been the most important suppliers of EO satellite data in support of Australian R&D needs over the last decades. However, the future supply prospects for the Priority Data Types identified suggest that a larger number of additional suppliers and data types will be important to Australia in the future. This has implications for both the planning and prioritisation of key relationships and infrastructure in support of these expanded data supply and management arrangements.

In the near term, Australia's relationship with ESA could potentially grow to one of equal importance for the provision of EO satellite data for Australian R&D needs, provided that data access terms improve, and that the current financial crisis does not affect ESA's launch schedule or ground segment capacities. Based on technical specifications, ESA (and in some cases the EC) was identified in this survey as a key future supplier for as many as seven Priority Data Types, based on data from the GMES program and the five series of Sentinel satellite missions.

Furthermore, to enhance access to other key EO datasets, and as a key participant in regional cooperation and space agency forums, Australia has a strong opportunity to continue and further enhance space-related cooperation in the region. More active 'export' of Australia's EO data calibration and analysis expertise, via bilateral or multilateral science collaborations or development assistance agreements in the Asia-Pacific region, would build goodwill and secure better access to various EO data streams provided by space agencies in the region (primarily Japan, India, China, Thailand and Korea).

Infrastructure Implications

In the near term, the rapid move to Internet-based distribution by major supply agencies, an increase in the variety of data types, and an increase in data volumes by up to a factor of ten over the next five years suggest that efficient on-line access will be critical to minimise data cost, duplication and latency. This has significant implications for national data networks and computing infrastructure with regard to data transmission, storage, pre-processing and provision, and will require national coordination.

The need for careful, systematic calibration and validation (Cal/Val) of EOS datasets is urgent. National infrastructure to support radiometric Cal/Val is considered by many researchers to be a fundamental element in ensuring both EO data quality and strong relationships with foreign collaborators, including in support of the growing number of operational programs relying on these data, especially in areas of legislative monitoring.

SAR data and hyperspectral imagery were both identified by the largest number of potential users as future priority data types for the R&D community. Future missions offering these data types, such as Sentinel-1 (ESA/EC, May 2013), ALOS-2 (JAXA, 2013), ALOS-3 (JAXA, 2014), PRISMA (ASI, 2014) and EnMap (DLR, Apr 2015), offer significant opportunities for data streams of high value to the research community. Adequate planning, with sufficient lead-time, for the reception, processing, archiving and distribution of these specialist data types will be essential if maximum national benefit is to be derived once these satellites are launched.

Table ES-1 Priority Data Types: Satellite 5-Year Supply Continuity Risk and Key Providers

Priority EO Data Type	5-year continuity risk	Current key providers (and missions)	Future key providers (and missions)	Predominant Latency Requirement
Optical: Low Resolution	Low	NASA (MODIS) NOAA/EUMETSAT (AVHRR) JMA (MTSAT series)	ESA/EC (Sentinel-3 series) NOAA (NPP/JPSS series) JAXA (GCOM-C series) JMA (MTSAT series)	Hours/Weeks
Optical: Medium Resolution	High	USGS (Landsat-5/7)	USGS (LDCM) ESA/EC (Sentinel-2 series)	Days/Weeks
Optical: High Resolution	Low	USA commercial providers (Worldview, GeoEye)	USA & European commercial providers (Worldview, GeoEye, Pleiades) Airborne operators	Days/Weeks
SAR: C-band	Low	ESA (Envisat) CSA (Radarsat)	ESA/EC (Sentinel-1 series) CSA (Radarsat & RCM)	Weeks
SAR: L-band	No current supply	-	CONAE-ASI (SAOCOM-1A) JAXA (ALOS-2)	Weeks
SAR: X-band	Low	ASI (COSMO-SkyMed) DLR (TerraSAR-X)	ASI (COSMO-SkyMed series) DLR (TerraSAR-X series)	Weeks
Passive Microwave Radiometry	Medium	NASA (Aqua – just concluded) NOAA/DoD (DMSP series) JAXA/NASA (TRMM) ESA (SMOS)	JAXA/NASA (GCOM-W series) NASA (GPM, Aquarius, SMAP) NOAA/DoD (DMSP series) ESA (SMOS) ISRO (Megha-Tropiques, RISAT-3)	Hours
Radar Altimetry	Medium	EUMETSAT-NOAA (Jason series) ESA (Envisat)	EUMETSAT-NOAA (Jason series) ESA/EC (Sentinel-3 series)	Hours
Hyperspectral Imagery	High	NASA (EO-1)	DLR (EnMAP) ASI (PRISMA) METI/JAXA (ALOS-3)	Weeks
Lidar	High	NASA (CALIPSO)	ESA/JAXA (EarthCARE)	Weeks
Ocean Colour	Low	ESA (MERIS) NASA (MODIS) ISRO (OCEANSAT)	ESA/EC (Sentinel-3 series) JAXA (GCOM-C series) ISRO (OCEANSAT) NOAA (NPP/JPSS series)	Hours

1 INTRODUCTION

1.1 Earth Observation

Earth Observation (EO) encompasses a diverse group of activities that quantify, map and monitor several key characteristics of the Earth using remote measurement techniques. This is commonly referred to as remote sensing. EO activities include measurements from satellite sensors, airborne sensors, and *in situ* sensors. Earth Observations from Space (EOS) describes a range of approaches that observe and measure Earth surface properties from space-based platforms.

For the purposes of this survey and report, the EO-related projects analysed here involve those which focus their work on directly using, or deriving products from, both satellite-based and airborne sensor measurements, as well as the use of *in situ* (ground) measurements that are taken to directly support or validate satellite and/or airborne data acquisitions.

There is a growing operational and economic dependence on EO data for a diverse range of applications in Australia. This currently involves at least 92 major Federal and State programs (Geoscience Australia, 2010) and $3.3 billion per year GDP contribution for both direct and indirect productivity measurements (ACIL Tasman, 2010). EO operational applications in Australia typically include modelling climate, forecasting weather, monitoring water management and quality, surveillance of oceans, mapping forests, estimating agricultural production, mitigating hazards, responding to disasters, assessing urban expansion, locating mining and energy resources, maintaining national security, protecting borders, positioning, transport and navigation (Geoscience Australia, 2011).

Australia does not have its own EO satellite system, so all EOS data are currently sourced from foreign satellites. Given our dependence on these data for multiple, critical national needs, it must be emphasised that security of supply from these foreign sources is beyond Australian control. In light of the ever-growing operational and research needs and dependencies on EO data continuity, this situation should be a matter of significant national concern.

1.2 Purpose

In the process of framing a new space policy for Australia, the Space Policy Unit (SPU), within the Department of Industry, Innovation, Science, Research and Tertiary Education (DIISRTE), conducted a number of information-gathering activities. As one part of this process, the SPU engaged CSIRO to survey the key dependencies and future priorities for EO data (space and airborne) used by the Australian research community. This survey, *Continuity of Earth Observation Data for Australia: Research and Development Requirements to 2020 (CEODA-R&D)*, focused on those teams and experts conducting basic and applied remote sensing research to advance EO science, and included those groups that undertake research and development (R&D) in support of major national programs that make operational use of EO data.

In particular, the survey aimed to characterise EO satellite and airborne data needs, requirements and gaps in Australia's EO-related R&D sector. The results of this survey are presented in Sections 2, 3 and 4.

A sample set of significant and representative R&D projects requiring EO were identified and surveyed in terms of their current and future EO data requirements, their current and future data supply preferences, and their linkages to national and international programs, both research and operational. Most importantly, the survey ascertained those areas where improved coordination and possible investments are needed to secure future data access for Australia's EO-related R&D sector.

The survey aimed to provide as complete a picture as possible of the Australian EO-related R&D community, identifying issues that are key to ensuring continuity of data supply for future development and innovation. As such, it involved a comprehensive set of questions (see Section 2.1.3 and Appendix C for details) and the cooperation of participants is both acknowledged and greatly appreciated. The process of this survey has enabled respondents to gain greater awareness and familiarity with the diverse range of EO data sources that are being planned for future use.

1.3 Objectives

This report, *CEODA-R&D*, seeks to address the following objectives.

1. To report the outcomes of a survey conducted by CSIRO to characterise satellite and airborne EO data requirements and gaps in Australia's EO-related R&D sector, including
    - the importance of the availability of the EO data in support of the R&D project outcomes, and the role and magnitude of the R&D in support of operational government or commercial programs and their related social and economic impact for Australia
    - data types of special importance to the R&D sector, based on the criticality of the data availability to the outcomes and whether certain data types are critical to multiple projects.
2. To determine how EOS data requirements are presumed to be satisfied by existing and planned satellite systems, to document the nature of the supporting arrangements for access by Australia and, where possible, to define how these requirements are expected to evolve in the next ten years, including identifying
    - which EOS missions are a priority for guaranteed access by Australia's R&D community over the next ten years
    - which relationships, with both space agency data providers and with related research partners, are a priority in terms of data access and activities related to improved data analysis and exploitation
    - opportunities for potential expansion of national and international collaborations and partnerships, and ways in which the Australian EO R&D sector can contribute and support foreign programs.
3. To highlight the implications of anticipated future EOS data requirements in terms of future support, infrastructure needs and capabilities, including
    - an assessment as to the likely future EOS access scenarios and continuity risks which face the R&D sector, and identifying future contingencies.

1.4 Related Reports

This report (*CEODA-R&D*) provides an important complement to several recent reviews of the extent and significance of EO data usage in Australia.

Of these, the recent report *A National Space Policy: Views from the Earth Observation Community* (Geoscience Australia, 2010) identified 92 Federal and State government programs that use EOS data on an operational basis. These programs encompass a wide range of applications areas, landscapes and localities. This set of operational programs was used in *The Economic Value of Earth Observation from Space* (ACIL Tasman, 2010) to estimate the direct contribution of EOS to Australia's Gross Domestic Product (GDP) at $1.4 billion per year in 2008-09. This estimate considered the combined value of imagery, technology and skilled labour within these programs. In light of the growing dependency on EOS for information on climate change, natural resource management, and environmental reporting and compliance, this figure is expected to exceed $4 billion per year by 2015. Additionally, the related productivity benefits to the Australian economy, that is, the impacts of EOS information on productivity in other market sectors[2], were estimated at

[2] Market sectors deemed to derive significant productivity benefits from EOS were Agriculture, Forestry, Fisheries, Mining and Petroleum, Property and Business Services, Federal and State governments, Natural Resource Management, Environment and Climate Change, Biosecurity, Defence and National Security, Counterterrorism, Emergency Management, and Maritime and Air Safety (ACIL Tasman, 2010).

$1.9 billion per year in 2008-09, and projected to be worth $2.5 billion per year by 2015. Further economic benefits totalling $1 billion per year, were estimated for providing enhanced information from EOS relating to climate change, natural resource management and emergency management.

Current Government expenditure on EO in Australia approximates $100 million per year (Space Policy Unit, 2010). Using the above estimate of the economic benefits of EOS to the Australian economy, namely a $3.3 billion per annum GDP contribution for both direct and related productivity benefits, EOS is providing a return on investment of more than 30 to one.

Many of the specific operational uses of EO data are underpinned by a diverse and talented R&D sector that comprises numerous research establishments. These institutions perform the essential functions of ensuring the quality of routinely used EO data, developing new uses for available data, and maintaining a watching brief on new and emerging technologies in this area. The Australian Academy of Science (AAS) and the Australian Academy of Technological Sciences and Engineering (ATSE), in consultation with space science and EO experts, prepared the *Australian Strategic Plan for Earth Observations from Space* (ATSE, 2009). This plan concluded that the growing future EO needs of Australia could only be reliably met by an increased national commitment to EOS data provision and associated R&D. The plan also identified eight key national challenges for Australia, each of which should involve extensive use of EOS:

- Climate change;
- Water availability;
- Natural disaster mitigation;
- Safe and secure transport;
- Energy and resources security;
- Agriculture, forestry and ecosystems;
- Coasts and oceans; and
- National security.

The most recent report, entitled *Continuity of Earth Observation Data for Australia: Operational Requirements to 2015 for Lands, Coasts and Oceans (CEODA-Ops)* (Geoscience Australia, 2011), detailed the projected EOS data requirements for land, coast and ocean applications for Australian government agencies in 2015, and assessed the expected availability of EOS data in Australia to 2020. Based on the data requirements for 91[3] of the 92 operational programs detailed in Geoscience Australia (2010), an almost twentyfold increase in EOS data usage was forecast over the next five years. The total annual EOS data storage requirements for those programs were conservatively estimated at 1.2 PB per year in 2015. By contrast, EOS data availability in Australia was projected to decrease in the same time period based on current supply arrangements and systems.

CEODA-Ops assessed data requirements in terms of five data categories – Low Resolution Optical (> 80 m pixel), Medium Resolution Optical (10 m – 80 m pixel), High Resolution Optical (< 10 m pixel), Synthetic Aperture Radar (SAR), and Passive Microwave Radiometry. (In this context, 'optical' implied detection of surface properties in multiple visible and/or near infrared wavelengths (bands), including thermal infrared). Two of these data categories, Medium Resolution Optical and SAR, were considered to be the most at risk of data gaps for land and marine applications before 2015. Medium resolution optical data is used by 79% of the sample operational programs for a wide range of land and water management applications, including the National Carbon Accounting System (NCAS). *CEODA-Ops* recommended that access to future EOS missions be formalised immediately and that a decadal infrastructure plan be formulated to safeguard the supply of EOS data in Australia.

[3] Program 26 was not included in this sample due to insufficient EOS data usage.

As detailed in the Objectives (see Section 1.3), the present report focuses on the data requirements in Australia's EO-related R&D sector, which were not considered in the *CEODA-Ops* report. On the basis of a cross-section of 56 sample R&D projects in this survey, those EO data types and missions that are of special importance to R&D in Australia are identified. To highlight potential EO data continuity risks, future data supply options are also considered, both in terms of projected R&D requirements and infrastructure capabilities. The collaborations involved in EO-related R&D, both nationally and internationally, are examined, and the interrelationships between R&D project outcomes and several key operational programs are described.

1.5 Report Annex

This report is accompanied by an Annex document, with appendices that provide more detail and data in support of the sections in the main report:

Appendix A – R&D Projects Included the Study: with details of organisations, contacts, project objectives etc.

Appendix B – Australian EO-dependent Operational Programs: details the 91 current EOS data programs being undertaken by Federal and State agencies in Australia, which were discussed in terms of project linkages in Section 2.

Appendix C – Survey Questions: documents the worksheets of which the study survey was comprised.

Appendix D – Instrument Details for Priority Data Types: provides technical characteristics for all the instruments discussed in the continuity outlook discussions.

Appendix E – Priority Data Types – Continuity Outlook: additional details and timelines to supplement the discussion in Section 5.

2 CONTEXT OF CEODA-R&D SURVEY

The processes involved with the *Continuity of Earth Observation Data for Australia – Research and Development Requirements to 2020* (*CEODA-R&D*) survey are described in Section 2.1. The survey population is summarised and described in Sections 2.2 and 2.3 respectively. Major projects are identified in Section 2.4.

2.1 Survey Structure

2.1.1 Scope

The *CEODA-R&D* survey included EO-related R&D projects that involve basic and applied research but not operational usage of this research. The evolving cycles of EO-related research and development are represented by concentric regions in Figure 2-1. Starting from the centre of Figure 2-1, these regions show the interrelationships between:

1. Basic EO-related R&D (shown as red), such as atmospheric correction, Cal/Val, new sensors and derived products;
2. Application of EO products (shown as blue), continuous improvement programs, pre-operational or demonstration pilots such as the set-up phase for the Sentinel Hotspots[4] program; and
3. Operational use of EO (shown as white), such as climate modelling, the National Carbon Accounting System (NCAS), or the operational Sentinel Hotspots program.

Activities that would fit into the red and blue regions in Figure 2-1 (described as 1. and 2. above) are considered in this report. The companion study *CEODA-Ops* (Geoscience Australia, 2011) addresses the EO data continuity needs of operational programs in Australia. Related studies, including ATSE (2009) and ACIL Tasman (2010) highlighted the significance of EO to the Australian science community and the Australian economy respectively (see Section 1.4).

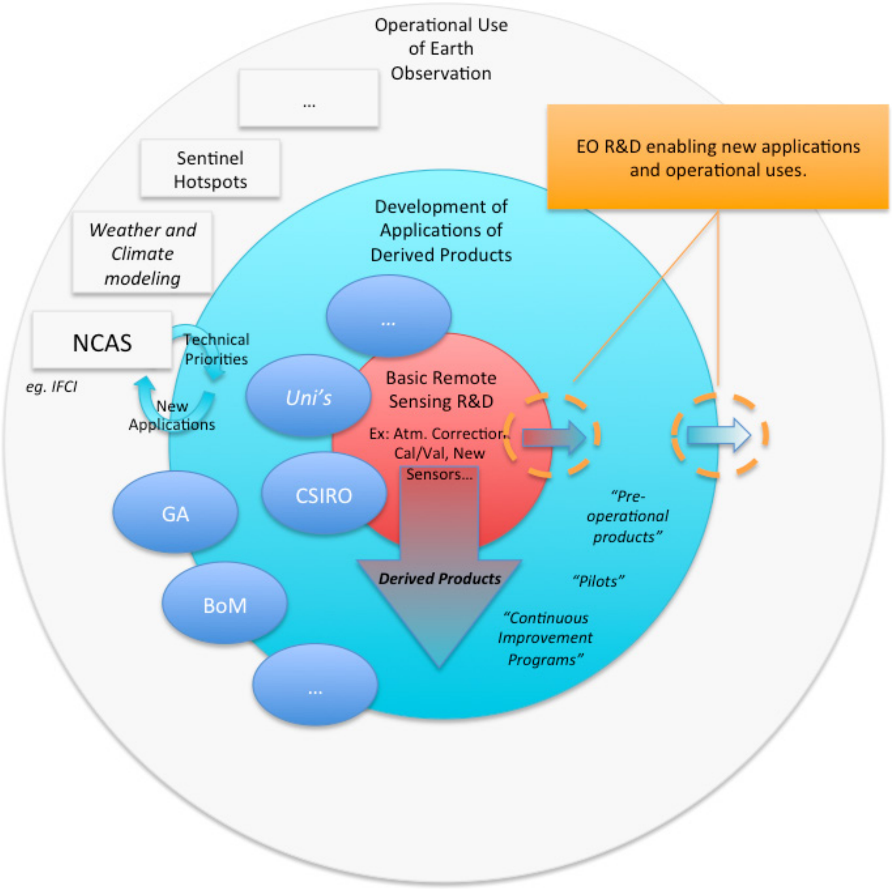
The sample set of EO-related R&D projects selected for this survey covers a diverse range of research topics, application areas, and EO data types. These projects are listed in Appendix A.

The study focus has been on R&D centres with research activity that is directly related to the exploitation and application of EO data. It should be noted that EO data are key inputs to a broad range of research beyond the scope of this survey. For example, almost every meteorological research study will make use of some EO data either directly in the form of images or through the use of datasets where EO have provided the key input data into analyses and historical reanalysis datasets, assimilated into a model framework.

[4] Sentinel is a national bushfire monitoring system that provides timely information about hotspots to emergency service managers across Australia (see: http://sentinel.ga.gov.au/acres/sentinel/index.shtml).

Figure 2-1 Scope of Survey

Only projects defined within the inner two concentric circles below are included in this survey.



2.1.2 Approach

The very wide range and dispersed nature of the EO R&D sector in Australia led to a two-stage survey process, conducted between July and September 2011:

Part 1 – Preliminary Survey

The first stage of the survey identified the majority of potential survey participants from relevant Federal and State organisations, including CSIRO, academia, CRCs, defence and land management agencies, who were asked to complete Worksheets 1 and 2a of the survey spreadsheet (see Table 2-1 and Appendix C). The questions therein were directed to the managerial staff responsible for overseeing multiple EO-related R&D capabilities and projects.

Projects vary substantially in size and significance across the survey sample—from a one-person research activity involving a single EOS data type, through to the R&D undertaken by the Centre for Australian Weather and Climate Research (CAWCR) in support of the nation's numerical weather prediction (NWP) capabilities, which involves dozens of different EOS data types and multiple researchers as well as weather applications including high impact events and applications such as rainfall estimation, fog detection, severe weather forecast development, volcanic ash etc.

An e-mail based survey was used to collate information in Part 1 of the process. A total of 217 EO-related R&D projects were identified, of which 187 projects from 31 organisations were considered for inclusion in Part 2.

Part 2 – Detailed Survey

The second stage in the survey refined the study sample further to a total of 56 projects based on the possibility of documenting project characteristics and with a view to ensuring that the sample represented the full spectrum of EO-related R&D activity in Australia and the balance of activity therein. (The survey sample is fully characterised in Section 2.2).

Part 2 of the process captured more detailed project information using an e-mail survey directed at the research staff responsible for managing the actual projects. Respondents were asked to complete, to the extent possible, the second half of Worksheet 2, and Worksheets 3-6 (see Table 2-1 and Appendix C) ahead of an extended interview with the survey team to review the responses provided. Telephone interviews were held in most cases to verify and complete the e-mail survey tables, with face-to-face meetings being held in a few cases.

The full list of survey participants is detailed in Appendix A. The survey structure is summarised in Table 2-1.

Table 2-1 Survey Approach

Survey Stage	Survey Worksheet	Topic	Information
Part 1 (Preliminary)	1	Organisation Information	High level details of the organisation responding to the survey
	2a	Research Projects	Listing of projects relevant to the survey within the research program and staff contact details
Part 2 (Detailed)	2b	Project Outcomes, Benefits and Resources	Listing of project outcomes, societal benefits, operational linkages, staff and funding resources, and EO data importance
	3	Project Overview	Objectives, reference material and collaboration relevant to the project
	4	EO Data Requirements	Current EO data requirements, supply, and future requirements by instrument type
	5	EO Data Supply	Current EO data supply overview, agreements, calibration and validation, volumes and costs for each instrument
	6	Continuity and Future Trends	Project continuity, emerging technology, sensor types, and potential new applications

2.1.3 Specific Questions

Survey respondents were asked to provide a wide range of information pertaining to their current and expected usage and supply of EO data. All survey questions are detailed in Appendix C. The following sub-sections summarise the primary survey information relating to data continuity as discussed in Sections 3, 4 and 5.

Table 2-2 Survey Instrument Types

Instrument Type	Abbreviation	Description and Example Applications
Atmospheric chemistry instruments	AC	Instruments that use various techniques and different parts of the electromagnetic spectrum to undertake measurements of the atmosphere's composition.
Atmospheric temperature and humidity sounders	ATHS	Passive measurements of the distribution of IR or microwave radiation emitted by the atmosphere, from which vertical profiles of temperature and humidity through the atmosphere may be obtained.
Cloud profile and rain radars	CPR	Active radars at cm wavelengths for rainfall as well as very short wavelength (mm) radar (typically 94 GHz) and lidar to detect scattering from non-precipitating cloud droplets or ice particles, thereby yielding information on cloud characteristics such as moisture content and base height.
Earth radiation budget radiometers	ERBR	Instruments taking measurements of the radiation balance between the incoming radiation from the Sun and the outgoing reflected and scattered solar radiation plus the thermal infrared emission to space.
Gravity, magnetic field and geodynamic instruments	GRAV	Instruments and supporting systems used to derive information on the Earth's gravity field, magnetic field or geodynamic activity.
Low resolution optical sensors (> 80 m)	Opt-Low	Instruments that take detailed optical images of the Earth's surface. Generally, nadir-viewing instruments with a horizontal spatial resolution in the range 1 m to 1100 m and swath widths up to thousands of kilometres. Note: the optical resolution standards from the CEODA-Ops report have been adopted for consistency between the analyses.
Medium resolution optical sensors (10 m - 80 m)	Opt-Med	
High resolution optical sensors (< 10 m)	Opt-High	
Hyperspectral imagers	HSI	Instruments that take optical images in many (usually 100 or more), narrow, contiguous, spectral bands. Often called "imaging spectroscopy".
Imaging multi-spectral radiometers (passive microwave)	IMS-PM	Operating at microwave wavelengths, these instruments use channels within 1 to 40 GHz and 80 to 100 GHz to get day/night information on the Earth's surface.
Imaging microwave radars (X-Band)	SAR-X	These instruments transmit at frequencies of around 1 to 10 GHz and measure the backscattered signals to generate microwave images of the Earth's surface at high spatial resolutions (between 10 m and 100 m), with a swath width of 100–500 km. Includes both synthetic aperture radars (SARs) and real aperture side-looking imaging radar systems.
Imaging microwave radars (C-Band)	SAR-C	
Imaging microwave radars (L-Band)	SAR-L	
Lidars	LIDAR	Lidars (LIght Detection And Ranging instruments) measure the radiation that is returned either from molecules and particles in the atmosphere or from the Earth's surface when illuminated by a laser source.
Multiple direction/polarisation instruments	MDP	Instruments that are custom-built for observing the directional or polarisational characteristics of the target's signature (either visible/IR or microwave), as a means of deriving geophysical information.
Ocean colour instruments	OC	Ocean colour radiometers and imaging spectrometers measuring the radiance leaving inland, coastal and marine waters in the visible and near IR spectrum in the range 400–1000 nm, where the colour is due to constituents of the water.
Radar altimeters	RA	Active sensors that use the ranging capability of radar to measure the surface topography profile along the satellite track.
Scatterometers	SCATT	Instrument transmits radar pulses and receives backscattered energy, the intensity of which depends on the roughness and dielectric properties of a particular target.

Importance of EO Data to Research

For each research project, survey respondents were asked to rate the importance of their current usage of EO data as either:

- Essential – primary input in support of the project's outcomes;
- Advantageous – secondary input but is not necessary to achieve the project's outcomes;
- Opportunistic – used on an *ad hoc* basis; or
- Promising – not currently used but could be useful in the future.

Importance of Individual EO Data Types

Using the CEOS Missions, Instruments and Measurements (MIM) database definitions (Table 2-2), respondents were also asked to categorise the importance of individual EO data types to their research.

EO Data Usage

For each data type, additional information was requested regarding current usage, including:

- Supply source and any substitutes available
- Spatial resolution
- Maximum extent of coverage
- Coverage area
- Number of coverages required per year
- Specific regions of interest
- Temporal coverage
- Latency
- Continuity and co-ordination requirements
- Technical details
- Expected data requirements in the 2-year, 5-year and 10-year timeframes; and
- Assessment of whether those requirements are expected to be met.

EO Data Supply

The following information was also requested about the supply of each data type:

- Instrument name
- Instrument agency
- Instrument mission
- Supply start and end dates
- Supply agreement type
- Unique agreement terms and conditions
- Agreement duration
- Physical supply route
- Current infrastructure obstacles
- Anticipated future data supply
- Quality control procedures
- Data volume (annual and historical); and
- Data costs (annual and historical).

2.2 Survey Population

Overall, the *CEODA-R&D* survey process identified 217 current Australian R&D projects. The survey ultimately comprised 187 candidate R&D projects, from which 56 were chosen for more detailed investigation. The 56 sample projects are being undertaken by 31 different organisations. The size and scope of these projects varied significantly.

- Academic Institutions (universities);
- Research Organisations (focused primarily on research and development, such as CSIRO, CRCs, CAWCR and WIRADA);
- Federal Agencies (undertaking both operational activities and some in-house research); and
- State Agencies (undertaking both operational activities and some in-house research).

The breakdown of organisations included in this survey, and the number of projects surveyed from each, are detailed for each of these four types of research establishment in Tables 2-3 to 2-6 respectively. A list of all surveyed projects is given in Appendix A.

The proportion of surveyed projects from each type of research establishment is shown in Figure 2-2.

Table 2-3 Academic Institutions Surveyed

Organisation	State	Part 1 Projects	Part 2 Projects
Australian National University (ANU)	ACT	3	1
Charles Darwin University (CDU)	NT	2	1
Charles Sturt University (CSU)	NSW	4	1
Curtin University	WA	8	1
Monash University	VIC	10	2
University of Adelaide (UAdel)	SA	7	2
University of New South Wales (UNSW)	NSW	4	2
University of Queensland (UQ)	QLD	5	1
University of Sydney (USyd)	NSW	5	1
University of Tasmania (UTas)	TAS	6	2
University of Technology Sydney (UTS)	NSW	8	1
University of Wollongong (UoW)	NSW	5	1
Total		**67**	**16**

Table 2-4 Research Organisations Surveyed

Organisation	State	Part 1 Projects	Part 2 Projects
Antarctic Climate & Ecosystems CRC (CRC ACE)	TAS	2	1
Centre for Australian Weather and Climate Research (CAWCR)	VIC	4	2
CRC for Spatial Information (CRCSI)	VIC	1	1
CSIRO Ecosystems Sciences	VIC	8	1
CSIRO Earth Science and Resource Engineering	WA	9	3
CSIRO Land and Water	ACT, TAS	6	5
CSIRO Marine and Atmospheric Research	ACT, TAS	11	5
Total		**41**	**18**

Table 2-5 Federal Agencies Surveyed

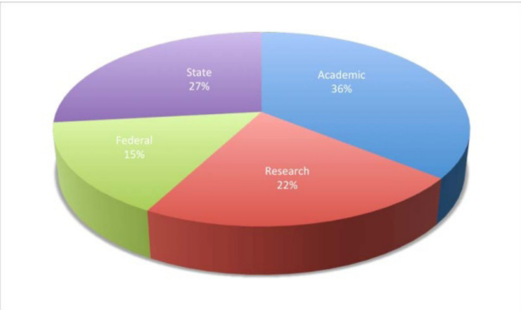
Organisation	State	Part 1 Projects	Part 2 Projects
Australian Antarctic Division (AAD)	TAS	7	1
Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES)	ACT	4	1
Australian Institute of Marine Science (AIMS)	QLD	3	1
Defence Science and Technology Organisation (DSTO)	SA	5	2
Geoscience Australia (GA)	ACT	10	5
Total		**29**	**10**

Table 2-6 State Agencies Surveyed

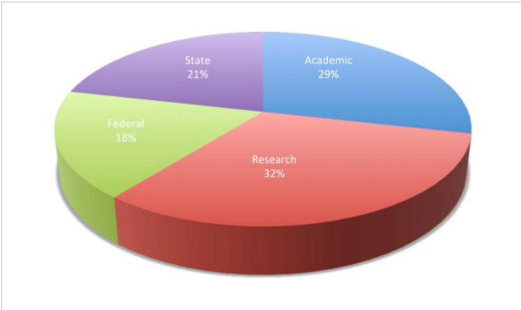
Organisation	State	Part 1 Projects	Part 2 Projects
Department of Sustainability and Environment (DSE)	VIC	9	1
Department of Employment, Economic Development and Innovation (DEEDI)	QLD	2	1
Department of Environment and Resource Management (DERM)	QLD	16	2
Department of Primary Industries (Vic DPI)	VIC	6	3
Landgate	WA	12	3
Office of Environment and Heritage (OEH)	NSW	4	1
Parks Victoria	VIC	1	1
Total		**50**	**12**

Figure 2-2 Surveyed Projects by Research Establishment Type

a. Part 1 (Preliminary Survey) Projects



b. Part 2 (Detailed Survey)Projects



As illustrated in Figure 2-3, survey results would suggest that, for the survey sample, academic institutions and State agencies currently conduct a greater proportion of low budget EO-related R&D projects, with lower staffing levels (see Figure 2-4), than research organisations and Federal agencies with in-house R&D activities.

Research organisations have the greatest proportion of large budget projects and the highest staffing levels (see Figure 2-4), while the research projects being conducted by Federal agencies are more evenly spread over all budget ranges.

Interestingly, half the projects within Federal and State agencies, as well as nearly 40% in academic institutions, were specified as ongoing (see Figure 2-5), compared to less than 20% in research organisations. The majority of surveyed projects in research organisations are currently funded for four to six years.

Figure 2-3 Annual Project Budgets

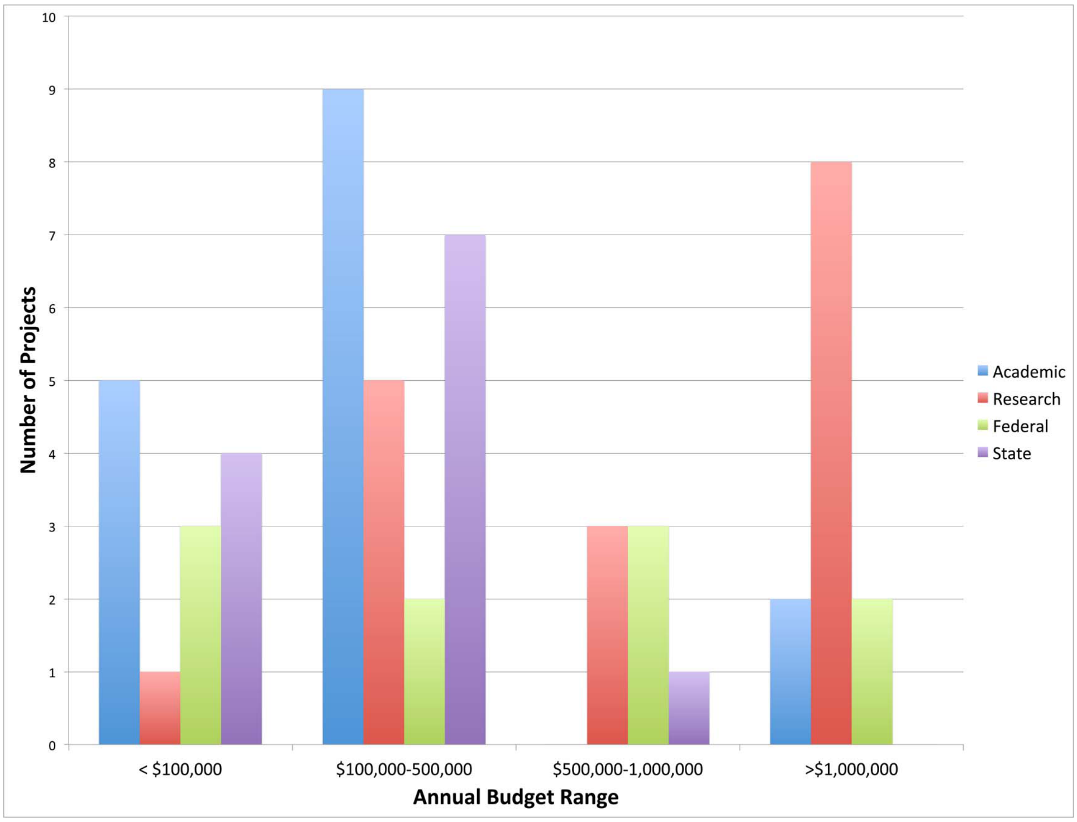


Figure 2-4 Average Annual Project Staffing

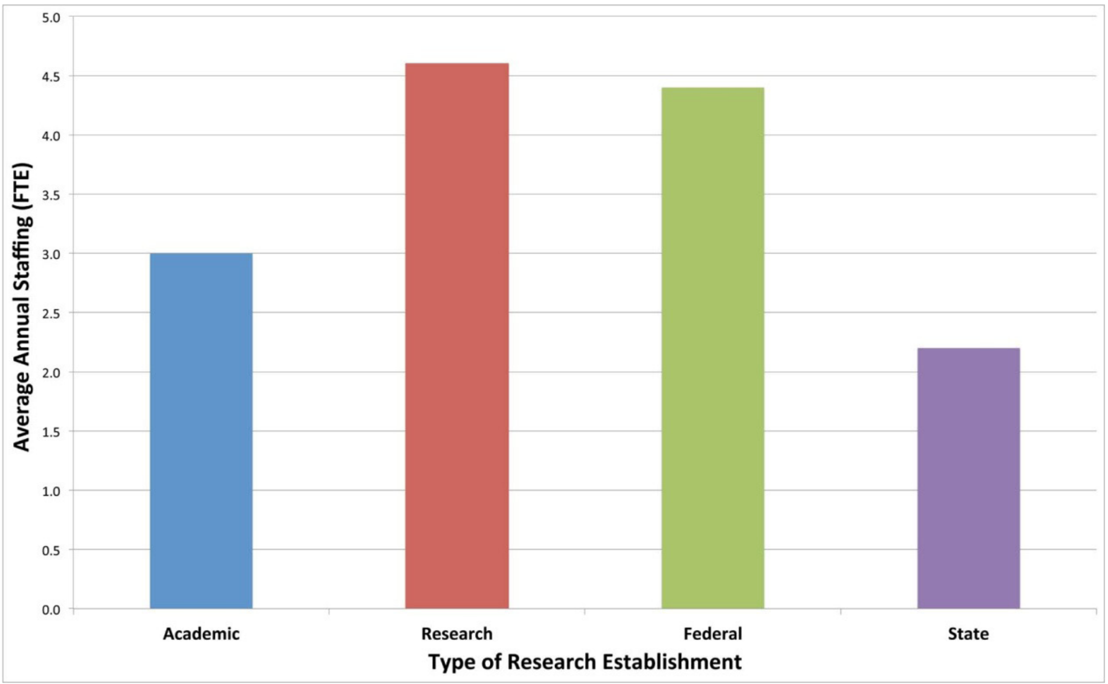
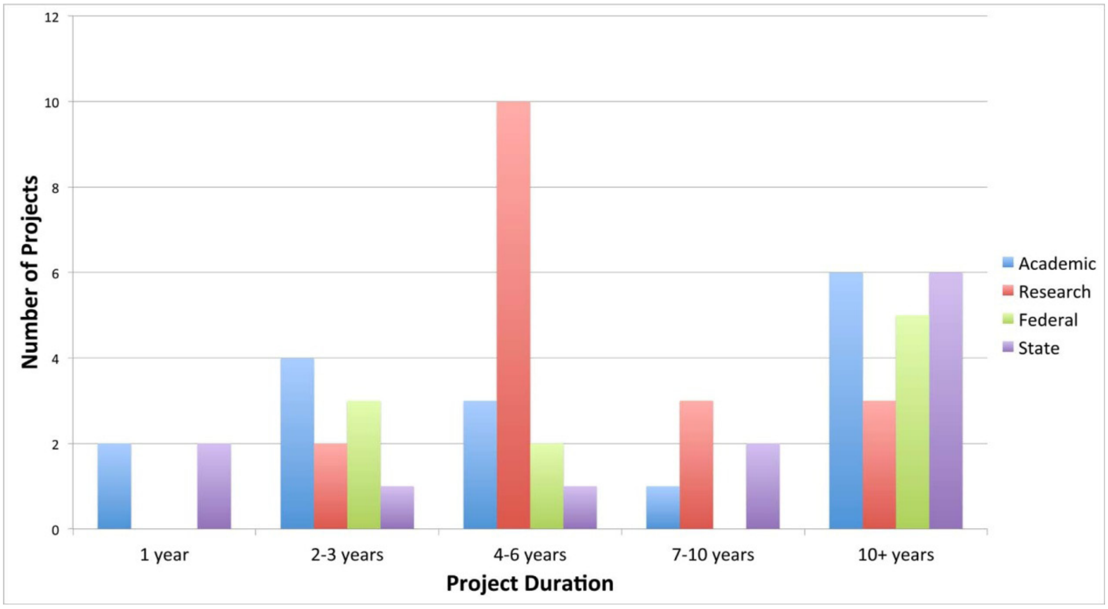


Figure 2-5 Project Duration



2.3 Benefits of R&D

2.3.1 Societal Benefit Areas

Survey respondents were asked to select up to three Societal Benefit Areas (SBAs) that were considered relevant to their project. As detailed in Table 2-7, the definition of SBAs is consistent with that used by the Group on Earth Observations (GEO) for the Global Earth Observation System of Systems (GEOSS).

The Ecosystems SBA was cited as relevant to over half the sample projects, with Agriculture, Climate, and Water being considered relevant to a little less than half. The SBAs of Biodiversity and Disaster were relevant to about 30% of the projects, while Weather, Energy and Health were only relevant to around 10% of projects. These results reflect the importance of EO data in understanding and monitoring the Australian landscape, and also highlight those application areas where its value is already well established, as well as being indicative of the current diversity and emphasis of EO-related research in Australia.

Survey respondents were also asked to list any other areas of benefit that were relevant to their research. These responses identified four additional benefit areas from EO-related R&D, namely Defence (three projects), Transport (three projects), and Minerals (two projects).

Table 2-7 Societal Benefit Area (SBA) Definitions

Societal Benefit Area	Description	Relevance to Projects
Ecosystems	Monitor and evaluate ecosystem health, function and change of coastal and near-shore marine systems, forests, inland water, oceanic islands and archipelagos, tundra, and watersheds.	34
Agriculture	Support local, national and regional activities for agriculture, rangelands, forestry and fisheries, including famine early warning, food security prediction, drought forecasting, agriculture production and forecasting, aquaculture production, timber, fuel and fibre management, forest perturbations and protection, carbon and biomass estimation.	27
Climate	Model, mitigate, adapt and assess risks of climate change for atmosphere, lands and oceans.	24
Water	Monitor terrestrial hydrology of surface waters, ground waters, forcings, water quality, and water usage.	22
Biodiversity	Assess condition and extent of ecosystems, distribution and status of species, and genetic diversity in key populations, as well as tracking invasive species.	17
Disasters	Predict and monitor earthquakes, floods, landslides, cyclones, volcanic eruptions, and wildfires.	17
Weather	Improve weather information, forecasting and warning using numerical weather prediction (global and regional), synoptic, aeronautical and agricultural meteorology, and atmospheric chemistry.	7[1]
Energy	Assess viability of renewable energy sources, including hydropower, wind power, bioenergy, solar power, geothermal power.	6
Health	Monitor aeroallergens, air quality, and infectious diseases, and provide early warning for public health risks such as heat waves and epidemic pre-conditions.	4

2.3.2 National Significance

Apart from providing important scientific advances and innovations, the majority of surveyed projects also support a range of social, security, environmental and economic outcomes and needs within Australia. They encompass a broad range of objectives and applications, as summarised in Table 2-8. These national benefit areas reinforce the relevance of EO-related research in Australia to the SBAs cited in Section 2.3.1.

Table 2-8 National Benefits and Significance of Surveyed Projects

National Benefit	Significance	Establishment
Improved weather forecasting and public safety warnings from extreme weather events	Sparseness of surface weather data in the Southern Hemisphere makes EOS data sources particularly valuable. It is EO usage that has resulted in vast improvements in weather forecast accuracy so that there is little hemispheric difference in skill.	CAWCR, BoM
Monitor aerosols and cloud	Enhanced weather understanding of aerosol and cloud processes, model validation, wind erosion and dust storms	CSIRO, BoM
Climate modelling	EO provides a growing number (currently about 30) of key data streams needed by modern numerical weather models. Research including refining model boundary conditions, quality control and production of new data inputs to climate models (i.e. soil moisture, sea surface temperature, ocean current heat transfer, emissivity, ocean current heat transfer, land-surface dynamics, etc.) Applications of EO for high impact weather is critical for the analysis and short term prediction of high impact weather including fog, volcanic ash, severe thunderstorms	CAWCR, BoM, UTS, MonashU, BLUELink, IMOS
Antarctic monitoring and surveillance	Monitoring global climate variability, monitoring of ice and glacier thickness and dynamics, assessment of current and potential sea-level rise, flora and habitat monitoring, exercise of Australian Antarctic sovereignty claims, forecast support to AAD operations	AAD, CRC ACE, UTas
Improved gravity models	More detailed mapping of Earth's crust, soil moisture dynamics at basin scales, detection of unique mineral deposits	ANU
Ocean forecasting and surveillance	Support safety of Defence and civil shipping, sea level rise, ocean ecosystem activity, standardisation of ocean datasets	CAWCR, BoM, BLUELink, CSIRO, IMOS, UTas
Coastal monitoring	Coastal water quality, coastal habitat change monitoring, sea-level measurement and calibration, improved tidal modelling, monitoring of the condition of the Great Barrier, Ningaloo and other reef systems	CSIRO, IMOS, UTas, CurtinU
Standardised, continental/ hemispheric EOS products	Monitoring land cover and condition, collecting sea surface Cal/Val measurements for one eighth of the Earth's surface	AusCover TERN, GA, IMOS, CurtinU
Early detection of environmental problems	Such as coral bleaching, wetland health, woody weed extent, droughts and vegetation dryness	AIMS, OEH, Parks Victoria, Vic DPI
Highlighting and quantifying environmental changes	Monitoring natural resources and support for legislated monitoring systems, environmental change assessment in support of major infrastructure works	UQ, OEH, DSE, ABARES, UAdel, CSIRO
International Forest Carbon Initiative	Allows Australia and regional neighbours to participate in new international climate-related agreements and incentive mechanisms related to forest carbon	CSCSI, DCCEE, UNSW, CSIRO
Estimate bushfire threats and emissions	Support emergency management, soil moisture, fuel loading ,carbon emissions reporting, seasonal fire forecast and assessment, hot spot monitoring	GA, BoM, CDU, Landgate
Flood disaster mapping	Disaster risk assessment, improved emergency response activities and support aftermath, flood risk assessment and response planning for isolated communities	GA, Landgate, DERM, UoW, MonashU, WIRADA
Improved geological models	Support of resource exploration and mining	USyd, GA, CSIRO
Improved geophysical measurements	Locate groundwater sources and quantify changes	GA
Assess irrigation water usage, productivity and weed infestation in agriculture	More efficient use of agricultural resources, reduced chemical management, and greater productivity	CSU, DSE, DEEDI, CSIRO
Quantify groundwater and surface water extent and volumes	Map flood extent, soil moisture, monitor evapotranspiration and vegetation response to climate change	CSIRO, BoM, UNSW, MonashU, Landgate
Inland water quality monitoring	Feasibility study for operational earth observation of inland water quality in response to monitoring requirements	CSIRO

2.3.3 Linkages to Operational Programs

The *CEODA-Ops* Report (Geoscience Australia, 2011) listed 91[5] operational EO programs currently being undertaken in Australia (see Appendix B). These were referenced in the *CEODA-R&D* survey to demonstrate the linkages between current R&D projects and operational outcomes. Survey respondents were asked to select up to three of these operational programs that were related to their projects. During the survey process, ten additional programs were identified to produce a final list of 101 operational programs (see Appendix B for details) that are related to the surveyed R&D projects.

Over 70% of the R&D projects surveyed cited one or more linkages to 60 of these current operational programs. Those programs supported by multiple research projects are listed in Table 2-9.

It should be noted that AusCover TERN and the Centre for Weather and Climate Research (CAWCR) were included in both the *CEODA-Ops* list of operational programs and the *CEODA-R&D* survey. These projects are unique in that they involve the joint establishment of research infrastructure and EO data centres to support both research and operational activities. As such, the two surveys address different aspects of their work.

Those operational programs that are most supported by the surveyed R&D projects involve large area monitoring and/or modelling of environmental resources. In particular, EO-dependent programs that involve legislative monitoring, such as the National Carbon Accounting System (NCAS), have been developed from, and continue to be refined by, Australian R&D projects. Australia is now a world leader in carbon accounting and shares this expertise with the global community through agreements such as the International Forest Carbon Initiative (IFCI) and co-leadership of the GEO Forest Carbon Tracking task and associated Global Forest Observation Initiative (GFOI).

Many of the methodologies being used in operational programs are also derived from R&D projects that are initiated without direct operational linkages. The Sentinel Hotspots program, for example, which was based on the adaptation of international fire detection systems (Dyce *et al.*, 2004), was conceptualised by CSIRO and the Defence Imagery and Geospatial Organisation, and implemented in collaboration with GA. This Australian expertise has also been used to help set up the multi-hazard Sentinel Asia program (Held and Kaku, 2007). Similarly, the successful Statewide Landcover and Tree Survey (SLATS) program initiated in Queensland is being adapted for use in NSW and Victoria. State agencies are generally focused on implementation, rather than development, of original methodologies for operational use, and rely on the results of R&D projects to direct their implementations.

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5 Program 26 was not included in this list due to insufficient EOS data usage.

Table 2-9 Operational Programs Supported by Multiple Surveyed Projects

Operational Program	Jurisdiction	Number of Surveyed Projects
AusCover TERN	DIISR	8
Australian Antarctic Division, Australian Antarctic Data Centre	DEWHA	4
Caring For Our Country	DAFF	4
Centre for Weather and Climate Research (CAWCR)	DIISR/DSEWPC	4
State of Environment (SOE)	DEWHA	4
Australian Collaborative Land Use Mapping Program (ACLUMP)	DAFF	3
Biomass Monitoring	QLD	3
Emergency Management Australia	AGD	3
National Plan for Environmental Information	DSEWPC	3
Statewide Landcover and Tree Study (SLATS)	QLD	3
BLUELink	DSEWPC/Defence / DIISR	2
DEM (Digital Elevation Model) and Surface Modelling	ANZLIC	2
Evapo-transpiration Modelling	VIC	2
FireWatch Program	WA	2
Groundcover Monitoring	QLD	2
International Forest Carbon Initiative (IFCI)	DCCEE	2
National Carbon Accounting System (NCAS)	DCCEE	2
National Forest Inventory	DAFF	2
National Land and Water Resources Audit	DAFF	2
National Land Cover Mapping	RET	2
National Weather and Climate	DEWHA	2
Pre-competitive Mineral Prospecting Research	RET	2
Queensland Wetland mapping and Classification	QLD	2
Satellite Altimetry	DEWHA	2
Sea Surface Temperature and Height Anomaly	NSW	2

2.3.4 Operational Outcomes

A wide range of future operational outcomes is expected to emerge from the research currently being undertaken by the survey population. Future operational outcomes cited by respondents are summarised in Table 2-10. The diversity, and national significance, of these outcomes clearly demonstrate the value of this research.

Table 2-10 Future Operational Outcomes from Surveyed Projects

Application Area	Operational Outcomes	Essential EO Data Types
Oceanography	Submarine detection; fishing surveillance; ocean weather alerts	Low Resolution Optical, Radar Altimeters, *in situ*
	Sea surface topography, tidal modelling, tsunami warnings	Passive Microwave, Radar Altimeters, *in situ*
	Sea surface temperature, coral health warnings, ocean colour	Earth radiation budget radiometers, Low Resolution Optical, Ocean Colour Instruments, *in situ*
Coastal	Monitoring seagrass health/extent	High Resolution Optical
	Systematic shallow coastal bathymetry/ vegetation mapping	Low Resolution Optical, Medium Resolution Optical, High Resolution Optical, Hyperspectral, Ocean Colour Instruments
	Routine water quality monitoring	Low Resolution Optical, Ocean Colour Instruments
Meteorology	Dust warnings;	Cloud profile and rain radars, Lidar, Multiple Direction/ Polarisation Instruments
	Improved weather forecasting and climate modelling	Atmospheric chemistry instruments, atmospheric temperature and humidity sounders, cloud profile and rain radars, Low Resolution Optical, passive microwave, Lidar, multiple direction/ polarisation instruments, Radar Altimeters, Scatterometers
	Atmospheric correction models	Multi-direction polarisation instruments, *in situ*
Glaciology	Monitoring velocity fields of glaciers and ice sheets	SAR (C-band)
Hydrology	Improved precipitation, flood forecasting, drought monitoring	Passive Microwave, SAR (L-band), *in situ*
	Monthly evapotranspiration estimate	Low Resolution Optical, High Resolution Optical, *in situ*
	Improved management of water resources from eco-hydrological dynamics	Low Resolution Optical
	Catchment scale changes in total water storage for water accounting	Gravity instruments
	Mapping surface permeability	Medium Resolution Optical, High Resolution Optical, Hyperspectral, *in situ*
	Routine monitoring of inland water quality	Low Resolution Optical, Medium Resolution Optical, High Resolution Optical, Hyperspectral, Ocean Colour Instruments
	Map paleovalleys for groundwater locations in arid and semi-arid Australia	Low Resolution Optical, Radar Altimeters
Geology	Understanding plate tectonics	Radar Altimeters; gravity, magnetic field and geodynamic instruments
	Quantifying methane gas emissions and other pollutants from mining	High Resolution Optical, Hyperspectral, *in situ*
	3D mineral maps (sub-surface and surface mineralogy)	Atmospheric chemistry instruments, Medium Resolution Optical, High Resolution Optical, Hyperspectral, *in situ*
	Characterising soil types	High Resolution Optical, Hyperspectral, *in situ*
	Integrated, continental GIS for Australian lithosphere for mineral exploration	Medium Resolution Optical; High Resolution Optical; Hyperspectral; gravity magnetic field, and geodynamic instruments; *in situ*

Table 2-10 (continued)

Application Area	Operational Outcomes	Essential EO Data Types
Disasters	Surface water mapping, flood mapping, cloud mapping,	Low Resolution Optical, Medium Resolution Optical
	Automated feature extraction for flood lines and fire scars	Low Resolution Optical, Medium Resolution Optical
	Monitor fire occurrence and spread	Low Resolution Optical
	Monitor live fuel moisture to assess fire risk and drought status	Low Resolution Optical
	Monitor oil slicks	Low Resolution Optical, Medium Resolution Optical, SAR
Agriculture	Paddock to plate tracking of products, crop auditing, regional yield and variability predictions,	Medium Resolution Optical, High Resolution Optical, *in situ*
	Monitor water requirements and usage in irrigated crops	Medium Resolution Optical
Carbon	Carbon Accounting	Low Resolution Optical, Medium Resolution Optical
	Measuring biosequestration	High Resolution Optical
	Monitoring forest extent for biomass and carbon estimates	Medium Resolution Optical, SAR (all, especially L-band), *in situ*
	Estimating emissions from bushfires in tropical savannahs	Low Resolution Optical, Medium Resolution Optical
Land Use	Land Use Information Systems	Low Resolution Optical, Medium Resolution Optical
Land Degradation	Monitoring soil erosion risk	Low Resolution Optical
Wetlands	Monitor inundation extent, identify ecologically significant wetlands	SAR (L-band)
	Operational monitoring of wetlands	Medium Resolution Optical
Vegetation	Automated large area monitoring of vegetation components, assessing impact of land management regimes	Medium Resolution Optical, Lidar, *in situ*
	Monitoring forest extent and disturbance	Low Resolution Optical, Medium Resolution Optical, High Resolution Optical, Lidar, *in situ*
	Fractional cover modelling and dynamic land cover classification	Low Resolution Optical, Medium Resolution Optical, *in situ*, atmospheric measurements
	Monitoring groundcover in rangelands	Low Resolution Optical, Medium Resolution Optical, *in situ*
	Mapping weed species	High Resolution Optical, *in situ*
	National, standardised biophysical products for terrestrial applications	Low Resolution Optical, Medium Resolution Optical, High Resolution Optical, Hyperspectral, SAR (L-band), Lidar, *in situ*
Cartography	Enhanced automation of feature extraction for mapping and change detection	High Resolution Optical, Lidar
Sensor and Platform Design and Validation	UAV functionality for low cost, flexible local area monitoring and/or Cal/Val	High Resolution Optical, Hyperspectral, Lidar, Radar Altimeter, *in situ*
	Monitoring Antarctica	High Resolution Optical, Lidar, Radar Altimeter, *in situ*
	Health applications e.g. pollen warnings	Low Resolution Optical, Medium Resolution Optical

Anticipated operational improvements in the following areas are expected to have particular benefit for Australia:

- Maritime forecasting—this is expected to mimic the development of weather forecasting in the last few decades;
- Climate modelling and carbon accounting—both domestically and internationally to support the National Carbon Accounting System (NCAS), Indonesian National Carbon Accounting System (INCAS) and International Forest Carbon Initiative (IFCI);
- Routine weather forecasting, high impact weather detection and nowcasting, climate monitoring, disaster monitoring, aviation safety, and carbon policy implementation;
- Water resource management—reliable long-term models of eco-hydrological factors, including evapo-transpiration, surface water and vegetation dynamics;
- Disaster mitigation and management—early detection and rapid response for fires and floods;
- Early warning for coral reef stress;
- Dust warnings and soil erosion risk assessment based on improved atmospheric and soil moisture measurements;
- Agricultural forecasting for yield, irrigation needs, risks and variability;
- Inland water quality monitoring in response to legislative requirements;
- Coastal monitoring of both water quality and habitat health, shallow water bathymetry; and
- Geoscience mapping for mineral exploration, groundwater locations and land management.

Several of these operational areas have progressed rapidly over recent decades and can be expected to develop further with access to improved EO datasets. Many of these areas involve commercial benefits and/or legislative requirements, and several methodologies have been exported for use overseas.

2.3.5 Collaboration

Survey results relating to interactions between projects and researchers and access to restricted EO data (in the sense that the data were only available to certain activities for a defined period) are summarised in Table 2-11.

Table 2-11 Project Collaboration

Type of Collaboration	Number of Surveyed Projects	% Projects
Part of Larger and/or External Program	43	77%
Domestic Collaboration	53	95%
International Collaboration	41	73%
Access to Restricted Datasets	23	41%

The significant extent of current domestic collaboration indicates that the majority of these research activities are not being conducted in isolation. These connections between researchers should reduce duplication of effort, and allow more efficient use of data and equipment.

Over three-quarters of Australian researchers surveyed are also actively connected to international research activities, with 20 having formal membership of international science teams. Considering the need to access primarily foreign satellite data for research, it is no surprise to see the strong international linkages used by most R&D teams. For the surveyed projects, these connections between Australian scientists and international space agencies are summarised in Table 2-12.

Table 2-12 International Space Agency Connections to Surveyed Projects

Agency	Linkages with Surveyed Projects	Principal Investigator/Mission Team
NASA (USA)	14	10
ESA (Europe)	10	6
JAXA (Japan)	9	1
ISRO (India)	5	1
CNES (France)	3	1
CSA (Canada)	3	1
DLR (Germany)	3	0
USGS (USA)	3	0
GISTDA (Thailand)	1	0
NOAA (USA)	1	0
TOTAL	**52**	**16**

In addition, several projects have linkages with other international bodies:

- 22 projects cited collaboration with 33 overseas universities and/or research organisations;
- 17 projects are working with 17 international partnerships (such as WMO);
- Eight projects are collaborating with 14 foreign government agencies (such as the British Geological Survey); and
- Five projects are collaborating with seven foreign corporations (such as US company ITT).

By virtue of these various connections, 20 (36%) of the surveyed research projects gain access to EO datasets that are not publicly available.

Australia's involvement with these international partners includes exporting methodologies for using EO data, designing sensor components for forthcoming space missions, and calibration and validation activities for new sensors. The latter is seen by many researchers to be Australia's major contribution to the international EO community.

2.4 Major Projects

To avoid the potential for bias in analysing survey results, the magnitude of some surveyed projects warrants particular consideration. One key complication in analysis of these projects, however, has been the need to decide what proportion of the work and resources are truly dedicated to R&D and quality control activities, versus basic operation of data access and delivery systems to other operational or external research programs. Selected characteristics for the 13 largest projects are summarised in Table 2-13.

It should be recognised that these major projects will be amongst the heaviest users of EO data in the country. For the sake of simplicity and to avoid debate over relative importance or ranking of one activity over another, the study has not weighted the analysis of data usage based on data volumes. Rather each project is given equal weight, and readers can draw their own conclusions based on the extensive information presented regarding the purpose of the underlying research and the related national outcomes and benefits. This does have a bearing on the nature of the conclusions regarding Priority Data Types in Section 3. Meteorology and climate research at BoM and CAWCR are the heaviest data users in the country, and accordingly atmospheric measurements – such as from IR sounders – would receive a significantly higher priority than in our analysis, were the results weighted. Instead it is seen that there are not a large number of users outside the focused weather and climate community. Their particular needs are the proposed focus of a further report in the CEODA series.

On the basis of their resources, duration, data usage, collaboration and nationally significant operational outcomes, six of these projects were deemed major, namely AusCover TERN, BLUELink, IMOS, Joint Remote Sensing Research Centre, Numerical Weather Prediction, and Other Meteorological Research. These will be referred to as the *CEODA-R&D* Major Projects in subsequent sections of this report.

Table 2-13 Large and Significant Projects in Survey

Project	Approximate Annual Budget ($ million)	Duration (years)	Annual Staffing (FTE)	Essential EO Data Types	Domestic Collaboration
Numerical Weather Prediction	5	1974-ongoing	19	9	BoM, University of Melbourne, Macquarie University, RMIT
BLUELink	4	2002-2014	8.5	2	BoM, CSIRO, Navy
AusCover TERN	2	2009-2014	10	6	GA, ABARES, ERIN-SEWPaC, Curtin University, RMIT, UQ, UTS, UAdel, CDU, QDERM, BoM, CSIRO
Other Meteorological Research	2	1974-ongoing	8	9	BoM, University of Melbourne, Macquarie University, RMIT
IMOS	2	2007-2013	2	4	WASTAC, BoM, GA, AIMS, CSIRO, UTas
Unlocking the Landsat Archive	1+	2011-2013	9	2	GA, Lockheed Martin Australia Ltd, NCI, CRCSI, Victorian Partnership for Advanced Computing
Virtual Geological Observatory (VirGO)	1+	2003-present	8	3	University of Sydney, CSIRO, AuScope, GA, Monash University
WIRADA	1+	2008-2013	7	3	CSIRO, CAWCR, ANU, UQ
C3DMM	1+	2009-2013	6.7	4	CSIRO, GSWA, AuScope Grid, iVEC, GA, BHP-B, Murchison Metals
ERSDAC Soil Mapping	1+	2009-2011	5	2	CSIRO, DAFWA and DEC (WA)
Paleovalleys	1	2008-2012	5	2	GA, WA+SA+NT Geological Surveys, WA+SA Dept of Water, NT DNREAS, UNSW, Flinders University
IFCI Demonstration	1	2009-2012	4	3	UNSW, CRCSI, CSIRO, DCCEE
Joint Remote Sensing Research Centre	0.4	2007-ongoing	6	6	UQ, DERM, NSW OEH, Vic DSE

2.4.1 AusCover TERN

This research facility within the Terrestrial Ecosystem Research Network (TERN) involves direct collaboration between CSIRO and ten other research organisations around Australia. AusCover will produce and deliver free and open access to nationally consistent land-surface biophysical map products that are validated for Australian conditions. These will be derived from long-time series of satellite and airborne datasets and next generation remote sensing research data.

2.4.2 BLUELink

This collaborative project between CSIRO, BoM and the Australian Navy is an operational oceanography system that can deliver ocean forecasts for coastal and marine industries. These forecasts provide day-to-day variations in coastal and ocean currents and eddies, and surface and subsurface ocean properties, that impact and are linked to maritime and commercial operations, defence applications, safety-at-sea, ecological sustainability, regional and global climate. BLUELink models are anticipated to generate a long-term, ocean-based climate monitoring system for primary producers.

2.4.3 IMOS

The Integrated Marine Observing System is an NCRIS facility that coordinates ocean observations across Australia, with EO comprising the largest dataset. It assembles and delivers free and open access to national datasets for physical, chemical and biological variables relevant to marine and climate science through its IMOS Ocean Portal. The sub-facilities within the IMOS Remote Sensing Facility include Ocean Temperature, Ocean Colour, TOPEX/Jason Microwave Radiometer (TMR/JMR) Radar Altimetry, and data cataloguing.

2.4.4 Joint Remote Sensing Research Centre

This Centre involves collaboration between the University of Queensland Centre for Spatial Environmental Research, Queensland Department of Environment and Resource Management, NSW Office of Environment and Heritage, and Victorian Department of Sustainability and Environment. It provides specialised training that supports research activities aimed at understanding the impacts that humans and climate have on the natural environment, and addresses research problems and long-term monitoring problems faced by the Queensland, NSW and Victorian governments in using satellite remote sensing for legislated activities.

2.4.5 Numerical Weather Prediction

BoM has recently implemented a new computer forecasting program (ACCESS) that relies on a wide range of EO data sources to provide improved weather forecasting over the Australian region. Satellite data from 30 to 50 satellite instruments are received in near real-time and used to develop, test and deliver methods for determining current and future atmospheric and the surface state for weather and climate monitoring and prediction, numerical weather prediction and a large number of other applications of use to governments, NGOs and private industry.

2.4.6 Other Meteorological Research

BoM also conducts research that is not directly related to numerical weather prediction, including monitoring short and long term condition of the atmosphere, oceans and vegetation. These include improved forecasting and nowcasting using additional information such as convective cloud development, rainfall measurement, cyclone positioning, and monitoring dust, drought, floods, fog, volcanic ash, short term forecasting of high impact weather, and grass curing status.

2.5 Summary

The *CEODA-R&D* survey has collated detailed information describing 56 EO-related research projects currently being conducted in Australia. The surveyed projects comprise a representative subset of the broader research activities in this area and include the major areas of EO-related R&D in this country. These projects represent a total annual budget of nearly $35 million and employment of over 190 full time equivalents in both civil and defence organisations. (Note that the 13 large and significant projects listed in **Table 2-13** collectively contribute nearly two thirds of this total annual budget and employ over half the staff numbers mentioned.) The 56 projects involved in the *CEODA-R&D* survey comprise less than a quarter of the current EO-related R&D projects in Australia.

Many more EO-related activities which are just outside the scope of this R&D-focused study are also underway, and some of these are documented in other studies such as *CEODA-Ops* (Geoscience Australia, 2011). The surveyed projects, nonetheless, make significant input to a range of operational programs in Australia, with over 70% citing direct support to or from the 91 programs identified in *CEODA-Ops*. This research services several areas of national importance, in particular those relating to environmental and resource monitoring and reporting.

3 EO DATA REQUIREMENTS: CURRENT

Based on the 56 sample projects described in Section 2, the following sub-sections detail the type, resolution, extent and volume of EO data that is currently being used in Australian research (Section 3.1) and consider the supply channels through which these data are delivered (Section 3.2). Based on the current usage and supply information, nine Priority Data Types are identified and further discussed in Section 3.3.

3.1 Usage

This section gives an overview of the usage of EO data in support of the R&D projects that have been surveyed. Usage is analysed both in overall terms, and by data type based on the 18 instrument definitions identified in the CEOS Handbook (see Table 2-2).

3.1.1 All Projects

Using the survey ratings described in Section 2.1.3, the overall importance of EO data usage to the sample set of projects is summarised in Table 3-1. Over 85% of the surveyed projects depend on some form of EO data from satellite sources, while nearly 40% require airborne EO data to conduct their research activities.

Table 3-1 EO Data Importance

Entries indicate the number of projects

EO Data Source	EO Data Importance Rating				
	Essential	Advantageous	Essential + Advantageous	Opportunistic	Promising
Satellite	48	5	53	2	0
Airborne	21	11	32	7	1

Another six projects that rated Airborne EO data as essential considered Satellite sources to be either advantageous or opportunistic for their research, and a further 11 projects that rated Satellite EO data as essential, considered Airborne sources as advantageous.

The results for these ratings for usage of individual data types are shown in Table 3-2 and Table 3-3 for satellite and airborne sources respectively. These numbers differ from those in Table 3-1 in that they indicate which specific EO data types are, or could be, relevant to the sample projects.

With reference to Table 3-2, Low Resolution Optical data was rated as the most important EOS data type, being used by just over half of the survey projects (essential + advantageous). Medium Resolution Optical data is also needed in nearly half of the projects, and High Resolution Optical imagery in nearly one third. Passive microwave and Synthetic Aperture Radar (SAR) data types were also essential for several projects, and considered both advantageous and/or promising to others. Hyperspectral, Lidar and Radar Altimeter instruments were among the most 'promising' prospects for future research from satellite sources.

Table 3-2 Satellite EO Data Importance

Entries indicate the number of projects

EO Data Type	EO Data Importance Rating				
	Essential	Advantageous	Essential + Advantageous	Opportunistic	Promising
Optical – Low Resolution	27	2	**30**	1	1
Optical – Medium Resolution	23	5	**28**	1	0
Optical – High Resolution	10	7	**17**	4	2
Passive Microwave Radiometry	7	3	**10**	2	4
Radar Altimetry	8	0	**8**	0	4
Synthetic Aperture Radar – C band	2	6	**8**	3	3
Ocean Colour	6	1	**7**	0	3
Lidar	5	2	**7**	0	8
Synthetic Aperture Radar – L band	5	2	**7**	2	5
Hyperspectral Imagery	4	3	**7**	1	6
Multiple Direction/ Polarisation	3	4	**7**	0	4
Atmospheric Chemistry	2	5	**7**	0	3
Synthetic Aperture Radar – X band	2	5	**7**	2	2
Cloud Profile and Rain Radar	3	3	**6**	1	1
Atmospheric Temperature and Humidity Sounding	3	2	**5**	1	2
Gravity, Magnetic Field and Geodynamic	3	2	**5**	1	3
Scatterometry	2	3	**5**	1	1
Earth Radiation Budget Radiometry	2	1	**3**	2	3
TOTAL	**117**	**56**	**174**	**22**	**55**

With reference to Table 3-3, Hyperspectral and Lidar were rated as the most desirable data types from airborne sources, each being essential to over 10% of projects. These results support those from Table 3-2, which imply that satellite sources for these datasets would be well utilised if they were more widely available. Passive microwave, SAR and geomagnetic data from airborne sources were also considered essential or advantageous for several projects.

Table 3-3 Airborne EO Data Importance

Entries indicate the number of projects

EO Data Type	EO Data Importance Rating				
	Essential	Advantageous	Essential + Advantageous	Opportunistic	Promising
Hyperspectral Imagery	8	5	**13**	3	3
Lidar	6	6	**12**	3	6
Optical – High Resolution	8	2	**10**	1	1
Gravity, Magnetic Field and Geodynamic	2	1	**3**	0	0
Synthetic Aperture Radar – L band	3	0	**3**	0	0
Passive Microwave Radiometry	2	0	**2**	0	0
Optical – Low Resolution	0	3	**3**	0	0
Scatterometry	0	2	**2**	0	0
Atmospheric Chemistry	1	0	**1**	0	0
Radar Altimetry	0	1	**1**	0	1
Synthetic Aperture Radar – X band	1	0	**1**	0	0
TOTAL	**31**	**20**	**51**	**7**	**11**

In addition to the CEOS Instrument list, respondents were asked to rate their usage of *in situ* and other types of satellite data. Results for usage of these data types are summarised in Table 3-4, showing that over half the projects need ground-based data to calibrate or validate their EO data analyses.

The rating frequencies in Tables 3-2 and 3-3 can be considered one measure of 'criticality' for these data types in current EO-related research activities in Australia. Within the subset of projects which rated any individual data type as 'essential', Table 3-5 separates data usage by project budget, showing that the most widely used data types, optical and SAR, are essential to projects from all budget ranges, and are especially popular in the smaller budget projects. Instruments specifically designed for atmospheric studies are mostly used for medium and large budget projects, as are the newer instrument types such as Hyperspectral imagers, Lidars and Radar Altimeters.

Table 3-4 *In Situ* and Other EO Data Importance

Entries indicate the number of projects

EO Data Type	EO Data Importance Rating				
	Essential	Advantageous	Essential + Advantageous	Opportunistic	Promising
In Situ	29	9	**38**	1	2
Other	5	1	**6**	1	0

Table 3-5 Project Annual Budget for 'Essential' Satellite EO Data Types

Entries indicate the number of projects

EO Data Type	Annual Budget				TOTAL
	up to $100,000	$100,000 to $500,000	$500,000 to $1,000,000	$1,000,000+	
Atmospheric Chemistry	0	0	0	2	2
Atmospheric Temperature and Humidity Sounding	0	1	0	2	3
Cloud Profile and Rain Radar	0	1	0	2	3
Earth Radiation Budget Radiometry	0	1	0	1	2
Gravity, Magnetic Field and Geodynamic	1	2	0	0	3
Hyperspectral Imagery	0	1	2	1	4
Passive Microwave Radiometry	0	4	0	3	7
Lidar	0	3	0	2	5
Multiple Direction/ Polarisation	0	1	0	2	3
Ocean Colour	0	1	3	2	6
Optical – High Resolution	3	4	2	1	10
Optical – Low Resolution	5	9	5	8	27
Optical – Medium Resolution	4	10	4	5	23
Radar Altimetry	1	1	0	6	8
Synthetic Aperture Radar – C band	1	0	0	1	2
Synthetic Aperture Radar – L band	2	1	0	2	5
Synthetic Aperture Radar – X band	0	0	1	1	2
Scatterometry	0	0	0	2	2
TOTAL	**17**	**40**	**17**	**43**	**117**

Similarly, an analysis of data usage in terms of the four types of research establishment is presented in Table 3-6. The results in Table 3-6 suggest that most Federal and State agencies rely on optical sensors to support their EO-related R&D activities, whereas research and academic institutions use a wider range of data types.

Table 3-6 Research Establishments Using 'Essential' Satellite EO Data Types

Entries indicate the number of projects

EO Data Type	Research Establishment				TOTAL
	Academic Institution	Research Organisation	State Agency	Federal Agency	
Optical – Low Resolution	7	10	4	6	**27**
Optical – Medium Resolution	5	6	8	4	**23**
Optical – High Resolution	2	4	3	1	**10**
Radar Altimetry	2	5	0	1	**8**
Passive Microwave Radiometry	4	3	0	0	**7**
Ocean Colour	1	5	0	0	**6**
Lidar	1	3	1	0	**5**
Synthetic Aperture Radar – L band	3	1	1	0	**5**
Hyperspectral Imagery	1	3	0	0	**4**
Atmospheric Temperature and Humidity Sounding	1	2	0	0	**3**
Cloud Profile and Rain Radar	0	3	0	0	**3**
Gravity, Magnetic Field and Geodynamic	2	0	0	1	**3**
Multiple Direction/ Polarisation	0	3	0	0	**3**
Atmospheric Chemistry	0	2	0	0	**2**
Earth Radiation Budget Radiometry	1	1	0	0	**2**
Synthetic Aperture Radar – C band	1	0	0	1	**2**
Synthetic Aperture Radar – X band	1	0	0	1	**2**
Scatterometry	0	2	0	0	**2**
TOTAL	**32**	**53**	**17**	**15**	**117**

3.1.2 Major Projects

The EO data usage within the *CEODA-R&D* Major Projects (defined in Section 2.4) requires special consideration. The importance of these Major Projects in terms of national outcomes was detailed in Sections 2.3.2 and 2.4. A summary of those data types rated as essential by each Major Project is presented in Table 3-7. Data usage in these projects confirms Low Resolution Optical data type as the highest single Priority Data Type for Australian EO-related R&D activities.

Table 3-7 Major Projects using 'Essential' Data Types

Entries indicate the number of different sensors cited

EO Data Type	CEODA-R&D Major Projects						TOTAL
	AusCover	BLUELink	IMOS	JRSRC	NWP	Other Met.	
Optical – Low Resolution	2	1	2	1	10	10	**26**
Atmospheric Temperature and Humidity Sounding	0	0	0	0	11	11	**22**
Radar Altimeters	0	3	1	0	5	5	**14**
Atmospheric Chemistry	0	0	0	0	6	6	**12**
Passive Microwave Radiometry	0	0	1	1	5	5	**12**
Cloud Profile and Rain Radars	0	0	0	0	3	3	**6**
Optical – High Resolution	3	0	0	2	0	0	**5**
Lidar	(airborne)	0	0	(airborne)	2	2	**4**
Scatterometry	0	0	0	0	2	2	**4**
Multiple Direction/ Polarisation	0	0	0	1	1	1	**3**
Optical – Medium Resolution	1	0	0	2	0	0	**3**
Gravity, Magnetic Field and Geodynamic	0	0	0	0	1	1	**2**
Ocean Colour*	0	0	0	0	1	1	**2**
Synthetic Aperture Radar – L band	1	0	0	1	0	0	**2**
Earth Radiation Budget Radiometry	0	0	1	0	0	0	**1**
Hyperspectral Imagers	1 (+ airborne)	0	0	(airborne)	0	0	**1**
Synthetic Aperture Radar – C band	0	0	0	0	0	0	**0**
Synthetic Aperture Radar – X band	0	0	0	0	0	0	**0**
In Situ	Yes	Yes	Yes	Yes	Yes	Yes	All yes
Other	0	0	0	2 (ground)	3	3	**6**
TOTAL (excluding airborne, *in situ*, and ground)	**8**	**4**	**5**	**8**	**50**	**50**	**125**

* Some key instruments that contribute to Ocean Colour are categorised under Optical – Low Resolution

Both data volume and sensor range are particularly large for the Major Projects being conducted by CAWCR, with many of the sensors cited only being used by these projects (see Section 3.2). Many of these products are widely used in the university research community as well as within projects that are not explicitly EO and so are not captured in this survey. While some of these Major Projects appear to involve a small number of sensors, they use large volumes of EO data. IMOS, for example, acquires 4 TB of Low Resolution Optical data annually and maintains an archive of 45 TB. Similarly, the Low Resolution Optical data archive for AusCover currently comprises 62 TB, with large, ongoing annual acquisitions.

3.2 Supply

The EOS data supply arrangements currently being used in the surveyed projects involve 59 unique data sources and are listed by data type in Table 3-8. The 17 instruments (nearly 30%) that are used exclusively by CAWCR for weather forecasting are differentiated in this table. Instruments that were identified by survey respondents as important but which have not yet been launched have not been included in this table.

Table 3-8 Supply Sources for 'Essential' Satellite EO Data Types

EO Data Type	Data Sources		TOTAL INSTRUMENTS		
	Instruments exclusively used by CAWCR/BoM	Instruments used by all CEODA-R&D projects (including CAWCR/BoM)	CAWCR/BoM only	Other Projects	All Projects
Optical – Low Resolution	Imager (GOES), Sounder (GEOS), SEVIRI (Meteosat), IVISSR (FY-2), MI (COMS)	MODIS (Aqua, Terra), MERIS (Envisat), Imager (MTSAT), AVHRR (NOAA, MetOp-A), AATSR (Envisat)	5	5	10
Atmospheric Temperature and Humidity Sounding	AMSU-A (Aqua, NOAA, MetOp-A), AMSU-B (NOAA), MHS (NOAA, MetOp-A), SSM/IS (DMSP), Sounder (GOES)	AIRS (Aqua), HIRS/3 (NOAA), HIRS/4 (NOAA, MetOp-A), IASI (MetOp-A)	5	4	9
Optical – High Resolution	-	MS and PAN (Ikonos-2), MSI (RapidEye), World View, Digital Globe, HRVIR (SPOT-4), HRS and HRG (SPOT-5), ASTER (Terra)	0	7	7
Atmospheric Chemistry	SCIAMACHY (Envisat), OMI (Aura), GOMOS (Envisat)	TANSO-FTS (GOSAT), AIRS (Aqua), IASI (MetOp-A)	3	3	6
Optical – Medium Resolution	-	HRVIR (SPOT-4), HRG (SPOT-5), ASTER (Terra), MSS (Landsat-5), TM (Landsat-5), ETM+ (Landsat-7)	0	6	6
Passive Microwave Radiometry	Aquarius (SAC-D/Aquarius), SSM/I (DMSP F-15)	JMR (Jason-1), MIRAS (SMOS), TMI (TRMM)	2	3	5
Radar Altimetry	-	POSEIDON-2 (Jason-1), POSEIDON-3 (Jason-2), SIRAL (CryoSat-2), ALT (HY-2A)	0	4	4
Multiple Direction/ Polarisation	-	MISR (Terra), POLDER-P (PARASOL), AATSR (Envisat)	0	3	3
Cloud Profile and Rain Radar	PR (TRMM)	CPR (CloudSat)	1	1	2
Gravity, Magnetic Field and Geodynamic	-	GRACE, CHAMP	0	2	2
Hyperspectral Imagers	-	Hyperion (NPM EO-1), HICO (ISS)	0	2	2
Ocean Colour*	-	OCM (OCEANSAT-2), GOCI (COMS)	0	2	2
Synthetic Aperture Radar – C band	-	ASAR (Envisat), SAR (Radarsat)	0	2	2

Table 3-8 (continued)

EO Data Type	Data Sources		TOTAL INSTRUMENTS		
	Instruments exclusively used by CAWCR/BoM	Instruments used by all CEODA-R&D projects (including CAWCR/BoM)	CAWCR/BoM only	Other Projects	All Projects
Synthetic Aperture Radar – X band	-	SAR 2000 (COSMO-SkyMED), X-Band SAR (TerraSAR-X)	0	2	2
Scatterometry	ASCAT (MetOp-A), Scatterometer (OCEANSAT2)	-	2	0	2
Earth Radiation Budget Radiometry	-	CERES (TRMM, Terra, Aqua)	0	1	1
Lidar	-	CALIOP (CALIPSO)	0	1	1
Synthetic Aperture Radar – L band	-	-	0	0	0
TOTAL			**18**	**48**	**66**
# Unique Instruments			**17**	**42**	**59**

* Some key instruments that contribute to Ocean Colour are categorised under Optical – Low Resolution

For each essential data type, respondents were asked to select the agreement type that governed data supply and the physical supply route used for data delivery (please refer to Appendix C-6 for details of supply categories). The vast majority of EO data used for R&D activities in Australia are available under public good agreements and are accessed via ftp/Internet arrangements, either from Geoscience Australia, or (often) directly from data servers operated by international agencies (e.g. NASA, USGS, ESA). This imposes significant loads on current Internet links to the USA and Europe. Some sources of meteorological data are covered by WMO Resolution 40, and a small number of researchers have enhanced access privileges based on either Primary Investigator status, data reception agreements or public good (research agreements).

While most respondents did not report current infrastructure obstacles, several commented in relation to overall data supply and download capacity. Some state governments impose extremely high download charges, which are avoided by consortia which include academic institutions. Bandwidth is a problem in more remote locations, such as Townsville, resulting in slow data transfer rates. For some data types, data access was compounded by 'data packaging' by the supplier. For example, AATSR data is only available via web access, without the facility to download sub-global coverages. The daily volume of data acquired over Australia by other sensors, such as CALIOP (CALIPSO), is too large to download in a single day. Some research projects currently lack the facilities and manpower to download ongoing data, so are concentrating on analysis of historical data. Certain key EO datasets in Australia are currently acquired and supplied largely on a 'good will' basis by selected research establishments, and these supply conditions were reported to contribute to unpredictable delays in data delivery.

The current data volumes being managed by seven of the 56 surveyed projects are listed in Table 3-9. Each of these projects involve storage, processing and ongoing acquisition of relatively large data volumes. The infrastructure implications of downloading these growing volumes of EO data, often from international sources, underline the importance of efficient data access and archiving facilities for Australian researchers, and the need for strategic infrastructure plans.

Table 3-9 Current Data Volumes for Selected Projects

CEODA-R&D Project	Historical Archives (approx. TB)	Annual Acquisitions (approx. TB)
AusCover TERN (CSIRO)	50	2.5
WIRADA (CSIRO)	50	4
IMOS (CSIRO)	45	13
Savanna Burning (CDU)	35	3.5
FireWatch (Landgate)	30	3
Cal/Val of VIIRS/GCOM-SGLI (UTS)	10	2.5
Ground Cover Mapping (DERM)	15	0.5
Total	**235**	**29.0**

Respondents were also asked about the quality control procedures used for each data type. The majority of researchers were satisfied with the quality of their data as supplied by the data provider, but some data types needed additional quality control procedures as well as calibration/validation (Cal/Val) for project requirements. In general, satisfaction with data quality among respondents was inversely correlated with an awareness of potential and/or current data acquisition problems with particular sensors. Those concerned with ongoing supply of calibrated and validated datasets for Australia stressed the need for algorithms and processing tailored to local conditions.

3.3 Priority Data Types

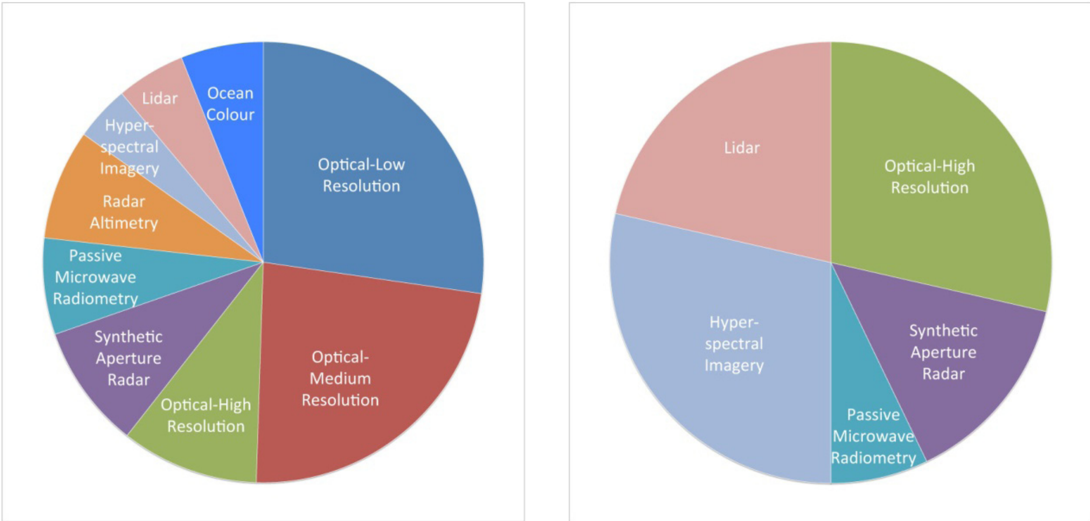
EO data usage in current R&D activities in Australia is analysed in Section 3.1, and current supply arrangements are considered in Section 3.2. The significance of these data types in supporting national outcomes is discussed in Section 2.3.2. On the basis of these results, the following nine EO data types can be considered as the 'Priority Data Types' in Australian research:

- Low Resolution Optical;
- Medium Resolution Optical;
- High Resolution Optical;
- SAR (C-, L- and X-band);
- Passive Microwave Radiometry;
- Radar Altimetry;
- Hyperspectral Imagery;
- Lidar; and
- Ocean Colour.

The proportion of projects rating each of these Priority Data Types as essential for current research is illustrated in Figure 3-1 (based on essential usage counts presented in Tables 3-2 and 3-3).

Figure 3-1 Usage of Priority Data Types by Surveyed Projects

a. Satellite Data b. Airborne Data



As noted in Section 2-4, this ranking makes no attempt to suggest the importance of one research project over another. Nor does it give weight to the data volumes involved. It simply indicates the frequency and diversity of use across all Australian research centres, and provides information on the anticipated national outcomes and benefits from the different research projects. Atmospheric data types (e.g. from temperature and humidity sounders such as IASI and AIRS) would no doubt appear in the list were a more arbitrary weighting scheme employed which reflected data volumes or project size. Further, atmospheric data corrections are a feature of almost every application involving calibrated land and ocean observations. The deeper significance of these data (other than suggested by the scope of this study) will be the subject of a CEODA Report focused on meteorological data needs. Section 2-4 explains the characteristics of the 13 'major projects' identified by the survey.

Some of the coverage characteristics required for these Priority Data Types are summarised in Table 3-10.

Table 3-10 Predominant Requirements of Priority Data Types

Priority EO Data Type	Spatial Resolution	Spatial Coverage	Temporal Coverage	Latency
Optical – Low Resolution	Low	National	Daily	Hours/Weeks
Optical – Medium Resolution	Medium	National	Various	Days/Weeks
Optical – High Resolution	High	Regional/Local	Other (field work/ irregular coverage)	Days/Weeks/ Not Important
Synthetic Aperture Radar	Medium	Regional	Annually	Weeks
Passive Microwave Radiometry	Low	Global	Daily	Hours
Radar Altimetry	Low	Global	Daily	Hours
Hyperspectral Imagery	High	Local	Monthly	Weeks
Lidar	High	Local	Annually	Weeks
Ocean Colour	Low	National	Daily	Hours

The coverage requirements listed in Table 3-10 highlight the different usage patterns that are associated with each of the Priority Data Types. As expected, those data types with higher spatial resolution tend to be preferred for smaller area studies, while lower spatial resolution data types are better suited to broader areas of coverage. The data types used for broad area coverage tend also to be required more often and more quickly.

Over all Priority Data Types, 32% of projects require national coverage, with 19% and 21% needing regional and global coverage respectively. New data are required each day for 32% of projects (mostly involving MODIS imagery), with 15% and 14% of projects requesting data each month and year. For 25% of projects, it was necessary that image acquisition coincided with:

- ground sampling;
- acquisition of other imagery;
- the time of maximum discrimination of a target feature; and/or
- occurrence of an external event (such as flooding).

The preferred latency—the delay between image capture and delivery—was surveyed as weekly for 35% of projects (mostly for Medium Resolution Optical data) and hourly for 26% of projects (mostly low resolution data).

For each of the Priority Data Types, usage and supply arrangements are detailed in Sections 3.3.1 to 3.3.9.

3.3.1 Low Resolution Optical (>80m)

Overview

Low Resolution Optical sensors record reflectances in the visible and infrared (including thermal) wavelengths with geometric pixel sizes greater than 80 m. Their large swath widths result in a higher frequency of acquisition than Medium Resolution systems (see Table 2-2) and most are operated for public good.

Being low cost and high frequency, this 'regional scale' data is used by a wide range of operational programs in Australia including:

- Disaster mitigation and management (bushfires, earthquakes, floods, and storms);
- Monitoring land use, land cover, ecosystems, native vegetation, salinity, water resources, and wetlands;
- Managing fisheries, reefs, floodplains, and environmental degradation;
- International agreements;
- Glaciology, oceanography, and climate studies; and
- Carbon accounting (Geoscience Australia, 2011).

Operational products currently being derived from Low Resolution Optical imagery include hotspot mapping of active bushfires, coastal water quality, ocean chlorophyll and temperature maps, land-surface temperature maps, regional landscape mapping, flood mapping, land use and land cover monitoring, and estimating greenhouse gas emissions.

Low Resolution Optical data are essential to 27 of the surveyed projects (nearly 50% of the sample across 17 different research groups). Of these 27 projects, 25 cited a total of 59 linkages to 32 different operational programs currently being conducted in Australia. The application areas being supported by this research are listed in Table 3-11. (Note that most projects support multiple application areas.)

Table 3-11 Projects Dependent on Low Resolution Optical Data

Application Area	Number of Surveyed Projects
Delivering national EO data products for terrestrial and marine studies	8
Monitoring and modelling land cover and condition	8
Locating active fires Mapping fuel moisture patterns and fire scars Estimating bushfire emissions	6
Monitoring coastal and inland water quality, and coastal habitats	5
Locating and monitoring groundwater sources, allocations and ecology	4
Monitoring sea surface temperature/height, ocean colour and reef health	4
Updating land use information	3
Mapping floods	2
Modelling weather, climate and atmospheric characteristics	2

Current Usage

The Low Resolution Optical sensors being used in EO-related research in Australia are listed in Table 3-12. Clearly the two most popular data sources are MODIS, being used by 45% of all surveyed projects, and AVHRR, being used by 21% of projects, in part due to their wide-area coverage, high frequency of acquisition, availability of standard derived products, and ease of access via Internet from the USA, or via several satellite ground stations operated by Australian agencies such as GA, BoM and regional multi-agency consortia. A number of projects expressed interest in moving from Low Resolution Optical to Medium Resolution Optical data should such data be available more frequently in the future.

Table 3-12 Usage of Low Resolution Optical Data

Entries indicate the number of projects

Low Resolution Optical Sensor	EO Data Importance Rating				
	Essential	Advantageous	Essential + Advantageous	Opportunistic	Promising
MODIS	25	1	**26**	1	0
AVHRR	12	0	**12**	1	0
Imager (MTSAT)	4	0	**4**	0	0
MERIS	4	0	**4**	0	0
VIIRS*	3	0	**3**	0	0
AATSR	2	1	**3**	0	0
Imager (GOES)	2	0	**2**	0	0
IVISSR (FY-2)	2	0	**2**	0	0
MI (COMS)	2	0	**2**	0	0
SEVIRI	2	0	**2**	0	0
Sounder (GOES)	2	0	**2**	0	0
TANSO-CAI	2	0	**2**	0	0
TOTAL	**62**	**2**	**64**	**2**	**0**

* VIIRS is not yet operational.

Table 3-12 includes both geostationary (over Australia and world-wide) and polar orbiting satellites, and is dominated by sensors that are provided in support of operational meteorological data needs. However, the priorities for meteorology and climate needs only would likely be rather different than that suggested by the table above. The imager on the MTSAT series of Japan, for example, is critical to BoM's operations.

Over half the projects using Low Resolution Optical data require daily, national coverage (often extending to continental shelf extents) without delay. These projects involve meteorological or coastal/marine applications, or the supply of data for disaster monitoring. Most of the other projects using Low Resolution Optical data are concerned with terrestrial monitoring applications at regional to national scale, and require updated information less frequently (weekly to monthly). In these cases, periodicity has often been adapted to the current supply options, such as the MODIS composite products, or management issues associated with data volumes, rather than the preferred frequency of updated information. Composite products, however, are also derived from daily acquisitions. A small number of projects use historical data to update land use/condition on an annual basis.

Visible and near infrared (NIR) channels are essential to over half the projects, with short-wave infrared (SWIR) and thermal infrared (TIR) being important to about a third, and around a quarter of the projects requiring all four spectral regions. An intermittent problem with one of the MODIS SWIR bands requires occasional correction by data supply agencies. Most of these projects involve calibration and/or validation of EO data with ground-based information. This is required both to calibrate EO instrument radiance counts with a standard measurement scale, and also to check and compensate for any inconsistencies within the instrument counts over time. For example, the solar reflectance channels on the NOAA AVHRR instrument have no on-board calibration source and are known to drift in sensitivity following launch. The CSIRO CalWatch project determined appropriate methods for post-launch calibration of these channels.

While coordination of imagery with fieldwork and/or *in situ* sensor observations was important for many of these projects, the regular acquisition cycle of Low Resolution Optical imagery already caters for this requirement. Some researchers felt that MODIS-derived products were not appropriate for Australian conditions, and that locally derived atmospheric correction methods yielded superior products, especially for coastal waters. These concerns underpin the impetus to develop and deliver nationally consistent and calibrated EO-based data coverages for Australia.

Eleven of the 25 projects relying on MODIS data currently maintain their own archives of more than 30 TB and acquire over 1 TB per year, often of duplicate datasets. Four of the 12 projects using AVHRR store more than 10TB of historical imagery and also acquire over 1 TB annually. Direct access to time series data is becoming increasingly valuable for many projects, both to gain an historical perspective on environmental change, and to detect and identify specific patterns and drivers, such as during disaster conditions. CSIRO has compiled the master time series of raw data for the AVHRR series of instruments in the Australasian region, and AusCover TERN will be placing several AVHRR-derived land cover datasets onto its open-access portal by 2013.

Should the current sources of Low Resolution Optical data became unavailable, most respondents thought that substitute data sources could be used if necessary, or would become available in the near future. While AVHRR may be used as a substitute supply source for MODIS imagery where spatial resolution is not critical, it is not suitable for some projects, such as flood mapping, which require SWIR data. MERIS (Envisat) and OLCI (Sentinel-3) were cited as the most likely replacement data sources for MODIS, assuming that the data will be freely available and easy to download directly into Australian ground stations or from ESA archive server systems. Other possible alternate sources for MODIS and AVHRR include VIIRS (on NPP and JPSS series, nominally the official replacement for both MODIS and AVHRR), VEGETATION (on SPOT-4 and SPOT-5) and imaging sensors on geostationary satellites like MTSAT.

Supply Arrangements

The 25 projects accessing **MODIS** data currently use a variety of channels for supply. The majority access the data independently via Internet from the relevant USA government on-line archives (*e.g.* the Land Products Distributed Active Archive Centre, LPDAAC, run by USGS). The data is supplied on a public good basis without charge, and there are no formal agreements in place governing the availability or supply of the data.

Eight of the projects surveyed, including several heavy users of this data class, receive MODIS data from the direct broadcast signal of the satellite. Australia has eight MODIS/AVHRR reception stations in six locations around the country (Perth, Darwin, Melbourne, Townsville, Alice Springs, Hobart) together with network infrastructure (like the Australian Academic and Research Network, AARNet) and processing capability to merge data (*e.g.* CSIRO High Performance Scientific Computing facility, HPSC). In a collaborative effort between IMOS, AusCover TERN, GA, BoM and the National Computing Infrastructure (NCI), a national satellite processing facility for MODIS/AVHRR/VIIRS data is being configured at the High Performance Computing and Communications Centre (HPCCC; a collaborative facility supporting the BoM and CSIRO) and the NCI (hosted by the Australian National University, ANU). Many of the Australian downlink facilities transfer their data directly to the HPSC where it is initially managed and processed for use in climate and weather monitoring. Some of this functionality may be transferred to the NCI at a later date. The access link to Canberra is being upgraded in the near future, which will halve the current data transfer time (of three hours) following image acquisition.

About half of Australia's research users receive **AVHRR** data via direct broadcast signal from the host satellites. The remainder obtain the data by Internet download. BoM/CAWCR and AIMS are also able to make use of the WMO's Global Telecommunication System (GTS) for supply of AVHRR and MODIS data. Many of the current data acquisition and archiving tasks appear to have been inherited by individual researchers, rather than formally assumed as responsibilities by research organisations. As such, delivery of data updates can be affected by the workload of those individuals, rather than guaranteed to follow a reliable timetable.

Technical failures early in 2011 have limited the direct-to-user broadcast capability of the Metop-A satellite. This capability has been a key feature of NOAA'a AVHRR data distribution system, which impacts near real-time reception of the data in Australia.

The main research users of **MERIS** data in Australia (CSIRO Land and Water) are Principal Investigators and have access to an ftp data feed courtesy of that agreement (although data is only available several days after image acquisition). In recent years ESA has relaxed the restrictions on access to MERIS data (in line with their overall trend to a free and open data policy) and data is available on-line via the MERIS Catalogue and Inventory (MERCI).

The multitude of **other** instruments utilised by BoM and CAWCR are acquired through a variety of means, including operational data systems, the WMO GTS, and on-line archives.

3.3.2 Medium Resolution Optical (10–80m)

Overview

Medium Resolution Optical sensors record reflectance in the visible and infrared (including thermal) wavelengths with geometric pixel sizes greater than 10m and less than or equal to 80m (see Table 2-2). Medium resolution optical sensors have traditionally been operated for public good, but an increasing number of commercial sensors have also become available.

This 'paddock scale' or 'management scale' data is used by a wide range of operational programs in Australia including:

- Emergency management (bushfires, earthquakes, floods, and storms);
- Mapping and monitoring land use and degradation, natural resources and vegetation dynamics;
- Water usage and quality,
- Drought;
- Pollution; and
- Minerals.

Medium resolution optical data products are being used to:

- Manage forests, rivers, fisheries, catchments and agriculture;
- Develop national inventories of forests, greenhouse gases, endangered species, maritime boundaries, land cover, topography, and carbon sinks; and
- Verify residential housing development applications, rural taxation valuations and environmental compliance (Geoscience Australia, 2011).

Supporting these operational programs, the R&D community uses Medium Resolution Optical data as an essential input to 23 of the surveyed projects (41% of the sample across 17 different research groups). Of these 23 projects, 19 cited linkages to 48 current operational programs in Australia. The application areas being supported by this research are listed in Table 3-13.

Table 3-13 Projects Dependent on Medium Resolution Optical Data

Application Area	Number of Surveyed Projects
Monitoring vegetation, biomass, ground cover, forests and forest carbon	7
Delivering national EO-based products for terrestrial and marine studies	5
Mapping floods and wetlands	4
Managing precision agriculture and irrigation	2
Mapping fires, fire scars and estimating bushfire emissions	2
Monitoring inland water quality and coastal habitats	2
Updating land use information	1
Validating future sensors	1

Current Usage

The Medium Resolution Optical sensors being used in EO-related research in Australia are listed in Table 3-14. The most popular single data source is Landsat-5/7 TM/ETM+, being used by nearly 40% of all surveyed projects.

Table 3-14 Usage of Medium Resolution Optical Data

Entries indicate the number of projects

Medium Resolution Optical Sensor	EO Data Importance Rating				
	Essential	Advantageous	Essential + Advantageous	Opportunistic	Promising
Landsat TM/ETM+	22	4	**26**	2	0
AVNIR	4	0	**4**	0	0
SPOT	3	1	**4**	0	0
ASTER	3	0	**3**	2	0
TOTAL	**32**	**5**	**37**	**4**	**0**

About half the projects requiring Medium Resolution Optical sensors use national scale data, with a smaller proportion needing state or regional coverage. Desired frequency of coverage varies with the type of application. Current expectations for coverage may be partially dictated by the availability of Landsat imagery, with some projects requesting a fortnightly update cycle and others only needing updated information each month, quarter, or year, or to coincide with specific events or conditions. Most projects can accept several weeks delay in data delivery, but a few require new data within days of acquisition.

The most commonly specified spectral requirements were for visible channels and NIR, although SWIR was also necessary for woody vegetation mapping and water detection in about a quarter of these projects. TIR was required for evapotranspiration studies. Some researchers would prefer access to a Medium Resolution Optical data source with a greater number of channels to achieve improved discrimination of herbaceous versus woody vegetation, water features, better atmospheric and other corrections, and increased accuracy of measurements.

Between 2000 and 2010, 100 TB of raw telemetry Landsat data over Australia have been archived by GA. Other projects are maintaining archives of up to 15 TB of Landsat data, with annual acquisitions of up to 1 TB. Smaller volumes of AVNIR, SPOT and ASTER imagery are also being acquired and stored to support current Australian EO-related research.

Possible substitute data sources for Landsat imagery included airborne imagery and a number of different satellite series including SPOT, CBERS, RESOURCESAT, DMC, THEOS, Kompsat, Formosat-3, and RapidEye. Most researchers stressed that use of these substitutes would involve a considerable amount of effort to modify algorithms and processing procedures, and that the vast majority of alternate sources do not offer the resolution, number and position of spectral bands or the reliability of the Landsat series.

Supply Arrangements

Landsat imagery is currently only available from the Landsat-7 satellite. This sensor is decades past its design life and has had ongoing image striping problems since 2003, which reduces the utility of that data. Until November 2011, when imaging activities were suspended for 90 days due to major hardware problems, Landsat-5 had been the primary data source of Medium Resolution Optical data in Australia for over 20 years, with decreasing reliability during the last decade. Since the LDCM will not be operational before June 2013, and given the inadequate operation of Landsat-7, continuity of Medium Resolution Optical imagery is a major concern for all Australian users.

GA has a data reception agreement with NASA/USGS to routinely acquire and archive Landsat imagery for Australia. A range of corrected products has been developed for Australian conditions, which are supplied on a commercial basis. Problems associated with ageing downlink infrastructure and data transfer arrangements between the reception site and the processing facility are being addressed.

Since 2008, USGS has provided free on-line access (via the Global Visualisation Viewer, GLOVIS) to the archive of Landsat imagery. While acquired imagery is available from this system within two weeks, some researchers would prefer a delay of less than one week.

Most Landsat data being used in Australian R&D is now accessed as public good (no agreement) via ftp/Internet download from USGS. Geoscience Australia researchers gain access to Landsat via their data reception agreement or local archives. One research project in this survey uses the Landsat-derived NCAS product archive.

Some researchers felt that quality control procedures were largely unnecessary with this data source and simply use the data as supplied, but others prefer to undertake their own geometric and atmospheric correction processing. A small number of geometric errors (placement) have been observed with USGS-supplied imagery. Several researchers also collaborate with NASA/USGS to calibrate and validate Australian Landsat data.

Historical imagery from **AVNIR-2** (Advanced Visible and Near Infrared Radiometer type 2) onboard **ALOS** is currently used by four projects via the original research agreement. A small volume of SPOT imagery is acquired commercially by three projects. Research agreements enable three other projects to access the 10-year **ASTER** archive.

3.3.3 High Resolution Optical (<10m)

Overview

High Resolution Optical sensors record reflectance in the visible and infrared (including thermal) wavelengths with geometric pixel sizes less than or equal to 10m (see Table 2-2). High Resolution Optical sensors are primarily operated by commercial enterprises, with an increasing number of sources becoming available from both satellite and airborne platforms. Recent launches of high-resolution satellites by countries such as China may offer free access to such data in the future, provided that data exchange agreements are in place.

These 'urban scale' data are used by a wide range of operational programs in Australia, including:

- Monitoring active and/or recent disasters;
- Estimating biomass, managing conservation areas, waterways and floodplains, marine jurisdictions, and electoral boundaries;
- Mapping geoscience resources, topographic features, shallow water bathymetry, wetlands and vegetation stress;
- Mapping of urban sprawl and associated infrastructure, and
- Auditing environmental compliance, urban water use and urban development (Geoscience Australia, 2011).

As more data sources and more frequent temporal coverage becomes available, it is expected that operational usage of satellite-based High Resolution Optical imagery will increase for some application areas, such as monitoring inland water quality and water storage levels.

High Resolution Optical data from either satellite or airborne sources are essential to 17 of the surveyed projects (nearly 30% of the sample across 11 different research groups), with nine projects only using satellite sources, seven projects only using airborne sources and one project using both. Of these 17 projects, 12 cited linkages to 24 current operational programs in Australia. The application areas being supported by this research are listed in Table 3-15.

Table 3-15 Projects Dependent on High Resolution Optical Data

Application Area	Number of Surveyed Projects
Monitoring inland water quality and coastal habitats	4
Delivering national EO-based products for terrestrial and marine studies	3
Mapping and monitoring weeds, forests, and greenhouse gases	3
Managing precision agriculture and viticulture	2
Mapping geoscience resources and soils	2
Developing and testing feature extraction methods	1
Mapping vegetation type and land degradation	1
Validating satellite sensors for Antarctica	1

As well as the 17 projects that considered High Resolution Optical data as an essential input, nine others rated it as advantageous. These projects were focused on mapping fires or their impacts and other disasters, managing irrigation, detecting weeds, monitoring ground cover, and defence.

In particular, two of the surveyed projects use Unmanned Aerial Vehicles (UAVs) routinely to collect Ultra-high Resolution (1–10 cm pixels) Multispectral and Hyperspectral imagery, Thermal Imagery and/or Topographic data. Compared with traditional airborne platforms, these vehicles offer the advantages of low cost, frequent and flexible timing, ultra-high spatial resolution and integration of multiple sensors to address a wide range of niche applications. Field measurements can be made coincidentally and linked to aerial data for validation and calibration. Experimental datasets have been used to map:

- Coastal erosion, landslides, stock piles and quarry faces
- Moss bed health in Antarctica (as an indicator of climate change)
- Vineyards, orchards, agricultural weeds, plant vigour and drought stress; and
- Paddock scale terrain models.

Current Usage

For the purposes of this report, High Resolution Optical sensors being used in EO-related research in Australia are grouped into three source categories, namely commercial satellites, in-house airborne, and commercial airborne (see Table 3-16). The most popular category is commercial satellite imagery, being essential to 16% of all surveyed projects. Commercial satellite sources for High Resolution Optical imagery that were cited by respondents include Quickbird, Worldview, Ikonos, RapidEye, SPOT, Formosat and DMC.

Table 3-16 Usage of High Resolution Optical Data
Entries indicate the number of projects

High Resolution Optical Sensor	EO Data Importance Rating				
	Essential	Advantageous	Essential + Advantageous	Opportunistic	Promising
Commercial satellites	9	5	**14**	3	0
In-house airborne	6	2	**8**	1	1
Commercial airborne	1	0	**1**	0	0
TOTAL	**16**	**7**	**23**	**4**	**1**

Half of the projects requiring High Resolution Optical data as an essential input need coverage of research sites only, and about a third need regional coverage. Two projects researching coastal and inland water quality need national coverage.

Frequent imagery was not paramount for most projects, with responses evenly spanning the full range of options. Several projects required image acquisition to be coordinated with field work, acquisition of other imagery, or conditions which optimise target discrimination. Many projects only require imagery to be updated annually. High revisit frequency was valuable for coastal and inland water studies to maximise coordination with *in situ* sensors for calibration purposes, and for disaster mapping.

Latency was less critical for this data type than for the lower resolution optical data, with most projects (but not all) being satisfied with delays of weeks or more.

The most common single spectral requirement mentioned by respondents was NIR, with several projects also mentioning the need for visible, SWIR and TIR. Increased spectral resolution was particularly important for water and geoscience applications. SPOT imagery was deemed less suitable for water applications due to the absence of a blue channel.

Accurate geolocation is important for most users of High Resolution Optical imagery. Spatial resolutions required from satellite sources ranged evenly between 0.5 m to 5 m pixels, whereas typical spatial resolutions for High Resolution Optical imagery from airborne sources were 1 cm to 50 cm. The lower spatial resolutions desired from satellite sources are not provided by all available High Resolution Optical sensors.

About 40% of the projects relying on High Resolution Optical data involve calibration and/or validation with ground-based information. In some projects, High Resolution Optical data is used as a form of ground truth for other data types.

Despite the higher spatial resolution, the reduced area of coverage means that smaller volumes of High Resolution Optical data are being archived by these projects compared with the lower spatial resolution optical data types. The volume of data associated with airborne imagery presents a data management problem for some researchers.

Most respondents believed that a sufficient range of high resolution commercial sensors now exist to allow at least one substitute satellite-based data source to be used if necessary. In most cases, airborne imagery could also be used if funds permit. Acquiring High Resolution Optical imagery from custom airborne missions is expensive and some projects relied upon aerial photography from routine state-wide coverages instead.

Supply Arrangements

Most projects cited use of multiple sources of High Resolution Optical imagery from commercial sources:

- Quickbird: 5 projects
- Worldview-2: 4 projects
- Ikonos: 4 projects
- RapidEye: 2 projects
- SPOT: 2 projects
- Formosat: 1 project; and
- DMC: 1 project.

Most commercial imagery is generally distributed via physical media, often with a fortnight delay between order and delivery. The majority of researchers apply their own atmospheric and geometric corrections to the supplied data, with mosaicking being required for large area studies.

While commercial imagery has typically been expensive relative to other EO data sources, some suppliers offer discounts for combined orders from a consortium of users. These arrangements can significantly reduce the per image cost. Most vendors also allow purchased data to be jointly owned by up to five users, which further reduces the unit cost, although some levy a surcharge for each new owner.

A continued supply is expected for these sensors, due to ongoing defence and civilian usage.

3.3.4 Synthetic Aperture Radar

Overview

Synthetic Aperture Radar (SAR) instruments transmit pulses of radio waves at a target and measure the returned echo waveforms. These wavelengths have the ability to penetrate vegetation and sample surface roughness and dielectric properties, and are unaffected by cloud cover, weather conditions and solar illumination. Instruments are designed to measure different wavelengths and polarisations, either individually or in combination, to discern particular properties of the target.

Three frequencies are commonly used for satellite-based SAR sensors: C-band, L-band and X-band (see Table 2-2). The characteristics of these frequency ranges are detailed in Table 3-17.

Table 3-17 Characteristics of SAR Frequencies

Band	Frequencies	Wavelengths	Applications	Advantages
L-band	1–2 GHz	15–30 cm	Floods, Soil Moisture, Vegetation	Less sensitive to surface textural changes; penetrates canopies for biomass estimation; also used for surface deformation mapping
C-band	4–8 GHz	3.8–7.5 cm	Ocean, Ice, Vegetation	Wavelengths suit ocean roughness to determine wind vectors and currents
X-band	8–12.5 GHz	2.4–3.8 cm	Defence, Land Surface,	High resolution for feature detection

SAR data is used by 14 operational programs in Australia to map and monitor natural disasters, land use, forest carbon, sea ice, marine borders, mineral resources, sea level, subsidence, woody vegetation and soil moisture (Geoscience Australia, 2011). Being relatively unaffected by solar illumination and weather conditions, SAR data is particularly useful for night time surveillance, and monitoring tropical areas in northern Australia and cloudy areas such as Tasmania.

Various bands of SAR data, from airborne and space-borne sensors, are essential inputs to nine of the surveyed projects (16% of the sample across six different research groups). These projects collectively cited linkages to 12 operational programs in Australia (see Appendix B). The SAR frequencies considered as essential to this research are summarised in Table 3-18. X-band and C-band SAR were also rated as advantageous for mapping floods and soil moisture.

Table 3-18 Projects Dependent on SAR Data

Project	SAR Frequencies
Mapping and monitoring Antarctic Fast Ice	C-band
AusCover TERN	L-band
Flood Dynamics in Semi-arid Wetlands	L-band
Mapping Vegetation Biomass	L-band
Soil Moisture	L-band
Defence	X-band
International Forest Carbon Initiative	X-band, C-band, L-band

Current Usage

The SAR sensors being used in EO-related research in Australia are listed in Table 3-19. The most popular single data source is PALSAR, being used by five projects. This usage may be influenced by increasing data accessibility and free access via research agreements. A significant number of researchers considered the various forms of SAR data as 'promising' for future use, particularly L-band, provided that data costs are low and data is more widely accessible for routine use.

Table 3-19 Usage of SAR Data

Entries indicate the number of projects

SAR Sensor		EO Data Importance Rating				
		Essential	Advantageous	Essential + Advantageous	Opportunistic	Promising
X-band	COSMO-SkyMED	1	2	**3**	1	0
	Airborne	1	0	**1**	0	0
	TerraSAR-X	0	1	**1**	0	0
	Total X-band	(2)	(3)	**(5)**	(1)	(0)
C-band	ASAR (Envisat)	2	1	**3**	0	1
	SAR (Radarsat)	1	3	**4**	0	1
	SAR (Sentinel-1)*	0	0	**0**	0	1
	Total C-band	(3)	(4)	**(7)**	(0)	(3)
L-Band	PALSAR**	5	0	**5**	1	0
	Airborne (in-house)	2	0	**2**	0	0
	SMAP SAR*	1	0	**1**	0	0
	Total L-band	(8)	(0)	**(8)**	(1)	(0)
TOTAL for all bands		**13**	**7**	**20**	**2**	**3**

* Not yet operational

** Terminated operations in April 2011

The scale of temporal and spatial coverage, spatial resolution, and latency required for all SAR data varied widely between research projects. Timing of acquisitions was important to enable several projects to co-ordinate with *in situ* measurements and/or optical data acquisition.

Depending on the coverage required, acquisition, processing and archiving of C-band SAR (ASAR, Envisat, Radarsat) was reported to be time-consuming, and can generate up to 3-4 TB of data per year.

Most respondents thought that substitute sensors were available for X-band and C-band SAR, but not for L-band. The continuity risk for this data type is considerable. With the termination of PALSAR operations in April 2011, there is no current source of regular L-band SAR data from space.

Supply Arrangements

SAR sensors being used in Australia are either operated as research instruments or supplied by commercial enterprises.

ALOS PALSAR (L-band) was supplied mainly as public good data (via research agreement with GA), which restricted operational usage of the data. However this source is no longer available, so future research will have to rely on historical data only. C-band data from Envisat ASAR is supplied as public good (third party or research agreement), or can be obtained via commercial arrangements from Radarsat. Airborne L-band data can also be acquired through facilities at Monash University.

The X-band SAR data currently being used are either from commercial sources (COSMO-SkyMed) or acquired using in-house instruments. Flexibility of COSMO-SkyMed is an issue for some users or applications. In-house airborne acquisition is available to DSTO via the Ingara system.

3.3.5 Passive Microwave Radiometry

Overview

Passive Microwave Radiometers detect microwave radiation that is naturally emitted from the Earth's land, seas and atmosphere as a result of thermal heating (see Table 2-2). The various temperatures measured by Passive Microwave Radiometers indicate physical properties and material states, and are unaffected by cloud cover, weather conditions and solar illumination. These passive instruments offer accurate spectral measurements but poor spatial resolution. They are primarily used to map snow and ice, but can also infer soil moisture content and ocean salinity.

Passive Microwave Radiometry is used by only four operational programs in Australia. These are involved with modelling ocean processes, refining geoid models, mapping soil moisture and groundwater hydrology, and monitoring Antarctic sea ice (GA, 2011).

This data type is an essential input to seven of the surveyed projects (12.5% of the sample across five different research groups). Of these seven projects, five cited linkages to seven current operational programs in Australia. The application areas being supported by these research projects are listed in Table 3-20. This data type was also used to estimate soil moisture for correction of large area L-band SAR mosaics as part of a vegetation biomass mapping project.

Table 3-20 Projects Dependent on Passive Microwave Radiometry

Application Area	Number of Surveyed Projects
Monitoring soil moisture and groundwater	4
Delivering national EO-based products for terrestrial and marine studies	3
Monitoring sea surface temperature, height and salinity	3
Precipitation and climate modelling and prediction	3
Identification of water bodies	1

Current Usage

The Passive Microwave Radiometers being used in EO-related research in Australia are listed in Table 3-21. All 'essential' R&D usage of Passive Microwave Radiometry currently occurs in academic institutions or research organisations. The most popular single data source was AMSR-E, which was being used as an essential or advantageous input by nearly 9% of all surveyed projects. DMSP and AMSR-E are used operationally by BoM/CAWCR. AMSR-E terminated operations during the development of this report (October 2011).

Table 3-21 Usage of Passive Microwave Radiometers
Entries indicate the number of projects

Passive Microwave Radiometer	EO Data Importance Rating				
	Essential	Advantageous	Essential + Advantageous	Opportunistic	Promising
DMSP (SMMR and SMM/I)	4	1	**5**	0	0
AMSR-E	3	2	**5**	1	1
SMAP Radiometer*	3	0	**3**	0	0
SMOS	3	0	**3**	0	2
Aquarius	2	0	**2**	0	1
JMR (Jason), TMR (TOPEX)	1	0	**1**	0	0
TMI (TRMM)	1	0	**1**	0	0
Airborne (in-house)	1	0	**1**	0	0
TOTAL	**18**	**3**	**21**	**1**	**3**

*SMAP will not be operational until 2014

Most of the projects using Passive Microwave Radiometry as an essential input require daily, global scale datasets, with the WIRADA project needing national coverage eight times per day. Near real-time, continuous access is available from most sources, but TMR/JMR data has a longer repeat cycle (9.8 days) with final products not being available for 8-10 weeks after acquisition.

Being passive remote sensing instruments, these sensors typically acquire measurements from large footprints (4-70km). Monash University acquires airborne Passive Microwave Radiometry with resolution varying between 50m and 1km depending on flying altitude.

The WIRADA project utilises the TRMM Multi-satellite Precipitation Analysis (TMPA) product from NASA, which combines data from three sensors to create a three hourly, global precipitation dataset with 25 km resolution (analysis "3B-42RT").

Most Australian R&D using Passive Microwave Radiometry incorporates ground-based information, such as rain gauges, tide gauges, weather gauges and moisture probes. The IMOS project provides calibration and validation data for the TPM/JMR satellite dataset.

Passive Microwave Radiometry has lower spatial resolution and a higher revisit frequency than most other EO data types. Australian coverage from MIRAS (SMOS) currently amounts to 2 GB per day. The WIRADA archive of TMPA data comprises 1 TB.

Substitute data sources suggested by respondents include airborne acquisition, GCOM-W (AMSR-2), SMOS, SMAP (from 2014), European Centre for Medium-Range Weather Forecasts (ECMWF) modelled fields (with a reduction in quality), and JPSS. While follow-on missions are not guaranteed for most research missions, continuity of datasets was at least partially expected by respondents. Future sensors are discussed in Section 5.

Supply Arrangements

Satellite-based Passive Microwave Radiometry is available to these projects as public good (no agreement), public good (research agreement) and/or via WMO resolution 40, and procured by ftp download. As part of research agreements, the IMOS project received restricted access to early data from TMR/JMR, and the MoistureMap project at Monash University has access to restricted data from MIRAS (SMOS) and SMAP Radiometer (SMAP).

3.3.6 Radar Altimetry

Overview

Radar Altimeters are active sensors that measure the time it takes for radio waves to be transmitted, reflected and returned. These measurements can provide terrain, ice and sea level profiles with millimetre accuracy (see Table 2-2).

Radar Altimetry is an essential input to eight of the surveyed projects (14% of the sample across seven different research groups). Collectively these eight projects cited linkages to nine current operational programs in Australia. The application areas being supported by this research are listed in Table 3-22. One project also used airborne Radar Altimetry data for geoscience research. This data source was rated as promising for mapping flood levels, and monitoring seagrass and ground cover in the future.

Table 3-22 Projects Dependent on Radar Altimeter Data

Application Area	Number of Surveyed Projects
Delivering national EO-based products for marine studies	2
Modelling weather and climate	2
Geoscience applications	2
Validating sensors	2

Current Usage

The Radar Altimeters being used in EO-related research in Australia are listed in Table 3-23. The most popular data source is the Poseidon series of sensors carried on the Jason missions. There are no satellite-based substitutes for the sensors currently being used.

Table 3-23 Usage of Radar Altimeters

Entries indicate the number of projects

Radar Altimeter Sensor	EO Data Importance Rating				
	Essential	Advantageous	Essential + Advantageous	Opportunistic	Promising
Poseidon-2 (Jason-1)	5	0	**5**	0	0
Poseidon-3 (Jason-2)	5	0	**5**	0	0
Poseidon-1 (TOPEX)	4	0	**4**	0	0
TBD RA (Jason-3)*	4	0	**4**	0	0
RA2 (Envisat)	3	0	**3**	0	0
Siral (CryoSat-2)	2	0	**2**	0	0
AltiKa (SARAL)*	1	0	**1**	0	0
ALT (HY-2A)**	1	0	**1**	0	0
KaRIN (SWOT)*	1	0	**1**	0	0
SRAL (Sentinel-3A/B)*	1	0	**1**	0	0
SRTM	1	0	**1**	0	0
Airborne (in-house)	0	1	**1**	0	0
IceSAT	0	0	**0**	0	1
TOTAL	**28**	**1**	**29**	**0**	**1**

* Not yet operational

** Recently launched but data not yet seen

Most researchers using Radar Altimetry require global data on a daily basis. Where possible, near real-time data was generally preferred by marine and atmospheric applications. Latency and temporal resolution are much less important for terrestrial applications, such as deriving Digital Elevation Models (DEM).

Most satellite-based Radar Altimetry data has a relatively coarse spatial resolution, and higher resolution data would be welcomed for most research. Simultaneous acquisition of other datasets is important, especially for sources with less frequent revisit times. Some of the sample projects are currently investigating the precision of available Radar Altimetry datasets.

The data volumes currently associated with these projects do not present infrastructure problems.

Supply Arrangements

All sources of Radar Altimeter data are available as public good. Two of the sample R&D projects have access to data from SIRAL (Cryosat-2) and AltiKa (SARAL–not yet launched) as part of research agreements. The majority of projects access Radar Altimetry datasets via ftp/Internet Download.

3.3.7 Hyperspectral Imagery

Overview

Hyperspectral imagers (also known as 'imaging spectrometers') simultaneously acquire reflected radiance measurements in many narrow, contiguous spectral bands (see Table 2-2). Whereas Multispectral scanners measure radiance in a small number of relatively broad wavelength bands (typically less than ten), Hyperspectral imagers collect measurements in a much larger number of bands (up to hundreds) across the full imaging surface, focused on adjacent, narrowly defined spectral regions (typically less than 10 nm) in the visible and infrared spectrum.

These highly resolved image radiance measurements allow continuous spectra to be derived for target features. Once the images are atmospherically corrected, the resulting spectra can then be compared with field and/or laboratory spectra to identify and map the location of surface materials. Hyperspectral imagery is particularly valuable for mapping minerals and soils, atmospheric gas concentrations, man-made materials, vegetation species, composition and health, shallow coastal and coral reef habitats and water quality. While it has been used in the defence, atmospheric chemistry and mineral exploration fields for over a decade, Hyperspectral imagery is a relatively new form of EO data in most other fields and its utility is still being assessed in many application areas. It has the potential to allow greater understanding of vegetation dynamics and physiology, and better monitoring of greenhouse and other atmospheric gases, and will also help determine the most discriminating spectral bands for particular target materials and/or conditions. This information is also valuable for designing future sensors, correcting atmospheric and illumination effects in other imagery, determining optimum timing (in the diurnal and/or seasonal cycle) for target discrimination, and/or calibrating data from other EO sensors.

Ten of the R&D projects (18% of the surveyed projects across seven different research groups) deemed Hyperspectral imagery to be essential to their research. The applications areas relevant to this research are listed in Table 3-24. Eight of these ten projects collectively cited linkages to 12 current Australian operational EO programs (see Appendix B).

Table 3-24 Projects Dependent on Hyperspectral Imagery

Application Area	Number of Surveyed Projects
Mapping minerals and soil types	3
Delivering national EO-based products for terrestrial studies	2
Mapping vegetation and greenhouse gas emissions	2
Monitoring inland water quality, coastal habitats & coral reef bathymetry	2
Defence	1

Current Usage

Most Hyperspectral imagery is currently acquired from airborne sources operated by Australian private companies or university groups, and from NASA/USGS in the case of Hyperion satellite data. The actual sensors being used in the ten R&D projects, and their relative usage ratings, are summarised in Table 3-25. Two research projects are trialling the acquisition of Hyperspectral imagery using UAVs.

Table 3-25 Usage of Hyperspectral Imagery

Entries indicate the number of projects

Hyperspectral Imager	EO Data Importance Rating				
	Essential	Advantageous	Essential + Advantageous	Opportunistic	Promising
Airborne (in-house)	5	3	**8**	0	0
Hyperion	2	2	**4**	0	1
Airborne (HyMap)	2	2	**4**	2	1
Airborne (HyVista)	2	0	**2**	1	1
Airborne (Other Commercial)	1	0	**1**	0	0
HICO (on ISS)	1	0	**1**	0	0
HyspIRI*	1	0	**1**	0	0
TOTAL	**14**	**7**	**21**	**3**	**3**

* Not yet developed

Hyperspectral imagery is typically used to acquire intensive measurements over research sites that are subsequently extrapolated to larger areas using other datasets. Some projects that are involved with geology or hydrology require state-wide or national coverage. Monthly, or less frequent, updates are satisfactory for most research, with a delay of weeks between image capture and delivery being acceptable in most cases. Repeat imagery is often required to monitor changes.

Timing of image acquisition is critical for many applications, to co-ordinate with *in situ* measurements and/or with periods of optimum discrimination of target features.

For some application areas, the value of Hyperspectral imagery is focused on specific spectral regions, such as TIR for soil moisture research, visible to SWIR for vegetation mapping, MIR plus TIR for mapping minerals and soils, or visible to NIR for shallow coastal and coral reef bathymetry and benthic cover mapping. Spatial resolution requirements typically vary from 10 m pixel size (larger for TIR bands) down to sub-metre pixels from airborne platforms, while the satellite-borne Hyperion Hyperspectral imager acquires 30 m pixels.

The intensive spectral sampling required for Hyperspectral imagery generates significant data volumes, but current Australian archives are manageable.

Supply Arrangements

Most airborne Hyperspectral imagery is supplied commercially on physical media, while Hyperion data is downloaded via the Internet from the USGS server directly. The TERN AusCover facility is also making the full Level-1R historical Hyperion archive for Australia (approximately 3-4 TB) freely available. The use of UAVs to acquire Hyperspectral imagery is being investigated in two of the surveyed projects.

3.3.8 Lidar

Overview

Lidars are active sensors that use laser returns reflected from solid objects (dust, smoke, vegetation, terrain and underwater objects) and the timing of their return to generate a 3D rendition of the geometry of the illuminated objects or surfaces. The different types of EO Lidar instruments are summarised in Table 3-26. Additionally, ground-based hemispherical Lidar is used to model vegetation structure, and correlate with EOS Lidar data.

Table 3-26 Characteristics of Lidar Instruments

Type	Description	Derived Parameters	Sources
Backscatter Lidar	Laser beam is backscattered, reflected or re-radiated by the target to give information on scattering and extinction coefficients of atmospheric layers	Cloud and aerosol properties; atmospheric composition; volcanic ash	CALIOP (CALIPSO); ATLID (EarthCARE)
Differential Absorption Lidar	Returns from tuneable laser at different wavelengths are analysed to determine densities of specific atmospheric constituents	Water vapour and temperature profiles	Airborne only
Doppler Lidar	Measures Doppler shift of the light backscattered from particles or molecules moving with the wind	Wind velocity profiles	ALADIN (ADM-Aeolus)
Ranging and Altimeter Lidar	Provide accurate measurements of the distance from a reference height to precise locations on the Earth's surface	Surface topography; vegetation height and cover; aerosol height distribution; cloud height and vertical profile	Airborne only

Lidar is a relatively new form of EO data with potential in many application areas (see Table 3-26). It is considered as an essential input to ten of the sample R&D projects (that is, 18% of the surveyed projects over eight research groups). These ten projects collectively cited linkages to 18 current operational programs in Australia. The application areas being supported by this research are listed in Table 3-27. Lidar is also considered as a promising data source for mapping flood levels in the future. In addition, lidar profiling from CALIPSO is extremely important for vertically resolved observations of cloud systems and aerosol including dust and volcanic ash.

Table 3-27 Projects Dependent on Lidar Data

Application Area	Number of Surveyed Projects
Deriving surface models for terrain, bathymetry, vegetation height or ice sheets	5
Modelling atmospheric parameters	3
Validating models, sensors and algorithms	3
Delivering national EO-based products for terrestrial and marine studies	2

Current Usage

The four sources of Lidar data that are being used in EO-related research in Australia are listed in Table 3-28. It is most commonly acquired from airborne platforms, including UAVs.

Table 3-28 Usage of Lidar Sensors

Entries indicate the number of projects

Lidar Sensor	EO Data Importance Rating				
	Essential	Advantageous	Essential + Advantageous	Opportunistic	Promising
Airborne (in-house)	5	3	**8**	3	1
CALIOP (CALIPSO)	3	1	**4**	0	0
Airborne (Commercial)	2	0	**2**	0	1
GLAS (IceSAT)*	1	0	**1**	0	0
TOTAL	**11**	**4**	**15**	**3**	**2**

* No longer operational

Projects focused on terrestrial applications require infrequent coverage of research sites only, while those involved with meteorological and marine applications need daily, national or regional coverage. It is important for many projects that the timing of Lidar data acquisition be co-ordinated with field work and/or acquisition of other EO datasets. For airborne data sources it is increasingly desirable that data from multiple EO data instruments be coincident and co-registered from a single mission.

Spatial resolutions of less than one metre were typically expected from airborne Lidars.

Data volumes for historical archives of CALIOP (CALIPSO) data currently comprise about 10 TB. While there are multiple suppliers for airborne Lidar, there are currently no substitute sources for the satellite-borne Lidar sensors currently being used.

Supply Arrangements

Most commercial airborne Lidar datasets are supplied on physical media. The restricted extent of this data means that it does not present data storage problems. However, the current packaging of CALIOP (CALIPSO) data by NASA into geographic regions around the globe means that daily coverage data for the Australian region takes more than one day to download. Indeed, the large area and frequent revisit times result in significant data management issues for this data source.

3.3.9 Ocean Colour

Overview

Ocean colour instruments are passive, Multispectral radiometers and imaging spectrometers designed to measure radiance from marine waters in visible and near infrared wavelengths (400–1000 nm), typically with high spectral resolution and low spatial resolution. Strictly speaking, they could be considered to fall within the low resolution optical instrument grouping, or indeed within hyperspectral imagers, since it is their narrow spectral performance within blue and green bands for ocean sensing that is of interest. However, per the classification in the CEOS database, which reflects the fact that 'ocean colour' is the subject of a recognised community, and the corresponding data is acquired and processed in a way which supports their applications, ocean colour is identified here as a valid data type in its own right.

Ocean colour instruments are considered essential for six surveyed projects (over 10% of the total, in three research groups). Collectively, these projects cited linkages to nine operational programs. The application areas associated with these projects are summarised in Table 3-29.

Table 3-29 Projects Dependent on Ocean Colour Data

Application Area	Number of Surveyed Projects
Monitoring continental shelf, coastal and inland water quality, and coastal habitats	3
Monitoring and modelling weather and climate	2
Delivering national EO-based products for terrestrial and marine studies	1

Current Usage

The Ocean Colour sensors currently being used in EO-related research in Australia, and their usage ratings, are listed in Table 3-30. MODIS and MERIS data are also used for Ocean Colour analyses by each of these projects, plus two others (IMOS and BLUELink). Since usage of these Low Resolution Optical sensors is discussed in Section 3.3.1, the numbers in Table 3-30 may underrate the real level of research interest in this data type in Australia.

Table 3-30 Usage of Ocean Colour Data

Entries indicate the number of projects

Ocean Colour Sensor	EO Data Importance Rating				
	Essential	Advantageous	Essential + Advantageous	Opportunistic	Promising
OCM-2 (Oceansat-2)	4	0	**4**	0	0
SeaWiFS (OrbView-2)	3	1	**4**	0	0
GOCI (COMS)*	3	0	**3**	0	0
TOTAL	**10**	**1**	**11**	**0**	**0**

* No coverage of Australia – covers Korea only

All respondents considered that the currently available sensors offered partial substitutes for each other, plus the (untested) possibility of using VIIRS data.

Most projects desire daily, national coverage, with minimum delay. Geostationary sensors, such as GOCI, trade high temporal frequency (multiple images per day) for lower spatial resolution, compared to the polar-orbiting satellites, such as SeaWiFS and OCM-2, which have a global revisit time of two to three days. Less frequent revisit times introduce particular challenges for *in situ* calibration equipment carried by buoys and platforms, and research cruises.

Typical spatial resolutions are currently 1 km pixels, with expectations for 300 to 700 m pixels in future sensors. For most oceanographic phenomena, increased spatial resolution is only valuable with increased temporal resolution to permit tracking of smaller features. Coastal applications, however, would benefit from higher spatial resolution.

Supply Arrangements

MERIS (Envisat) data is received via ftp/Internet download, though this introduces a delay of several days, so a direct broadcast is preferred. Direct downlink access to OCM-2 is currently being negotiated. Calibration problems, which reduce the quality of OCM-2 data, are also being addressed by NASA, so that a substitute data source would be available in case the supply of MODIS data were to be interrupted.

SeaWiFS ceased operation in December, 2010, so current data usage relies on historical archives.

3.4 Summary

The *CEODA-R&D* projects are collectively using 59 instruments across 17 EO data types. Of these 59 instruments, 17 are used exclusively by CAWCR/BoM.

The coverage requirements for different EO data types vary with different application areas. These are summarised in Table 3-31 for the Priority Data Types. Time series data are becoming increasingly important in most application areas.

The majority of researchers now acquire imagery via ftp download. The current EO data archives for the surveyed projects are estimated to exceed 300 TB, with annual acquisitions growing rapidly. The infrastructure implications of current EO data supply and usage are discussed in Sections 4, 5 and 6.

Table 3-31 EO Coverage Requirements by Application Area

Priority EO Data Type		Atmosphere	Coasts	Oceans	Hydrology	Geology	Vegetation	Disasters
Optical – Low Resolution	Delay	Hours	Hours	Hours	Hours	-	Hours	Hours
	Repeat	Daily	Daily	Daily	Daily	Annual	Daily	Daily
	Area	Global	National	Global	National	National	National	National
Optical – Medium Resolution	Delay	-	Hours	-	Hours	-	Days/ Weeks	Hours
	Repeat	-	Daily	-	Daily	Annual	Various	-
	Area	-	National	-	National	National	National	National
Optical – High Resolution	Delay	-	Weeks	-	Weeks	-	Days/ Weeks	Hours
	Repeat	-	Months	-	Months	Irregular	Seasonal/ Annual	Irregular
	Area	-	National	-	National	Regional	Regional	Local
Synthetic Aperture Radar	Delay	-	-	Various		-		Hours
	Repeat	-	-	Various		-	Annual	Irregular
	Area	-	-	Global	National	-	Regional	Local
Passive Microwave Radiometry	Delay	Hours	-	Hours	Hours	-	-	-
	Repeat	Daily	-	Daily	Daily	-	-	-
	Area	Global	-	Global	National	-	-	-
Radar Altimetry	Delay	Hours	-	Hours	-	-	-	Hours
	Repeat	Daily	-	Daily	-	Annual +	Annual	Irregular
	Area	Global	-	Global	-	National	National	Local
Hyper-spectral Imagery	Delay	-	-	-	-	-	Days/ Weeks	Hours
	Repeat	-	Biannual	-	-	Annual	Seasonal/ Annual	Irregular
	Area	-	National	-	-	National	Local	Local
Lidar	Delay	Hours	-	-	-	-	Days/ Weeks	-
	Repeat	Daily	-	-	-	Annual	Seasonal/ Annual	-
	Area	Global	-	-	-	National	Local	-
Ocean Colour	Delay	-	Hours	Hours	Hours	-	-	-
	Repeat	-	Daily	Daily	Daily	-	-	-
	Area	-	National	Global	National	-	-	-
In situ		Ongoing	Ongoing	Ongoing	Ongoing/ As required	Ongoing/ As required	Ongoing/ As required	As required
Other		GPS, Gravity, Atmospheric Chemistry, Atmospheric Temperature & Humidity, Cloud Profile & Rain Radars, Earth Radiation Budget Radiometers, Multiple Direction/ Polarisation, Scatterometry	GPS	GPS	GPS, Gravity, Earth Radiation Budget Radiometry	GPS, Multiple Direction/ Polar-isation, Gravity, Magnetic Field and Geo-dynamic	GPS	GPS

4 EO DATA REQUIREMENTS: FUTURE

Future expectations of EO data requirements and supply were identified for the 56 sample projects defined in Section 2. This section highlights significant trends in these results and discusses their implications. Some caution should be exercised when considering the trends that emerged, however, since researchers were often uncertain about their future requirements beyond more than two to three years.

It should also be noted that EO data usage in Australian R&D tends to be somewhat opportunistic, relying exclusively on data sources that are provided by other nations (frequently free of charge). EO data requirements tend to be framed in terms of the systems available, rather than in isolation, or with a view to specifying domestic needs for observing systems.

Awareness of future EO satellite program plans also varies significantly among individual researchers, with some being extremely well informed with regard to alternatives and contingencies (and active in building the necessary relationships), and others content to use the same data sources to which they have become accustomed (and unaware of the alternatives). Given this, there are fewer conclusions as to future priority missions for Australian researchers than had been anticipated at the study outset. However, this study can provide a catalyst for discussion in the community regarding these priorities, and raise awareness of future EO data supply among researchers. Section 4.6 presents an opinion as to possible future priority missions, based on known Australian observation priorities and known plans detailed in the CEOS database.

4.1 Expected Data Requirements

Using the importance ratings defined in Section 2.1.3, survey results for researchers' expectations of future EO availability, in 2-year and 5-year time frames, are summarised in Tables 4-1 and 4-2 respectively. The 2-year and 5-year change is calculated relative to Table 3-2.

Table 4-1 EO Data Type Importance: 2-Year Self-Assessment by Researchers

EO Data Type	Future Requirements – 2-Year						Expected to be Met	
	Essential	Advantageous	Essential + Advantageous	2-Year Change	Opportunistic	Promising	Yes	Partially + No
Optical – Low Resolution	23	3	**26**	-3	1	0	23	5
Optical – Medium Resolution	20	5	**25**	-3	1	0	17	10
Optical – High Resolution	14	7	**21**	+4	1	0	18	4
Hyperspectral Imagery	10	6	**16**	+9	0	0	8	8
Lidar	10	1	**11**	+4	2	3	8	9
Passive Microwave Radiometry	7	3	**10**	0	1	0	4	7
Synthetic Aperture Radar – L band	8	1	**9**	+2	1	0	0	10
Atmospheric Chemistry	7	0	**7**	0	0	0	4	3
Radar Altimetry	7	0	**7**	-1	1	0	5	3
Synthetic Aperture Radar – C band	3	4	**7**	-1	1	1	4	4
Synthetic Aperture Radar – X band	2	5	**7**	0	0	0	4	3
Cloud Profile and Rain Radar	3	3	**6**	0	1	0	1	6
Earth Radiation Budget Radiometry	4	1	**5**	+2	2	0	6	1
Ocean Colour	4	1	**5**	-2	0	0	1	4
Multiple Direction/ Polarisation	3	1	**4**	-3	0	0	1	3
Atmospheric Temperature and Humidity Sounding	3	0	**3**	-2	0	0	3	0
Gravity, Magnetic Field and Geodynamic	2	1	**3**	-2	0	1	0	4
Scatterometry	2	0	**2**	-3	1	0	1	2
							56%	**44%**

Table 4-2 EO Data Type Importance: 5-Year Self-Assessment by Researchers

EO Data Type	Future Requirements – 5-Year						Expected to be Met	
	Essential	Advantageous	Essential + Advantageous	5-Year Change	Opportunistic	Promising	Yes	Partially + No
Optical – Low Resolution	22	2	**24**	-5	0	0	17	7
Optical – Medium Resolution	20	4	**24**	-4	1	0	19	7
Optical – High Resolution	10	10	**20**	+3	1	0	16	5
Hyperspectral Imagery	9	5	**14**	+7	0	0	7	7
Lidar	8	5	**13**	+6	0	2	6	9
Passive Microwave Radiometry	7	3	**10**	0	0	0	4	6
Synthetic Aperture Radar – L band	9	0	**9**	+2	0	0	7	2
Synthetic Aperture Radar – C band	4	4	**8**	0	0	0	5	2
Atmospheric Chemistry	6	0	**6**	-1	0	0	4	2
Radar Altimetry	6	0	**6**	-2	0	0	2	4
Synthetic Aperture Radar – X band	3	3	**6**	-1	0	0	5	1
Cloud Profile and Rain Radar	3	2	**5**	-1	1	0	0	6
Ocean Colour	4	0	**4**	-3	0	0	2	2
Multiple Direction/ Polarisation	3	0	**3**	-4	0	0	2	0
Earth Radiation Budget Radiometry	2	1	**3**	0	2	0	4	1
Atmospheric Temperature and Humidity Sounding	2	0	**2**	-3	0	0	2	0
Gravity, Magnetic Field and Geodynamic	2	0	**2**	-3	0	0	0	2
Scatterometry	2	0	**2**	-3	0	0	0	2
							61%	**39%**

Keeping in mind the caveats outlined at the beginning of Section 4, the following emerge through analysis of the survey data:

1. Across the Australian research community, little change is foreseen in the Priority Data Types over the next five years – the Types are generally expected to be the same in 2016 as they are now, with some possible increased usage in Atmospheric Chemistry data anticipated (largely for the correction of other EO imagery). The other eight Priority Data Types are expected to remain as important in 2016 as they are now.
2. Researchers have indicated an increasing interest in and need for Hyperspectral and Lidar data types, yet many of the same researchers do not expect their future requirements to be fully met by EOS data by 2016. Projections discussed in Sections 5.9 and 5.10 confirm the scarcity of suitable guaranteed satellite sources for these data types. It is therefore assumed that researchers expect their future requirements to be met primarily by airborne data sources. A number of space-based Hyperspectral imagers are anticipated within the next 3-5 years, and are generally expected to be available on commercial terms, once the customary small supply of free data for R&D purposes is exceeded.
3. There is also a trend towards increased migration from lower to ever higher optical resolution – the need for High Resolution Optical data, together with that for Hyperspectral imagery, appears to correlate with a decrease in the need for Low and Medium Resolution Optical data. Nonetheless, the latter two data types are still expected to be the highest priorities in 2013 and 2016.
4. SAR data remains a high priority across several projects, with usage of L-band data expected to increase in the future. Over the next two years, the L-band SAR community does not expect its requirements to be met by EOS data, which reflects the lack of imminent space-borne sensors for this data type. Some satisfaction appears to be expected by 2016.
5. Cloud Radar data users have the lowest expectation for EOS data requirements to be met in the next five years. While there is no supply scenario outlined in Section 5 (which focuses only on the Priority Data Types), the launch of the Global Precipitation Measurement (GPM) Core Observatory is noted as a possible valuable source of data. Since Australian researchers currently enjoy access to CPR (Cloud Profiling Radar) data from CloudSat (NASA), this surveyed response is assumed to indicate that they do not anticipate the availability of data from suitable substitutes.

4.2 Future Usage Trends

4.2.1 Hyperspectral Imagery

There is a gradual move from Multispectral to Hyperspectral imagery, as applications require increasing levels of measurement precision and sensor calibration for quantitative mapping (*e.g.* of pollutant concentrations in water). Several projects are eagerly anticipating the wider future availability of satellite-based Hyperspectral imagery for vegetation, coastal and geological applications beyond the currently available civilian demonstrator satellite instruments (Hyperion and CHRIS). The value of this data type was stressed by over a third of researchers surveyed. Current research is being developed using Hyperion archives (held by CSIRO and TERN) and airborne imagery. The fusion of Hyperspectral imagery with SAR or Lidar data is valued for defence applications, and for improving the separation of fractional cover components in evergreen vegetation.

4.2.2 Infrared Sensors

Infrared data are essential for a large number of R&D projects, including those relating to vegetation, weather, agriculture, irrigation, groundwater, flood mapping, geology and resources exploration studies. However, concern was expressed over the reduction in IR capability for the next generation of USA land surface imaging missions, especially with respect to SWIR and TIR data acquisition.

4.2.3 Multiple Data Sources – Data Assimilation

There is a growing trend in the environmental area, including weather forecasting and atmospheric analysis, land surface and ocean analysis, whereby data sources from many sensors are assimilated into a single analysis system using data assimilation and model-data fusion techniques. This produces consistent analyses where the weaknesses (*e.g.* signal noise) of some instruments are augmented by the independent and complementary observations of others, and where constraints on information retrievals are imposed by other (non-EOS) observations.

4.3 Expected Data Volumes and Access

4.3.1 Data Volumes

The *CEODA-Ops* Report projected the total data storage required for 91 Australian operational programs to be 1.2 PB in 2015, a twentyfold increase on current requirements. Such an increase will impact the entire EOS supply chain and place significant pressure on supporting infrastructure, including satellite downlink capabilities and Internet access constraints. This pressure will be felt by both data providers and data users.

While some researchers did not expect future data volumes to change significantly, due to usage of historical archives, projected data gaps, or project focus, over 60% of surveyed researchers anticipated two to tenfold increases in EO data volumes in the next five years. These increases will be due to improved spectral and spatial resolution and revisit frequency, as well as the availability of a larger variety of high density data sources (such as Imaging Radar Altimetry, Hyperspectral sensors, and atmospheric profilers with thousands of spectral bands). In some instances new platforms (*e.g.* Himawari-8, Japan) will be transforming capability.

Many of these researchers are involved with projects that monitor natural resources and/or deliver nationally consistent datasets. Greatest increases are expected for users of Hyperspectral and High Resolution Optical imagery, though new satellite sources of higher-quality Hyperspectral imagery are not expected before 2014 at the earliest. As the value of time series datasets is becoming more widely appreciated, many researchers also prefer increased temporal resolution. Increased data frequency not only allows greater insight into the dynamics of an imaged target, but also offers greater opportunity for optimal atmospheric conditions (such as the absence of cloud).

The current data volumes being managed by seven of the 56 surveyed projects are listed in Table 4-3. Each of these projects involve storage, processing and ongoing acquisition of relatively large data volumes. Their combined expected annual data volumes in 2016 could be up to ten times the current figures, that is, nearly 300 TB per year. Efficient access to, and archiving of, such data volumes will be essential for all research projects.

Table 4-3 Current and Projected Data Volumes for Selected Projects

CEODA-R&D Project	Historical Archives (approx. TB)	Annual Acquisitions (approx. TB)	Projected Acquisition in 2016 (TB)
WIRADA (CSIRO)	50	4	40
AusCover TERN (CSIRO)	50	2.5	25
IMOS (CSIRO)	45	13	130
Savanna Burning (CDU)	35	3.5	35
FireWatch (Landgate)	30	3	30
Cal/Val of VIIRS/GCOM-SGLI (UTS)	10	2.5	25
Ground Cover Mapping (DERM)	15	0.5	5
Total	**235**	**29.0**	**58-290**

Rough estimates provided by BoM for their operational data usage of both polar and geostationary satellite data indicate that their anticipated usage is in the region of 60-70TB annually by 2016 (a tenfold increase from 2011). But only a fraction of this might be considered as being within scope of the R&D focus of this study.

High performance computing (HPC) requirements are expected to increase, both to cope with the increased data volume and also to support the implementation of new processing standards for image calibration and validation. Several surveyed projects are already utilising the capabilities of the NCI to process large and complex datasets. Computing requirements associated with the processing of high resolution EO data were considered to be the limiting factor in Australian EO-related weather and climate research.

Some pre-processing procedures that have been traditionally undertaken using in-house facilities will be expected to be performed by data providers in the future. For example, SMAP plans to deliver a geo-referenced product that will significantly reduce the pre-processing required for current Imaging Microwave data sources. In such cases the quality of supplied data will still need to be validated locally before routine use.

The physical storage of EO data can be accommodated with continually improving hardware solutions, but management and access to EO data archives present an ongoing challenge for both R&D and operational users. Current research is addressing the need for nested data structures, and consistent product calibration and validation. National co-ordination of EO data access and archives would minimise the potential for duplication of effort and redundancy.

For example, there is potential interest in SMOS for ocean salinity, and Scatterometers for sea-surface roughness (and therefore ocean winds) to be used in weather and climate forecasting. A national facility, such as IMOS, would be well placed to negotiate national access to these kinds of datasets, in preference to having research groups engaging individually with relevant provider agencies. Such an arrangement would also help to streamline sharing of Cal/Val data.

4.3.2 Infrastructure Efficiencies

An increasing number of researchers are anticipating access to national, standardised datasets that are pre-processed for use in particular application areas (such as NDVI coverages for vegetation, climate and groundwater studies). Since many of these datasets need to be updated on a daily basis, efficient processing pathways are essential in ensuring near real-time data delivery.

To minimise delays in accessing newly acquired data and/or data products, high speed Internet access will also be essential for the increasing number of EO data sources becoming available on-line. This is equally important for operational EO users, especially for applications requiring frequent and/or large area coverage.

For example, by 2013 approximately 200 TB of AusCover data products, including base data for the products, will be available on-line. It is expected that ten times this volume will be available by 2016, that is, up to 2 PB annually for new data and products. This increased volume will necessitate upgraded bandwidth at satellite receiving stations and increased bandwidth for data transfer networks, as well as high performance computing and storage infrastructure.

It should be remembered that several of the most frequently used sensors, such as MODIS and Landsat, will be replaced with new, but different, data sources over the next few years. It will require a significant research effort to re-establish the legacy of experience that has been established with these sensors, and standardise existing archives to allow seamless access to valuable time series data.

Survey results indicate that most Australian researchers are currently acquiring EO data via multiple parallel access paths to on-line archives, principally from international suppliers. To reduce the overheads and costs associated with international Internet traffic, it would be worth evaluating the cost-effectiveness of an increased number of national archives for key datasets. These datasets could be downloaded once from the international supply agency and maintained and indexed in Australia for local users. Such an arrangement would introduce significant savings for future EO data access costs.

4.3.3 Low Latency Data

In the foreseeable future, the most common supply channel for EO data used by Australian researchers will continue to be the Internet. Researchers will typically utilise ftp servers maintained by supply agencies, or their data processing partners, to secure their routine data needs. Landsat-8 (LDCM) is believed to be moving towards a centralised data supply model, with less dependence on overseas ground stations, and with a central on-line repository at the Earth Resources Observation and Science (EROS) Data Centre. While the GMES Sentinel series data supply model is not fully defined, it is likely to be based on a similar arrangement. Further, the distributed ALOS Data Node concept that saw local downlink and processing in Australia (by Geoscience Australia) will not be repeated and JAXA is understood to be moving towards a centralised data distribution model. Imagery from the Himawari-8 and -9 missions will not be available through direct broadcast as with the current MTSAT missions, but will be distributed over the Internet. Together, these missions are likely to generate the majority of future EO data for Australian researchers and a significant increase in future Internet traffic related to the supply and exchange of EO data. This will be compounded by the expected move to higher spatial and spectral resolution data, including High Resolution Optical, Hyperspectral and Lidar data types.

A number of Australian researchers with links to the operational meteorological community, via CAWCR/BoM or their overseas counterparts, have low latency access to essential EO data supply via the WMO Information System (including its Global Telecommunication System, GTS). It is assumed that these relationships will continue to support the ongoing flow of data and, indeed, the number and type of instruments whose data is supplied in this way may increase as stronger ties between research space agencies (such as ESA and JAXA) and their operational counterparts (mainly NOAA and EUMETSAT) are developed. Several of the research space agency missions are seen as being of high importance to the operational and research meteorology, oceanography and hydrology community, and this is increasing interest in using WMO distribution systems for low latency data distribution.

There are many more researchers who utilise the free access to data available from the direct-broadcast capabilities of USA instruments such as MODIS and Landsat (the two most widely used instruments in Australian research). Inclusion of direct-broadcast is in question for LDCM, but is expected to continue for the VIIRS instruments that continue MODIS heritage on the NPP and JPSS missions (although VIIRS may not satisfy the technical needs of some projects currently using MODIS). However, direct broadcast capabilities are not included in the data architecture plans for either the ESA/EC Sentinel series or the forthcoming JAXA missions, which may become significant EO supply sources in future. In this case, the large number of R&D projects and related operational activities that have been dependent on direct-broadcast capabilities will need to reassess data access options. It should be a matter of some urgency, therefore, to evaluate the opportunities for low latency data access to the future missions of ESA/EC and JAXA with a view to securing continued access to data with a suitable latency for Australian needs.

For example, the systems for access to ESA/EC satellite data by Australian researchers, and the policies that will govern the terms and conditions for that access, will affect seven of the nine Priority Data Types identified by this study. The same policies and systems can also be expected to be critical for operational programs in Australia. Four of the seven Priority Data Types for which ESA will be a key supplier have user-defined latency requirements of 'hours'. It remains to be seen whether the ESA/EC GMES data architecture will support Australian needs, unless special provision is planned for and negotiated in advance.

The opportunity may exist for more coordinated national access to the operational meteorology distribution channels enjoyed by CAWCR/BoM, and any such opportunities should be investigated.

4.4 Emerging Technology

While consistency and reliability of EO data sources are essential in research projects with an operational emphasis, the nature of R&D is such that knowledge and consideration of future technologies is important. Apart from next generation Optical/Hyperspectral or Radar sensors, there are a number of new and near-future sensors and technologies that warrant future investigation by the EO R&D community, particularly with regard to augmenting current observations with additional EOS technologies, as well as ensuring the continuity of more conventional data types in support of R&D information needs.

4.4.1 New Sensors

Full Wave-Form Lidar

Several researchers expressed an interest in access to full wave-form Lidar data. Multi-wavelength Lidar was considered to be useful for directly sensing the above-ground biomass for calibration/validation of satellite products. With only one or two airborne systems currently available in Australia, research over the next decade will evaluate its utility for improving estimates of, for example, biomass and Leaf Area Index.

Frequency Modulated Continuous Wave (FMCW) Radar

Frequency Modulated Continuous Wave radar is potentially interesting for Antarctic research. It was flown on a helicopter in 2007 (with mixed results due to the high-vibration environment) and is being flown on a fixed wing aircraft as a part of NASA's IceBridge program. IceBridge is intended to bridge IceSat (which stopped collecting data in late 2009) and IceSat-2 (currently scheduled for launch in 2016), and flies a combination of sensors, including an IR laser, a range of radar sensors and, eventually, a green laser. These flights cover Antarctica quite extensively and underfly a number of satellite coverages.

The Australian Space Research Program (ASRP) has funded ($4.6 million) the Garada consortium led by UNSW to investigate technologies related to the development of a space-based L-band SAR system proposed primarily for disaster monitoring. Among the novel aspects of the proposed system is the radar signal and data collection model, which uses Continuous Wave (CW) radar to enable implementation of low-peak-transmit-power signals.

GRACE

The GRACE Follow-on mission will duplicate NASA's GRACE mission and will also include a laser meteorology system to complement the K-band inter-satellite measuring system. However, failure of GRACE and/or delays in GRACE Follow-on will leave the scientific community without any sensor to "weigh" the continents, monitor melting of ice sheets or provide estimates of the hydrological changes at catchment scale.

Meteorological and Environmental Sensors

Environmental forecasting and analysis would benefit from access to additional data types, including Rain Radar (such as the Global Precipitation Measurement mission), Ultraspectral (0.3-14 μm) imagers, Ultraspectral sea surface temperature instruments, geostationary Microwave Sounders (global precipitation), GPS radio occultation, and Hyperspectral Sounders.

Imaging Radar Altimeters

When available, Imaging Radar Altimeters will provide higher spatial resolution and contiguous data sampling, which will be especially valuable for coastal regions, but also generate much higher data volumes.

Ocean Colour Instruments

ESA, JAXA and NASA are all planning next generation ocean colour instruments that should satisfy Australian R&D needs. Korea plans to continue its supply of ocean colour data from geostationary orbit – which could potentially open new and significant capabilities if coverage of Australia could be negotiated.

Higher Resolution Passive Microwave Radiometry Data

The technologies and wavelengths involved in Passive Microwave Radiometry naturally result in low spatial resolution data (with spatial resolution of tens of kilometres). Higher resolution or synthetically enhanced Passive Microwave Radiometry would be welcomed by several research communities currently using this data to generate sea-ice concentration products, monitor soil moisture and estimate ocean salinity.

Multi-Sensor Integration

The integration of multiple data sources will become increasingly important for many applications as the logistical issues of image registration become more streamlined and adequate processing power becomes commonly available. As noted above, there are many applications whereby multiple data streams are ingested into models using data assimilation and model fusion approaches to optimally produce analyses of multiple variables.

4.4.2 Platforms

Airborne and Unmanned Aerial Vehicles

Traditionally, many of the higher resolution or newer EOS sensor technologies have been tested by the R&D community from manned airborne platforms, which have served as important underpinning data sources, often as stepping-stones to development of new applications which can be applied to satellite-derived data. In addition, two of the surveyed projects are now trialling a range of compact EO sensors on unmanned aerial vehicles (UAV) for a diversity of applications. These platforms offer significant advantages in terms of pre-flight programming, flexibility in the timing, location, orientation and scale of recorded data, and (relatively) low cost simultaneous and integrated data acquisition from multiple instruments. UAVs are also able to operate where piloted aircraft are not practical, such as over very remote or unsafe locations (e.g. Antarctic surveys or military conflict areas). Such features offer enormous efficiency in tailoring instrument development to specific applications and to cross-compare the products from different sensors.

While currently addressing issues related to hardware integration, researchers expect a dramatic increase in the use of UAV platforms for EO in the next few years. They also anticipate the emergence of several turnkey-style solutions, which will encourage more operational use. In relevant applications areas, UAV technology will potentially benefit from and mimic recent advances in precision GPS-guided devices.

Geostationary Sensors

An increasing number of researchers are looking to geostationary satellites with higher spatial resolution (such as GOCI/COMS) and small satellite constellations to supply low latency data. The frequency of geostationary image updates potentially reduces the impact of cloud cover and improves understanding of the diurnal cycle. The emergence of platform constellation configurations will improve effective revisit frequency for time-critical applications such as flood mapping. The most significant advance in this area will perhaps be the availability of the upgraded sensor suite on the Japan Meteorological Agency (JMA) geostationary weather satellites (from Himawari-8, available operationally from 2015). The improved spectral and temporal resolution will allow new and improved products to be developed and used by forecasters, including a number of multi-band composites.

4.5 Data Quality

As an increasing number of applications use optical data (Multispectral and Hyperspectral) for quantitative measurement, the need for careful calibration and data corrections (*e.g.* for atmospheric effects, imaging directionality and topography) is becoming more critical. As a result, two-thirds of the surveyed projects involve ever-improving calibration and/or validation of EO data with ground-based information.

Currently the calibration and correction of EO data is not coordinated in Australia for all data types. For different EO data sources, the responsibility for data quality is currently assumed by data providers, researchers, and/or users, with some duplication of effort occurring between various organisations.

The majority of survey respondents felt that EOS data quality in Australia should be the responsibility of an adequately funded national body (whether it be one or more Government agencies, a national facility such as TERN, or a national technical group) which could rigorously test new sensors and also manage international contact with data providers.

National infrastructure to support radiometric Cal/Val was also considered to be a fundamental factor in ensuring data stream quality. International links, such as involvement with global Cal/Val teams, helps to ensure the quality of relevant data products in Australian conditions, especially in those cases when Australia is the only contributor to such activities in the Southern Hemisphere. Most respondents from state agencies felt that this was a role for the Federal Government, and that the availability of calibrated, validated datasets would be welcomed.

In order to begin to address this issue, a new National Satellite Calibration Working Group is currently being established and jointly coordinated by CSIRO and GA, in collaboration with BoM, DSTO, TERN, IMOS and several university teams, to better coordinate field calibration activities, ground-sensor inter-comparison, National Institute of Standards and Technology certification, and so on.

While data quality can mean different things, with each user having potentially different thresholds for 'acceptable', the design purposes, and their limitations, need to be understood for competent usage of any dataset. An organisation formally responsible for quantifying these attributes for all EO data types in Australia would help to ensure appropriate use of these data.

4.6 Significant Future Missions

As noted above, awareness of future EO satellite program plans varies significantly among the research community surveyed. Accordingly, this report has focused on assessment of the continuity of the Priority Data Types for the next five years, in order to support short- to medium-term infrastructure planning. Less focus has been placed on far-future missions, and further consultation and consensus-building will be required to identify priority missions for the R&D community in the long-term. This will require the community to be better informed as to future planned missions and their capabilities. However, knowing the current observational priorities for Australia, it is possible to suggest a set of future missions that will have a high national significance and might form the basis of a provisional list of future priorities.

The eight key national challenges for Australia identified in the *Australian Strategic Plan for Earth Observations from Space* (ATSE, 2009), were:

- **Agriculture, forestry and ecosystems;**
- **Climate change;**
- **Water availability;**
- **Natural disaster mitigation;**
- Safe and secure transport;
- Energy and resources security;
- Coasts and oceans; and
- National security.

Those indicated in bold were identified in Table 2-7 as being the most frequent sectors (or Societal Benefit Areas) for EO-related R&D in Australia.

The CEOS database features hundreds of future missions with the potential to contribute to these areas – climate change in particular is extremely broad and could be associated with more than half the missions in the database in support of one or more of the over 50 Essential Climate Variables used to define climate information needs. Section 5 focuses on continuity outlooks for the Priority Data Types for the next five years – with an emphasis on the missions which are well-known and assumed to form the core of the data streams meeting Australian researchers' observation needs. Below, a number of missions have been identified which may bring novel capabilities and are highly anticipated internationally for their potential to deliver new types of information and to enable new science, and in due course, new operational information streams. The list is not exhaustive.

Agriculture, Forestry and Ecosystems

DESDynI (Status uncertain, NASA, no launch date): DESDynI is a science mission providing important observations for land surface change and hazards (surface deformation), and climatic variables (terrestrial biomass and ecosystem structure and ice dynamics). The DESDynI spacecraft features an L-band SAR system with multiple polarizations. The mission uses polarimetric SAR for biomass estimation and spatial variability of ecosystem structure. The science community world-wide keenly anticipates the vegetation structure and biomass capabilities which DESDynI may provide. Earlier mission concepts included a lidar but this appears to have been removed.

BIOMASS (Considered, ESA, no launch date): BIOMASS features a full polarimetric P-band SAR with interferometric capability. It aims to: improve current estimates of forest carbon stocks; reduce uncertainty in deforestation emissions to a level comparable to uncertainty in net ocean flux; and improve estimates of terrestrial carbon sinks from regrowth and reforestation.

HJ-1C (Approved, China, Dec 2012 launch): S-band SAR is a new data type, which will be first available from space from the Chinese HJ-1C mission in late 2012. S-band SAR is understood to support agricultural applications including classification of crop-type, mapping agricultural land, assessing crop condition and moisture content. It should also be able to provide land use classifications.

Hyperspectral imagery is discussed in Section 5 but it is worth noting the **EnMap** (Approved, DLR, 2015 launch), **PRISMA** (Approved, ASI, 2014), **ALOS-3/HISUI** (Planned, JAXA, 2014) and **HyspIRI** (Considered, NASA, 2020+) missions, given their potential to contribute to many different research projects in Australia.

Climate Change

Missions of special interest in relation to carbon observations and greenhouse gases:

OCO-2 (Planned, NASA, 2013): OCO-2 is designed to provide space-based global measurements of atmospheric carbon dioxide (CO_2) with the precision and resolution needed to identify and characterize the processes that regulate this important greenhouse gas. With its three high-resolution grating spectrometers, data collected by OCO-2 could be combined with meteorological observations and ground-based CO_2 measurement to help characterize CO_2 sources and sinks on regional scales at monthly intervals for 2 years.

MERLIN (Planned, DLR/CNES, 2016): Lidar measurements of atmospheric methane globally over a three year period.

Water Availability

GRACE Follow-on Mission (Approved, NASA/DLR, 2016 launch): GRACE Follow-on will continue the observations pioneered by the GRACE mission, which has been in operation since 2002 and will extend operations through 2013 if fuel allows. GRACE measures the change in all of the water stored on land after precipitation has been stored as snow, infiltrated into the ground, evaporated, or left the basin as streamflow - accounting for these inflows, outflows and storage changes is called water balance. GRACE is able to track water storage in large river basins.

GPM (Approved, NASA/JAXA/others, 2013 launch): The Global Precipitation Measurement mission aims to provide precipitation measurements on a global basis with sufficient quality, Earth coverage and sampling to improve prediction of the weather, climate and specific components of the global water cycle. GPM aims to ensure a repeat observation cycle of approximately three hours.

SWOT (Considered, NASA/CNES, 2020 launch): The Surface Water Ocean Topography mission will make the first global survey of Earth's surface water, observe the fine details of the ocean's surface topography, and measure how water bodies change over time. Given our basic need for fresh water, hydrologic observations of the temporal and spatial variations in water volumes stored in rivers, lakes, and wetlands are extremely important. Unfortunately, our knowledge of the global dynamics of terrestrial surface waters and their interactions with coastal oceans in estuaries is very limited. By measuring water storage changes in all wetlands, lakes, and reservoirs and making it possible to estimate discharge in rivers more accurately, SWOT will contribute to a fundamental understanding of the terrestrial branch of the global water cycle. SWOT will also map wetlands and non-channelized flow.

Section 5 contains a discussion of upcoming **soil moisture** missions, which have multiple critical research and operational applications in Australia (our geography being ideal for such applications). These include **GCOM-W, Aquarius, and SMAP**.

Natural Disaster Mitigation

Overall, several sensors on upcoming geostationary and polar orbiting satellites should provide several options for continuity across disaster monitoring and mapping programs that monitor tropical cyclones, storms, bushfires and floods. In the case of bushfires, for example, the following missions would be of interest.

TET-1 (ready for launch – DLR). This new, dedicated thermal infrared sensing mini-satellite is a follow-up of the BIRD satellite, developed by DLR (Germany) in the late 90's, and which provided unprecedented bushfire detection qualities, in terms of spatial resolution (about 300 m) and radiometric quality, to measure radiant heat output by fire fronts with good accuracy. TET-1 is designed to be the first of a constellation of such satellites, which would offer much higher repeat pass capabilities and off-nadir pointing to track the progression bushfires on a close to near real-time basis. DLR is currently looking for other countries to contribute towards the other satellites in the constellation.

VIIRS (launched – NASA/NOAA). Somewhat of a hybrid between AVHRR and MODIS, VIIRS is expected to provide the same thermal detection capabilities and spatial resolution as MODIS and AVHRR, with similar dynamic range and sensitivity as MODIS. Therefore the continuity of programs such as Sentinel Hotspots (operated by Geoscience Australia), Firewatch (Landgate WA), and NAFIS (NT) are expected to have only minimal disruption upon stoppage of MODIS.

SLSTR (Sentinel-3 series of GMES, ESA). A follow-on of the ATSR and Advanced ATSR sensors with 1 km resolution in the TIR, this sensor should provide sufficient data in addition to VIIRS, as well as guaranteed follow-on spacecraft, provided that data or derived fire-detection products from these spacecraft can be transferred to Australia's operational fire detection and tracking systems with sufficiently low latency.

It should be stressed that the above sample of missions are suggested as *possible* national priorities – and have not been indicated as such by the study survey process. Of this small set, it is interesting to note that, although NASA may not feature prominently as a future supplier of data for Priority Data Types of interest to Australian R&D (**Section 5**), they continue to pioneer a range of important scientific EO satellite missions which will be of interest and value to Australian researchers.

Similar analyses, not undertaken here, for missions of potential interest can also be undertaken for other applications including flood mapping, cyclone trajectory, rainfall and wind-speed tracking, and storm or tsunami/high-tide monitoring purposes.

4.7 Summary

The survey indicated that, across the community, Australian researchers expected little change in their Priority Data Types over the next five years. Researchers have indicated an increasing need for Hyperspectral and Lidar data types, yet many of these researchers do not expect their future requirements to be fully met by 2014-2016. Since it is likely that there will be few or no satellite missions acquiring these data types on terms suitable to Australian researchers before 2014-2016 (see **Sections 5.9** and **5.10**), it is assumed that researchers expect these requirements to continue to be met primarily by airborne data sources.

There is also a growing need for High Resolution Optical data. The increased requirements for High Resolution Optical and Hyperspectral imagery appear to correspond with a decrease in the need for Low and Medium Resolution Optical data. The latter two data types are still expected to be the highest priorities in 2013 and 2016.

SAR data remains a high priority, with an expected increase in L-band data usage. This requirement is unlikely to be met by EOS data, however, given the lack of imminent space-borne sensors for this data type.

Future data volumes and the variety of data sources are anticipated to rise several-fold in coming years, although the data volumes associated with most R&D projects are not as large as those identified for operational programs (and detailed in the *CEODA-Ops* Report).

A number of infrastructure issues have been identified that merit further analysis:

- The establishment of an increasing number of national archives for key datasets (which are downloaded once from the international supplier, and stored and distributed locally) would save significantly on the overhead and cost of international Internet traffic related to future EO data supply.
- The majority of researchers support the establishment of a mandated national coordination group or body to take responsibility for EO data quality of existing and new sensors, including coordination of national Cal/Val activities and delivery of calibrated and validated datasets.
- Given the possible reduction in direct-broadcast capable satellites and the loss of low latency data for many critical applications, negotiations with NASA, ESA/EC, JAXA and other key space agencies are required to define access conditions that would ensure data supply for Australia's future research needs.
- Maintaining technical capability and capacity to meet increasing societal demand for outputs from EO is also likely to be an issue, as discussed further in **Section 6.2.5**.

The Australian EO R&D sector has discovered efficient ways to access key EO datasets, often via strategic relationships established by individuals with overseas science collaborators or space agencies. To increase access to, and adoption of, more advanced, new generation EO data streams, however, it would be advisable that stronger inter-institutional data agreements with key data providers be established at the Federal Government level, as well guaranteed access to bandwidth, and time-allocation for use of current satellite downlink infrastructure for these science missions. The need for a national negotiating position may be exacerbated in future if the main EO data supply agencies continue their trend towards centralised Internet-based data distribution systems that may not meet Australian latency requirements.

5 EO DATA AVAILABILITY

Future data supply scenarios for each of the Priority Data Types are explored in this section. Characteristics of the global supply of EO satellite data required in support of Australian research activities, and issues and trends that may impact that supply, are discussed in Section 5.1. Section 5.2 summarises the supply outlook for each of the Priority Data Types.

The risk of EO data gaps are high for several Priority Data Types, namely Medium Resolution Optical, L-band SAR, Hyperspectral and Lidar. From this group, the recent malfunction of Landsat-5 and the current gap in L-band SAR data both warrant close attention. In addition, the widespread reliance on the ageing MODIS sensor, and uncertainty on the utility of VIIRS for certain applications, merits further consideration. Section 5.2 also outlines the implications of Landsat, MODIS and L-band SAR data continuity risks on current EO-related R&D in Australia, in terms of the:

- National significance of the EO data type;
- Likelihood of the EO data gap;
- Availability, suitability and cost of alternative data sources; and
- Impact of using alternative data sources—or having no data—on research and operational outcomes.

Appendix D presents information tables for those instruments cited in the supply outlooks. Appendix E contains some additional detail and timelines for the supply outlook for each of the Priority Data Types.

Airborne data sources are not considered in this section due to the *ad hoc* nature of image acquisition.

5.1 Global supply context

5.1.1 Overview

As stated in the Australian Strategic Plan for Earth Observations from Space (ATSE, 2009), "EOS data are the single most important and richest source of environmental information in Australia". World-wide, EO is also the primary satellite-based application, with governments spending around USD $7 billion per year—about 20% of government non-classified investment in space (based on estimates in The Space Report (The Space Foundation, 2011) and by Euroconsult, 2008). While estimates of the total number of operational and planned EO satellites vary, the following sources agree that this is, and will remain, an extremely active sector:

1. The 2011 survey of CEOS space agencies was completed in October 2011, and the CEOS database updated accordingly (CEOS, 2011). The database now features details of 256 civil Earth observing satellite missions involving 769 instruments (399 distinct instruments and 370 duplicates), currently operating or planned for launch in the next 15 years. These missions are funded and operated by around 30 space agencies world-wide. About 85 of the planned missions have meteorology as a primary objective. The other 171 missions will be applied to a diverse range of research, operational and commercial activities.
2. Northern Sky Research (2009) forecasts that the number of operational Earth observation satellites will increase from 180 satellites in 2009 to approximately 240 satellites by 2019. It is expected that 77% of these satellites will be used for civil government or military services, with North America, Europe, and Asia leading the growth.

Lower cost satellites and the ability to address local issues have made EO the top priority space application for a number of countries, particularly emerging space programs in Asia. Growth in EO budgets is also being driven by society's increasing need for information on our planet, this being the essential foundation for sustainable development policies aimed at ensuring our continued health and prosperity in the face of population growth, environmental degradation and a changing climate.

The CEOS database suggests that space agencies have already approved and will launch 18 new missions during 2012. By 2016 agencies in a total of 29 countries will have launched an EO satellite, compared to just 17 in 2006. These numbers include both long-established EO programs, such as those managed by ESA and NASA, and emergent EO programs in Nigeria, Turkey, Thailand and Vietnam.

The *CEODA-R&D* study process has highlighted the predominance of the Australian R&D community using 'whatever free data are available', provided it offers suitable data quality, continuity, coverage and access arrangements. In practice, these conditions significantly reduce the supply options for Australian R&D to those provided by very few agencies and sometimes only a handful of suitable missions.

5.1.2 Government versus Commercial

Only a few, typically very high resolution, EO satellites are funded and operated as truly commercial ventures. These include the US high-resolution optical data licenses held by DigitalGlobe and GeoEye. Both of these companies have benefitted significantly from the commercial markets driven by the Virtual Globes (like Google Earth and Microsoft). These Virtual Globes have already had a very large impact on the geographical information/EO industry, and most companies involved in the sector are currently reassessing their strategy to adapt their product portfolios to the new market environment. The success of the first generation of high-resolution commercial satellites has paved the way for a second generation, for example WorldView-1 and WorldView-2 from DigitalGlobe and GeoEye-1. These satellites are partly funded through the US Government *NextView* and *Enhanced View* contracts to meet information needs for national security purposes.

Europe's first commercially operated systems (other than the SPOT series) could be considered to be the public-private partnership (PPP)-funded TerraSAR-X/Tandem-X (Germany) and the RapidEye constellation (also Germany, now Canadian-owned). The launch of Radarsat-2 (Canada, 2008) and Deimos (Spain, 2009) added to the number of commercially underwritten missions for EO. Success of PPP-financed missions could pave the way for future programs. In addition to the commercial systems, a number of government satellite programs are looking to profit directly from their commercially viable data. Similar to the commercial operators' focus on high-resolution data, governments operating similar resolution systems are likely to look to commercialisation. These include satellites from India and South Korea, as well as dual-use (civil and military) programs such as Pleiades (France) and COSMO-SkyMed (Italy).

A trend towards higher resolution data is expected in future commercial systems, such as GeoEye-2 in 2013 with 25 cm pixel resolution. US Government licensing regulations may, however, limit access to imagery at the full spatial resolution.

Australian R&D programs rely primarily on airborne data suppliers for high resolution imagery; relatively little commercial satellite data is supplied and used, due to the significant costs involved and uncertainty of data acquisition relative to coincident field measurement and calibration activities. Australia is almost entirely dependent on the continued supply of free data from governmental missions (both scientific and operational) that are provided as a global 'public good' resource and that have a supporting open data policy. There are both significant opportunities and significant risks associated with sustaining a position whereby Australia continues to exploit at virtually no cost the investments of other countries in EO data supply.

5.1.3 Research versus Operational

The international governmental EO sector on which Australia is reliant is typically organised along two lines:

- 'operational'—effectively covering meteorology missions but with an expanding sphere of influence into climate, water, security, and disaster monitoring; and
- 'research'—effectively covering everything other than meteorology.

National agencies which operate satellites typically belong to one category or the other. In the USA, NOAA and USGS are the operational agencies handling meteorological and land-mapping satellites respectively, and NASA is the research agency handling non-meteorological satellites. In Europe, EUMETSAT is responsible for meteorological satellites and ESA, supplemented by scientific satellite missions from several individual countries (*e.g.* Germany, Italy, France), for the non-meteorological satellites. In Japan, these roles are fulfilled by JMA and JAXA respectively. It should be noted, however, that in all cases the technical build of the spacecraft is often the responsibility (at least in part) of the research space agency, and NASA, ESA and JAXA are good examples of this in practice.

The operational space agencies are heavily focused on the application of satellite data to weather forecasting. They are well-organised internationally, for that purpose, under the auspices of the World Meteorological Organization (WMO), and specifically via the Coordination Group for Meteorological Satellites (CGMS). CGMS provides a forum for the exchange of technical information on geostationary and polar-orbiting meteorological satellite systems and research & development missions. The key systems of interest to Australia, in this context, are the geostationary satellites provided by Japan (as well as China and South Korea) and the polar orbiting satellites provided by the USA and Europe.

CGMS membership is open to all operators of meteorological satellites, to prospective operators having a clear commitment to develop and operate such satellites, and to the WMO in recognition of its unique role as representative of the world meteorological data user community. Further, CGMS membership is open to space agencies operating R&D satellite systems that have the potential to contribute to the WMO and supported programs (*e.g.* ESA, NASA and JAXA attend meetings). Some 13 national agencies, as well as the WMO and GEOSS' Initial Operating Capability (IOC), participate in CGMS for this purpose. These agencies collectively have responsibility for around one third of the international government-funded EO missions currently in operation or planning. The remaining two thirds (180 satellites over the next 15 years in CEOS agencies alone) are the responsibility of the research space agencies, with an increasing number of missions being provided by emerging space nations.

It should also be noted that an increasing amount of data from the research space agencies (notably NASA, ESA, and JAXA) is supplied and shared world-wide through the WMO distribution channels, these data being of both operational and research interest to national weather and climate agencies in their numerical weather prediction activities. For this reason, most large meteorological agencies are strong participants in CEOS. Australian researchers obtain a significant amount of their data through WMO channels, and for a wide range of purposes far beyond weather and climate applications, for applications such as the prediction and possible detection of coral bleaching.

Accordingly, the nature of the arrangements between the research space agencies and the operational space agencies, and in particular the link between individual missions and the WMO Information System (including the GTS), is of great interest to Australian researchers, as these connections have a significant bearing on the availability of relevant data sources. Through BoM, Australia has a long history of effective engagement in support of satellite data supply from the operational space agencies through the WMO system.

There is a more *ad hoc* nature to Australian relations with the research space agencies—NASA, ESA, JAXA and others—and this represents a significant risk to continued supply, as well as involving considerable inefficiencies through repeat and duplicated access to the same datasets by different research groups.

5.1.4 Global Trends and Data Policies

Data access policies are of critical importance to Australian researchers, who tend to work with whatever data is available for free. This effectively allows trends in international data access policy to determine Australia's capability to undertake EO-related research. A number of surveyed researchers consider that a high level of risk is associated with the expectation of ongoing goodwill from several EO data suppliers, given that many of the supply countries (*e.g.* Japan and the European states) are now experiencing more difficult financial circumstances than Australia. This issue could jeopardise Australian access to the Sentinel series of satellites (Europe) and to future Japanese land imaging satellites (*e.g.* ALOS-2). The recent change in Japan's data supply policy, which ended the free supply of national land-mapping data to non-contributing operational agencies in 2010, has already resulted in the loss of Australian access to ALOS data via Geoscience Australia (although a limited number of scenes may be granted to research organisations free of cost, on request).

The current situation and trends within Australia's three main supply regions—USA, Europe and Japan—are further detailed in the following paragraphs.

USA (NASA, NOAA, USGS)

The remote sensing budgets of the main US suppliers of satellite data for Australian research have been subject to major fluctuations in recent years.

NASA's EO satellites are launched under the Earth Systematic Missions (ESM) program, aimed at providing long-term environmental data, and the Earth System Science Pathfinder (ESSP) program, addressing specific requirements in earth science research. NASA has historically been the largest EO investor world-wide. However, budget reductions in the early 2000's had a significant impact on data continuity of key EO missions, leading the US National Research Council of the National Academies (2007) to release a decadal survey articulating the US scientific community's EOS priorities for the next ten years and beyond, to assist in continuity planning.

NOAA's next generation polar orbiting system, National Polar-orbiting Operational Environmental Satellite System (NPOESS), was originally conceived as a joint mission between NASA, NOAA and the US Department of Defense. Due to significant cost and time overruns, however, this program has been restructured to become the NOAA-operated JPSS (Joint Polar Satellite System), with science input from NASA. JPSS is expected to be operational from 2015 to 2026, though funding limitations may preclude the deployment of the full mission.

USGS currently anticipates the launch of Landsat-8 (LDCM) in early 2013. Free and open data access will be offered via the USGS LPDAAC, providing much-needed continuity to the Landsat series satellites.

This recent trend in the USA towards a free and open data policy, using Internet-based distribution systems, is expected to continue into the future, and is becoming a model for other countries' EOS programs. The opening in recent years of the on-line Landsat archive has seen an explosion in its use world-wide, including in Australia. In addition, the early decision by NASA and NOAA to provide MODIS and AVHRR data freely, both via an ftp service or via direct-broadcast, has further enabled many more R&D programs and associated operational programs to use this data. Furthermore, NASA's decision to fund a comprehensive ground segment (nearly as costly as the space segment), with well-designed data management and distribution systems, as well as a suite of over 40 derived, standardised level-3 and -4 products from the MODIS data streams, has opened the door to many non-expert users of EOS data across a wide range of climate and environmental monitoring domains.

Europe (ESA/EC, EUMETSAT and National Agencies of Germany, France, Italy, etc)

Together with several new ESA Science Explorer missions, the ESA/EC Global Monitoring for Environment and Security (GMES) program will be supported by five Sentinel satellite missions, and will provide a significant new source of EOS data for civil applications. The five missions, each based on a two-satellite constellation, are:

- Sentinel 1: providing continuity of C-band SAR data for operational applications, notably marine services, land monitoring and emergency services;
- Sentinel 2: supporting land and coastal monitoring-related services (10m optical imagery in four bands); this may be operational before LDCM;
- Sentinel 3: supporting global land and ocean monitoring services (Ocean Colour sensor, radiometer, and altimeter);

- Sentinel 4: geostationary atmospheric composition and trans-boundary pollution monitoring;
- Sentinel 5: low Earth orbit atmospheric composition monitoring. The Sentinel 4 and 5 missions will be carried on meteorological satellites operated by EUMETSAT.

It is intended that the Sentinel series—covering land surface, ocean, atmosphere, and operational meteorology—will operate with guaranteed continuity for 20 years, and with a free and open data policy for all users.

However, as of late 2011, the EC had not yet agreed to provide funding for GMES operations. While ESA management continues to lobby the EC and individual countries for a free and open data access policy as well as the required funding for GMES, the severe financial situation currently prevalent in many EC countries leaves the ultimate outcome uncertain at the present time.

If, however, the data access policy and data delivery arrangements outside the EU membership, as well as European funding issues, are resolved favourably, the Sentinel series missions (particularly those that are polar orbiting and not stationary over Europe) may well become a high priority for Australian researchers in the future. Australia does not currently have any existing agreements with ESA/EC regarding the direct reception and exploitation of data from ESA's EO missions.

Apart from Europe's central space agency ESA, other European national EO programs may also become significant direct partners for Australian researchers. For example, Germany's aerospace agency, DLR, has launched the X-band radar system TerraSAR-X/TanDEM-X, will soon launch the first satellite (TET-1) of the bushfire monitoring mission FireBIRD, and is building the EnMAP Hyperspectral satellite mission. All of these are of considerable interest to agencies like CSIRO, where dedicated cooperative agreements (MoUs) are being established with DLR. Similarly, the French space agency CNES and the Italian space agency ASI are operating their own internal budgets for missions such as COSMO-SkyMed (Italy) and separate hyperspacetral programs. Data from these latter missions, however, may be provided to users other than the funding government on a commercial basis only. This is yet to be clarified.

Japan (JAXA & JMA)

The Japanese EO program has experienced several on-orbit system failures on key missions of interest to Australia, resulting in poor continuity of data supply. The most recent mission, ALOS, which terminated unexpectedly earlier in 2011, was well regarded internationally for its utility. Geoscience Australia was originally permitted to receive and archive ALOS data as a regional data node, but a change of government in Japan in 2009 resulted in adoption of a more commercial access policy for these data when they are to be used for other than relatively small R&D projects. The direction for data access policies for ALOS-2 and beyond is presently uncertain.

In contrast, it is assumed that data associated with the JAXA EO satellite programs that are focused on climate observations (e.g. GCOM-W and GCOM-C series) will continue to be available free of charge. JMA (Japan Meteorological Agency) and JAXA coordinate efforts for the planning, development and launch of satellites for operational meteorology. The JMA Meteorological Satellite Centre has operated the series of geostationary platforms (1977-ongoing), located over 140°E, that provide the region with timely access to meteorological imagery. The current series of geostationary platforms is scheduled to operate through 2017. Official interaction between JMA and Australia is conducted through a Bilateral Agreement between JMA and BoM. BoM relies on the availability of JMA's imagery for operational weather forecasting and disaster mitigation. The continued requirement for data from JMA geostationary platforms will ensure that JMA remains a key provider of data for Australia.

Others

China and India are two emerging and significant suppliers, but neither has a history of EO satellite data sharing internationally for public good purposes, other than for meteorology. India has made recent changes in this regard through changes to data access policy, and participation in international bodies like CEOS.

Similar unknowns currently surround the increasing number of potentially interesting missions that comprise the Chinese EO program, where currently only a few direct collaborations exist between Australian R&D groups and equivalents in China.

Korea also now operates both geostationary and low-Earth orbiting observing satellites, and has indicated considerable interest in expanding bilateral agreements with Australia on, for example, joint Cal/Val opportunities.

5.2 Priority Data Type Scenarios

The supply scenarios in this report are derived primarily from the CEOS Missions Instruments Measurements (MIM) database (CEOS, 2011), recently updated by ESA. This is the only official and consolidated statement of civil space agency EO programs in the world, and represents a reliable and current source of information on the programs and plans of the many suppliers of data to Australian researchers.

Due to the programmatic and political reasons cited above, mission plans are always subject to change. Nonetheless, the most current information available is used to make the following projections.

The scenarios postulated below cover the following issues for each of the Priority Data Types:

- Current data sources and their life expectancy;
- Statistics from the CEOS database regarding individual data types and their outlook, together with risks and opportunities that have been identified; and
- An overall assessment of whether Australian R&D requirements will continue to be met, and how.

Appendix D presents information tables for those instruments cited in the supply outlook for each of the Priority Data Types identified. Some additional information on data supply scenarios and timelines is also provided in Appendix E.

5.2.1 Low Resolution Optical (>80m)

This data type is essential to around 50% of the entire R&D activity surveyed and, as such, must be considered the highest priority. It requires sustained coverage, and consistency in spectral, geometric, and calibration quality, given the large areas being covered.

Table 5-1 indicates the key sensors in terms of current data usage – with MODIS (on NASA's Aqua and Terra missions) being the most widely used. AVHRR (NOAA and Metop series), IMAGER (on the Japanese geostationary meteorological series) and MERIS (on ESA's Envisat) are also important current sources.

NASA, NOAA, ESA, EUMETSAT and JAXA all have plans for future systems that should largely satisfy Australian R&D project requirements.

Table 5-1 Data Continuity Options: Low Resolution Optical

Current Sensor	Expected End of Life	Possible Substitute	Expected Availability	Comments
MODIS (Aqua, Terra)	Recently revised to end 2013	VIIRS (NPP/JPSS)	Early 2012 – 2029 (Oct 2011 launch)	Reduced spatial and spectral resolution.
		OLCI (Sentinel-3)	Jul 2013 – 2027 (Apr 2013 launch)	Reduced spatial resolution.
		SGLI (CGOM-C)	Jun 2014 – 2027 (Feb 2014 launch)	
AVHRR (NOAA & Metop series)	5 years life expected on NOAA orbiters. 10 years life expected on Metop series	VIIRS (NPP/JPSS)	Early 2012 – 2029 (Oct 2011 launch)	
IMAGER (MTSAT series)	2017	MTSAT series presumed to be continued operationally	TBD	Alternates might be Chinese or Korean GEO satellites
MERIS (Envisat)	Around late 2013	OLCI (Sentinel-3)	Jul 2013 – 2027 (Apr 2013 launch)	
		VIIRS (NPP/JPSS)	Early 2012 – 2029 (Oct 2011 launch)	
		Ocean colour sensors	See **Section 5.2.9**	

MODIS is well past its design life but data continuity should be assured from the USA by the **VIIRS** sensor on the recently launched NPP satellite (NASA/NOAA), and follow-on VIIRS instruments on the JPSS (NOAA) series in due course, with the launch of JPSS-1 scheduled for 2017 (earliest). There is, however, some concern amongst some in the R&D community (as noted by the US National Research Council, 2001) that VIIRS characteristics, and ensuing global Level-3 and -4 products, will not satisfy many of their needs. VIIRS has a Ground Sampling Distance (GSD) of 400m – 1.6 km (compared to 250/500/1000 m GSD for MODIS) and 22 bands from 400 nm to 1250 nm, as opposed to the 36 bands of MODIS from 400 nm to 1440 nm. Several researchers have indicated that the loss of spatial resolution and key MODIS bands will make VIIRS less capable or less suitable for their R&D. This is yet to be verified upon more thorough scientific analysis.

AVHRR is currently operating on several active NOAA satellites (NOAA-15 through NOAA-19), as well as on EUMETSAT's Metop-A. Both the NOAA and Metop satellites are operating nominally and many more years of continued operation are anticipated, with the VIIRS data streams potentially also adding further value.

MERIS (on ESA's Envisat) is operating beyond its design life, and operations are scheduled to terminate as the Sentinel satellites come on-line from 2013.

In addition to VIIRS, key future Low Resolution Optical data continuity options are: the **OLCI** instrument on the **Sentinel-3** series (from early 2013 with operational continuity for around 20 years, via three consecutive spacecraft); and the **SGLI** instrument on JAXA's **GCOM-C** mission series. Furthermore, in 2014, JMA will launch the next generation of geostationary meteorological satellites, named Himawari-8 and -9, which are expected to be operational by October 2015. Himawari-8 will have improved spectral and temporal resolution and will allow new and improved products to be developed and used by forecasters, including a number of multi-band composites (airmass, dust, cloud microphysics and severe storm). Imagery from the Himawari-8 and -9 missions will not be available through direct broadcast as with the current MTSAT missions, but will be distributed over the Internet.

NOAA is the main provider agency for the JPSS series that hosts the MODIS and AVHRR replacement, VIIRS. Metop A/B/C (AVHRR) data are provided by EUMETSAT. The generous provisions of the WMO framework, through which Australian users can access the data free of charge (generally via BoM), cover both of these relationships. Likewise, the continuity of data from the Japanese geostationary weather satellite series is assumed to be guaranteed through WMO frameworks, with JMA being the key agency.

Low Resolution Optical Data Gap Risk Assessment: MODIS

Sensor Status

MODIS (MOderate Resolution Imaging Spectroradiometer) sensors are carried by the NASA Terra and Aqua satellites. Terra (launched in 1999) and Aqua (launched in 2002) are both operating well past their design life and are showing signs of senescence.

National Significance

MODIS is the single most widely used EO data source among the researchers consulted during the *CEODA-R&D* survey, being considered an essential research input to 45% of surveyed projects. Research which depends on this data source includes flood mapping, fire detection and forecasting, land condition and cover monitoring, ocean colour and temperature studies, monitoring of coastal and inland water quality, evapotranspiration modelling, and weather and climate analyses.

It is also currently used by 45% of the operational projects reported in the *CEODA-Ops* Report. Operational usage includes disaster mitigation and management, environmental and agricultural monitoring, oceanography and reef management, glaciology, and carbon accounting. A MODIS data gap would dramatically and rapidly demonstrate Australia's current dependence on this data source.

Alternative Data Sources

The MODIS platforms have enabled most areas of the globe (and all regions of Australia) to be imaged two to four times per day for over a decade. MODIS records 36 spectral bands from blue to TIR with varying resolutions of 250 m, 500 m or 1000 m. An extensive range of MODIS data products has been developed and are routinely available from NASA at no cost. In particular, the global Fire and Thermal Anomalies (MOD14/MYD14) product relies on data from multiple MIR and TIR channels to highlight potential fire hotspots.

Low resolution sensors that might be used in place of MODIS are detailed in Table 5-2.

Table 5-2 Possible Alternative Sensors for MODIS

Current Sensors	Relative EO Data Characteristic						Likely change in analytical accuracy
	Number of Bands	Spectral Range	Pixel Size	Scene Size	Revisit Interval	Access	
VIIRS (NPP/JPSS, USA)	↓	~	↑	↑	↑	Open	↓
AVHRR (NOAA/Metop, USA/ Europe)	↓	~	↑	↑	~	Open	↓
MERIS (Envisat, Europe)	↓	↓	~	↓	↑	Open	↓
Future Missions							
OLCI (Sentinel-3, Europe) 2013+	↓	↓	↑	↓	↑	Open	?
SLSTR (Sentinel-3, Europe) 2013+	↓	~	~	↓	↑	Open	?
SGLI (GCOM-C, Japan) 2014+	↓	~	~	↓	↑	Constrained	?

~ indicates approximate equivalence.

Although the recently launched VIIRS is the official replacement sensor for MODIS, none of the current EO sensors match the spectral range, spatial resolution and revisit interval of MODIS. Only one VIIRS instrument is likely to be operational in the next five years, and it will have fewer and different spectral bands, lower spatial resolution and less frequent coverage than MODIS. The AVHRR sensor series has faithfully provided low resolution global imagery for decades and will continue to be used for oceanographic work, but offers lower resolution than MODIS for many land applications. MERIS data is principally used for coastal and ocean applications but lacks TIR bands for land and sea surface temperature mapping applications.

The planned Sentinel-3 sensor, OLCI, will not provide TIR data, and so will not be directly useful for applications requiring surface temperature mapping; however, the SLSTR sensor (which builds on AATSR heritage) will. A further possible replacement for the MODIS sensor, SGLI, is not due for launch until 2014.

Impact of Potential Data Gap for Australia

Many key EO-based land monitoring activities in Australia have grown from easy access to the frequent, high quality imagery provided by MODIS. While many of these activities will be transferable to other EO data sources, including the partial follow-on VIIRS, the process of source shifting will inevitably be experimental and costly. It is also likely to result in significant disruption to the many existing MODIS-dependent national archives and derived-product users that expect continuous access to standardised derived products (such as Leaf Area Index or aerosol products). If a MODIS data gap occurs before the future replacement options become available, or if production of key geophysical level 3-4 products is not continuring in a similar manner for the replacement data sources, the use of the currently available substitute data sources is likely to permanently undermine the continuity and reliability of these records, thus affecting the budgets of key national monitoring programs which rely on these data.

While not designed as an ocean colour instrument, MODIS has been widely used for ocean colour applications. The VIIRS instrument was expected to replace MODIS in this capacity but according to the National Research Council (2011), "*Many, if not most, users did not believe VIIRS could sustain the SeaWiFS/MODIS-Aqua time-series for quantitative observations*". Similarly, VIIRS is not expected to perform as well for flooding mapping or fire detection.

One of the most critical Australian applications that currently relies on MODIS imagery is bushfire detection and monitoring. The Sentinel Hotspots (operated by GA) and FireWatch (operated by Landgate) systems provide timely information about fire locations to emergency service managers across Australia, and have particular value for less-populated regions. The working performance of VIIRS in fire detection remains to be evaluated and the revisit frequency would be considerably less than for the two MODIS sensors, given that only one VIIRS will be in orbit for the next five years. Alternative sensors, such as AVHRR, may be used to locate fire hotspots, but their spectral bands do not match the precision and reliability currently afforded by MODIS data. Should a MODIS data gap eventuate before suitable replacement sensors are routinely acquiring comparable data, current users of these systems will have to lower their expectations and interpret results more judiciously.

5.2.2 Medium Resolution Optical (10–80m)

This data type is essential to more than 40% of the R&D activity surveyed, making this the second most essential data to Australian researchers behind Low Resolution Optical data (primarily MODIS, VIIRS and AVHRR).

Of these, the instruments on the **Landsat** series dominate (particularly TM and ETM+), being essential to all 23 surveyed projects using this data type. Landsat-5 is well past its design life, having been launched in 1984, and is currently suspended after a significant technical failure. Landsat-7 was launched in 1999, with a 5-year design life. As a result of the launch failure of Landsat-6 and the failure of the Scan Line Corrector (SLC) in the Landsat-7 ETM+ instrument in 2003, however, approximately one quarter of the data in a Landsat-7 scene is missing. Landsat-7 continues to acquire data in this mode, and data products are available with the missing data optionally composited or filled in using other data from Landsat-7 or other satellites; however, this satisfies only a few applications (such as the Department of Climate Change and Energy efficiency's annual forest-cover change mapping program for the National Carbon Accounting System).

As is the case for Low Resolution Optical instruments, only the largest of the space agencies are typically capable of providing the kind of long-life and high-capacity system, with high data quality, that Australian researchers require in support of their continued data requirements for the Medium Resolution Optical data. This data type requires sustained coverage and consistency in spectral, geometric, and calibration quality, given the large areas being covered.

There is a short-term continuity risk for this data type as a result of the delay in launching the Landsat Data Continuity Mission (LDCM/Landsat-8; launch currently scheduled for early 2013) and the Sentinel-2 series (scheduled for launch from 2013). The recent failure (and possible termination) of Landsat-5 makes this the most serious data continuity risk imminently facing many Australian researchers, and would have serious consequences, given that Australia has invested heavily in the use of Landsat both operationally and for several R&D programs of national significance.

In the short term, there are no ideal candidates to replace Landsat data, and none that are free of charge. While SPOT (Spot Image), Resourcesat-2 (ISRO), RapidEye (Canada/Germany) and the DMC constellation data are available, all come at a significant cost to an R&D community which generally has low budgets for data procurement. In addition, these data sources do not always match the technical characteristics of the Landsat data, particularly in the radiometric signal-to-noise, geometric accuracy, as well as key visible, NIR and SWIR bands, which several Australian researchers have indicated are particularly important their specific projects.

The medium term (from 2013), however, looks more promising, with planned availability of new generation systems from USGS and ESA (**see** Table 5-3).

Data policy is not seen as a major risk for this data type, given the position being taken by both ESA and USGS.

Both Sentinel-2 and LDCM are expected to operate on centralised, Internet-based data systems. The continuity of the world-wide network of Landsat ground stations is uncertain as of 2011 (although Australia is understood to be one of the favoured partners for a continued ground station partnership). This may have implications for supply channels to Australian researchers, although most already use an ftp/Internet channel.

USGS is the operational provider of the Landsat series data and maintains the free on-line archive. As such, USGS can be expected to remain the most important partner for Australian researchers using this data type, in particular those who wish to use the full 30+ year time-series.

Table 5-3 Data Continuity Options: Medium Resolution Optical

Current Sensor	Expected End of Life	Possible Substitute	Expected Availability	Comments
MSS, TM, ETM+ (Landsat-5 & -7)	Imminent (Landsat-5 data acquisition was suspended on 18 November 2011 for a period of 3 months)	OLI, TIRS (LDCM)	Early 2013 launch	Simulation data for VIS, SWIR and TIR bands is needed for further evaluation.
		MSI (Sentinel-2)	Sep 2013 (May 2013 launch)	Simulation data for VIS-SWIR bands is needed for further evaluation. No TIR bands. Operational continuity for 20 years.
		SPOT-4 & -5	Current	No TIR bands. Commercial data policy
		AWiFS & LISS-III (Resourcesat-2)	Current	No TIR bands. Data policy predominantly commercial
		IRS, MUX, WFI-2 (CBERS-3)	Oct 2012 (Jun 2012 launch)	Data capacity and architecture to be determined
		UK DMC constellation; (Deimos, UK-2, NigeriaSat-2)	Current	Simulation data for VIS-SWIR bands is needed for further evaluation. No TIR bands. Commercial data policy.
HRVIR, HRG (SPOT-4 & -5 series)	Operations expected through to 2013 and 2014 respectively	SPOT-6, -7	2012 launch	Spatial resolution is higher (8m) but temporal and spatial coverage reduced. Simulation data for VIS-NIR bands is needed for further evaluation. Commercial data policy remains.
		MSI (Sentinel-2)	Sep 2013 (May 2013 launch)	Simulation data for VIS-SWIR bands is needed for further evaluation. Operational continuity for 20 years.
ASTER (Terra)	Sep 2013	No obvious replacement. ASTER optimised for geological applications with 11 SWIR/TIR bands		Combined Multispectral and Hyperspectral missions (e.g. ALOS-3 or HyspIRI) would satisfy spectral requirements.

Medium Resolution Optical Data Gap Risk Assessment: Landsat-5 TM

Sensor Status

The Landsat-5 satellite has been operating for over 27 years. On 18 November 2011, USGS reported major hardware problems with the Landsat-5 TM sensor which have necessitated suspension of its imaging activities for at least 90 days. These problems have substantially increased the likelihood of mission termination.

National Significance

The Landsat-5 TM sensor has supplied the vast majority of Medium Resolution Optical data used by the Australian EO community, both for R&D and operational usage, since 1984. This imagery has been prized for its high quality, low cost, routine acquisition and outstanding reliability. It is considered an essential input to over 40% of R&D projects in this survey, and is being used by over three-quarters of the operational programs detailed in the *CEODA-Ops* Report. The EO dependencies within these operational programs have been valued at more than $949 million (GA, 2010).

Nearly one quarter of the R&D projects in this survey are totally reliant on Landsat-5 TM, with many more using this data type in combination with other EO data sources. Research areas covered by these projects include flood mapping, land use planning, ground cover mapping, forest carbon mapping, bushfire emission estimates, water usage and quality monitoring, forest monitoring, and evapotranspiration studies. Over a quarter of the operational projects cited in Geoscience Australia (2011), including the National Carbon Accounting System (NCAS), the International Forest Carbon Initiative (IFCI) and the National Forest Inventory, also rely heavily on this data source. These projects and programs (and others that have not been included in these surveys) will be directly affected by the recent Landsat-5 TM failure and resulting data gap.

Alternative Data Sources

Landsat-5 TM imaged all areas in Australia in 185 km strips every 16 days. This sensor recorded six spectral bands from blue to SWIR as 30 m pixels and one TIR band with 120 m pixels. Imagery was continuously acquired on a routine schedule and is now made available via the USGS Data Server without licensing restrictions.

In Table 5-4, current and proposed sensors that could provide substitute datasets for Landsat-5 TM data are summarised in terms of their relative EO data characteristics. This list includes six currently available, medium resolution optical sensors, none of which offer routine acquisition or open access (that is, images are only acquired on demand and are generally supplied with restricted licensing). Each of these sensors has data characteristics that could provide comparable (or better) analytical accuracy to Landsat-5 TM for some applications, but all would incur substantial data acquisition costs, as well as possible research on adapting current Landsat-specific processing methodologies and algorithms. Three future missions will offer comparable (or higher) resolution data, but these data sources are not expected to be routinely available before 2013.

Data costs in Table 5-4 should be compared with the free availability of Landsat-5 TM imagery offered by the USGS GloVis website, or the standard price for new or archived Landsat-5 TM data from Geoscience Australia (GA) of 0.015 cents/km^2. While it can be assumed that an economy of scale would reduce these costs for bulk ordering of data, the comparable data sources listed in Table 5-4 could cost from 133 to 4000 times more than Landsat-5 TM imagery sourced from GA.

The ASTER sensor is the only alternative to Landsat-5 TM that offers an equivalent spectral range (blue to TIR), but records much smaller areas (60km *cf.* 185km). For large area studies, this would be a significant impediment to operational use.

Usage of all other sensors would involve restrictions for some applications. All of these sensors record green, red and NIR wavelengths (that are relied upon for vegetation monitoring), and none record TIR wavelengths (that are used to study evapotranspiration and detect fires). Some sensors also do not record blue wavelengths (that are important for water quality studies), and/or SWIR (which is increasingly relied upon to differentiate woody land cover components in environmental monitoring applications).

Given these restrictions, the most viable alternatives for Landsat-5 TM would be provided by the SPOT, RapidEye and Disaster Monitoring Constellation (DMC) satellites. While the LISS-III sensor offers inexpensive imagery, past experience with image delivery has been problematic for several researchers surveyed, which suggests that this data source is unlikely to be sufficiently reliable for operational use.

Two SPOT satellites, SPOT-4 and SPOT-5, are operated commercially by Spot Image and imagery is supplied with restricted licensing. These satellites currently only acquire imagery on demand but could be used in tandem to provide continental coverage (though at less frequent intervals than Landsat in northern Australia). While offering higher resolution than Landsat, the RapidEye constellation of 5 spacecraft offers at commercial rates Multispectral imagery at 6.5 m resolution and a revisit of 5.5 days at nadir. In Australia, RapidEye data is marketed by the AAM Group. The DMC comprises multiple satellites constructed by

Surrey Satellite Technology Ltd (SSTL). Each satellite is independently owned and operated by different nations, including the UK (UK-DMC2), Spain (Deimos) and Nigeria (NigeriaSat-2). In Australia, data products from Deimos are marketed by Astrium, and have been used principally for agricultural applications. Imagery from UK-2 and NigeriaSat-2 are available without licensing restrictions via the Optical, Geospatial, Radar and Elevation panel (OGRE).

Several operational programs in Australia that involve vegetation monitoring have already adapted to using SPOT data in place of Landsat-5 TM, but the absence of SWIR and TIR bands limits use of this data source in some application areas. Other data from the RapidEye and DMC constellations, as well as LISS, is not yet widely used, although this may change with the loss of Landsat-5 data. The DEIMOS sensor has been used for agricultural applications in Australia. Like the SPOT sensors, it does not record SWIR or TIR wavelengths, and also does not record blue wavelengths. Of the current sensors listed in Table 5-4, MRI (NigeriaSat-2) would be the most compatible with Landsat-5 TM. This new sensor offers large scenes and records both blue and SWIR wavelengths.

High resolution optical imagery could feasibly be used in place of Landsat-5 TM data. Usage of this data type, however, would involve significant increases in the cost of data acquisition, processing and storage. Data costs for these commercial sources range from \$1.50/km^2 to \$30.00/km^2—a very significant increase on the current GA cost for Landsat-5 TM imagery of 0.015 cents/km^2. Data sharing would also be governed by restrictive licensing conditions. In some situations, low resolution optical data could be substituted for Landsat-5 TM, but this substitution would result in significant reduction in the accuracy of analytical results.

Table 5-4 Possible Alternative Sensors for Landsat-5 TM

Current Sensors	Relative EO Data Characteristic							Likely change in analytical accuracy
	Number of Bands	Spectral Range	Pixel Size	Scene Size	Revisit Interval	Standard Cost (cents/km2)	Availability and Access	
ASTER (Terra, Japan)	↑	~	↓	↓	= (Flexible)	4-16	By request; licensing conditions	↑
HRVIR/HRG (SPOT, France)	↓	↓	↓	↓	↑ (Flexible)	70-106	By request; licensing conditions	Depends on application
LISS-III (Resourcesat-1, India)	↓	↓	↓	↓	↑	2	By request; licensing conditions	Depends on application
MRI (NigeriaSat-2/DMC, Nigeria)	↓	↓	~	↑	↑ (Flexible)	NI	By request; open licence offered via OGRE	Depends on application
RapidEye Imager (RapidEye, Germany)	↓	↓	↓	↓	↑	NI	By request; licensing conditions	Depends on application
SLIM-6 (Deimos/DMC, Spain)	↓	↓	~	↑	↑ (Flexible)	NI	By request; licensing conditions	Depends on application
SLIM-6 (UK-2/DMC, UK)	↓	↓	~	↑	↑ (Flexible)	14-36	By request; open licence offered via OGRE	Depends on application
Future Missions								
CBERS-2 (2012+)	↑	~	↑	↑	↓	NI	Open	↑
LDCM (2013+)	~	~	~	~	~	NI	Open	↑
Sentinel (2013+)	↑	↓	↑	↑	↓	NI	Open	Depends on application

~ indicates approximate equivalence. NI indicates no information.

Impact of Potential Data Gap for Australia

The economic impact to Australia of losing access to Landsat-5 TM data has been assessed as $100 million in the first year of a data gap, with a flow on effect in subsequent years for the duration of that gap (ACIL Tasman, 2010). Even when substitute data sources are suitable and affordable, the process of source shifting will inevitably disrupt many monitoring applications and delay product delivery. If substitute data sources do not exist, or cannot be obtained under existing budgetary provisions, some research and operational activities will not be able to deliver their expected end-products.

The most critical application areas affected by this data gap are land-use change and agriculture mapping, carbon accounting, water resource assessment (including monitoring of water quality, availability and usage) and bushfire warning and emissions abatement systems. These applications require regular, and often high frequency, Medium Resolution Optical data which have measured blue and/or SWIR/TIR wavelengths. Of the possible alternative sensors listed in Table 5-4, these wavelengths are only currently recorded by the ASTER sensor for pre-ordered imagery. It must be stressed that several of these applications areas now involve legislative monitoring (such as NCAS and the recent Carbon Farming Initiative) and further legislation is expected to be forthcoming for water resource monitoring.

While Landsat-7 composite imagery can be used for some, but not all, of these applications, it must also be stressed that this satellite is operating well past its design life.

In addition, several ongoing government monitoring activities have been nurtured by the ready availability of Landsat-5 TM, but may not be equipped with the resources to purchase commercial imagery and/or undertake source shifting. Such activities could include land use planning, compliance monitoring, native vegetation monitoring, and coastal, wetland and water resource management. Interruption to these activities will deprive resource managers from these, now customary, data inputs and will result in irreplaceable gaps in Australia's environmental information records.

5.2.3 High Resolution Optical (<10m)

High Resolution Optical data sources are carried on both satellite and airborne platforms. Current usage (outlined in Section 3.3.3) is dominated by commercial providers (typically US companies).

There are an increasing number of countries with ambitions to compete in this area in future. France, which will launch the Pleiades satellites, providing 70 cm resolution data from 2012, India, Korea, China, Japan (*e.g.* ALOS-3), Spain and Israel all cite advanced planning for the provision of similar data in coming years. There should be ample supply, although most is likely only on commercial terms.

China launched two new high-resolution imaging satellites in late December 2011 and January 2012 (ZY-1-02c and ZY-3, respectively), with stereo capability and spatial resolutions between 2 m and 3.5 m. Data access and policy for Australian users is still to be negotiated; however, if these follow similar free and open data policies as the CBERS series of Earth resource satellites, also co-managed by CRESDA (China) and INPE (Brazil), the data may become widely accessible for Australian R&D users.

5.2.4 Synthetic Aperture Radar

This data type covers the three SAR bands (C-, L-, and X-band) needed by Australian researchers. The major sources of EO data in each of these bands are summarised in Table 5-5.

C-band SAR

A number of agencies have plans for systems that should largely satisfy identified project requirements in the future. The **Sentinel-1 series** (ESA) and the Radarsat-2 constellation aim to provide free and open access to C-band SAR data for all users from mid-2013 (Sentinel-1) and 2015 (Radarsat-2), with operational continuity for two decades. Until a similar level of continuity for L-band SAR data is established, these C-band data sources would likely represent the favoured SAR data of choice for Australian researchers and dominate future usage.

L-band SAR

L-band data is of great value in vegetation and forestry studies, and the termination of ALOS was a significant loss to research in support of programs such as the International Forest Carbon Initiative and other woody vegetation mapping studies. The best prospect for recommencement of the supply of appropriate data is the **SAOCOM 1A** mission being planned by CONAE (Argentina) in 2014. **ALOS-2** PALSAR data will also be available from 2013, but it is anticipated that the data policy may still emphasise commercial distribution.

X-band SAR

The Italian and German PPP X-band systems (**TerraSAR-x/TanDEM-X** and **COSMO-SkyMed**) will continue data provision with follow-on missions planned. Spain will join this group with the launch of the **PAZ** satellite in 2012. It can be assumed, given Spanish Government policy, that PAZ data will be fully commercial.

Table 5-5 Data Continuity Options: SAR

Current Sensor	Expected End of Life	Possible Substitute	Expected Availability	Comments
C-Band ASAR (Envisat) & SAR (Radarsat series)	Envisat – 2013 Radarsat-2 – 2015	Sentinel-1 series RCM series	Sentinel-1: Oct 2013 (May 2013 launch) RCM C-1: Dec 2015 (Aug 2015 launch)	Sentinel-1 data policy expected to be free and open with 20 year continuity. RCM data policy TBD.
L-Band None		SAOCOM 1A ALOS-2	Apr 2015 (Dec 2014 launch) May 2013 (Jan 2013 launch)	SAOCOM data policy TBD. Indications are it may be open for forest carbon use. ALOS-2 data policy currently likely to be commercial but TBD.
X-Band X-band SAR (TerraSAR-X series) & SAR 2000 (COSMO-Skymed series)	TerraSAR-X – 2013 TanDEM-X – 2015 COSMO-SkyMed – 2014 to 2017	KOMPSAT-5 (Korea) TerraSAR-X2 COSMO 2nd Gen PAZ SAR-X (Spain) HY-3 series (China)	Early 2012 (late 2011 launch) 2015 2015 Early 2013 (late 2012 launch) From 2012	European missions are commercially operated. Chinese data availability is unconfirmed.

China's HJ series of satellites will include S-band SAR from 2012. The UK's S-band NovaSAR (SSTL) has been proposed for rapid implementation and has received some seed funding already. ESA's BIOMASS mission (launch date to be determined) will offer P-band SAR.

Open access to the ESA/EC Sentinel series should significantly improve the continuity of C-band SAR data, and may result in increased Australian R&D use of this data type. Relations with CONAE and JAXA will be very important if Australian researchers are to secure access to L-band SAR data. The role of China as an X-, S- and C-band SAR data supplier is yet to be established.

SAR Data Gap Risk Assessment: L-band SAR

National Significance and Sensor Status

L-band SAR, when combined with a systematic global acquisition strategy like the one used by ALOS, is the most information rich space-based SAR data source available to researchers studying vegetation cover change, vegetation classification and routine optical satellite mapping. In the case of forest monitoring, such applications are of vital importance to the viability of one of Australia's main international climate policies and overseas development assistance programs – the use of space data in support of inclusion of forests in a post-Kyoto climate agreement and in future carbon market mechanisms. Such capabilities have been the subject of considerable investment through the International Forest Carbon Initiative (IFCI), the GEO Forest Carbon Tracking (GEO-FCT) activity, and now the Global Forest Observations Initiative (GFOI) – which Australia has been leading. Australia has been promoting the international adoption of its methodologies and systems for the use of satellite data as employed in the National Carbon Accounting System (NCAS), particularly in Indonesia.

The sudden termination of the only spaceborne L-band sensor in April 2011 (PALSAR on the ALOS spacecraft) has left all of these efforts without their most productive data stream. JAXA had already signalled prior to the termination of ALOS that they were revising their national data policy to focus on commercial pricing of the PALSAR data, rather than generous supplies for public good.

Alternative Data Sources

There will be no L-band SAR satellite data sources until early 2013, with the launch of ALOS-2, or late 2014 with the launch of SAOCOM-1A. ALOS-2 is likely to have a commercial data policy.

Impact of Potential Data Gap for Australia

In the absence of L-band SAR, it remains to be determined whether the necessary coverage and information extraction will be possible world-wide using other available SAR data (C-, S- and X-band), and combined with optical data, in order to meet the requirements of the GFOI. The L-Band SAR data would have been especially useful in support of coverage needs of regional neighbours such as Indonesia.

Estimates of alternate data cost are somewhat academic (in the absence of an L-band SAR data source), but the current pricing by the Japanese distributor RESTEC for a 30x70km polarimetric PALSAR archive scene is around AUD $675 – or around $0.3 per km^2 (Japanese EO data has never been priced at full commercial rates). A national scale dataset is not necessary for all applications but to give an indication of commercially equivalent data costs, the annual cost to provide national scale coverage twice a year (as needed in forest carbon reporting applications) of Australian territory (which is 7.7 million km^2) would be approximately $4.6 M. For comparison, X-band SAR data pricing is around $1.6 per km^2 (i.e. more than five times as much, and considerably more expensive for fine resolution data). All of these price estimates assume data from the archive and not by satellite tasking – which can increase the cost by a factor of 10 or more – and do not take into account possible bulk purchase discount arrangements. Licenses for re-use of commercially provided data by multiple users can typically increase the data cost by 2-4 times.

5.2.5 Passive Microwave Radiometry

This data type is essential to seven of the 56 R&D projects covered by this survey. Table 5-6 summarises the key satellite supply sources for Passive Microwave Radiometry.

The most immediate challenge in relation to this data type is finding a replacement for the **AMSR-E** instrument (aboard NASA's Aqua platform), which failed in October 2011 after providing invaluable data for nine years. The data was used in several Australian research applications, most notably in the CAWCR/BoM and WIRADA projects reviewed in the context of the present survey. Fortunately, JAXA plans to launch

AMSR-2 on GCOM-W1 in February 2012. NOAA is supporting efforts by JAXA to have AMSR-2 data distributed via the WMO systems, and this should guarantee access to the data for Australian researchers, on the timescales that they require. The microwave instruments (**MWRI**) aboard the Chinese polar orbiting weather satellite series (**FY-3**, currently operating and with planned replacements) could offer a back-up alternative to the AMSR series in the event of unexpected data gaps, such as might occur in the lead-up to GCOM-W1 data availability.

There is reasonable confidence that the US Department of Defense will assure continuity of the **DMSP** series missions, and of the **SSM/I** and **SSM/IS** instruments that are used by CAWCR/BoM, WIRADA and other researchers. The NASA/JAXA **TRMM** mission is close to completion, with the Global Precipitation Measuring (**GPM**) mission, a multi-national constellation of satellites, set to follow it from mid-2013.

Table 5-6 Data Continuity Options: Passive Microwave Radiometers

Current Sensor	Expected End of Life	Possible Substitute	Expected Availability	Comments
AMSR-E (Aqua)	Unexpectedly terminated Oct 2011	AMSR-2 (GCOM-W1)	Jun 2012 (Feb 2012 launch)	Immediate data gap
		MWRI (FY-3 series)	Current	Access arrangements uncertain. Data capacities uncertain.
SSM/I (DMSP series)	Operational continuity guaranteed by US DoD	SSM/IS	Ongoing	SSM/I instrument will evolve as SSM/IS on future DMSP satellites
TMI (TRMM)	Imminent	GMI (GPM)	Oct 2013 (Jul 2013 launch)	Operational continuity for 20 years
		MADRAS (Megha-Tropiques)	Late 2011 (Oct 2011 launch)	Data access arrangements are TBA
MIRAS (SMOS)	Late 2012	Aquarius (SAC-D)	Current	
		L-band Radiometer/ Radar (SMAP)	Late 2014	
		SAR-L (RISAT-3)	2016	Considered, not confirmed

The **Megha-Tropiques** (CNES/ISRO) satellite, launched on 12 October 2011, carries the **MADRAS** microwave imager, designed primarily for studying precipitation and cloud properties, and may be a source of data for Australian R&D centres with an interest in water cycle issues.

The **SMOS** mission of ESA (launched in 2009) is a new source of data for soil moisture measurements but it ends life in 2012. Soil moisture is a critical parameter for flood forecasting, severe weather prediction, and agricultural and water management activities. The Argentina-USA mission **SAC-D/Aquarius**, launched in June 2011, offers a second source of this new data type for Australian researchers. Still another will be available when NASA launches the **SMAP** (Soil Moisture Active Passive) mission in late 2014.

The USA (DoD/NOAA) and Japan (JAXA) will be the providers of the main data sources from the DMSP and GCOM-W series. Rainfall data from GPM is also a predominantly USA-Japan contribution. China could emerge as a contributor using the FY-3 series, and the recent launch of Megha-Tropiques also brings India and France into this sector. Nonetheless, for the foreseeable future, soil moisture data will depend on ESA, NASA, and perhaps India.

5.2.6 Radar Altimetry

Current Data Sources and Life Expectancy

Radar Altimeters are an essential source of data for eight of the 56 projects included in the present survey. Key application areas for these projects include: global mean sea level climate data records, ocean current applications and geoscience applications. The key supply instruments are summarised in Table 5-7.

Table 5-7 Data Continuity Options: Radar Altimeters

Current Sensor	Expected End of Life	Possible Substitute	Expected Availability	Comments
POSEIDON-2 (Jason-1)	Sept 2013	POSEIDON-3 (Jason-2)	Currently available	POSEIDON-2 well past 3-year design life
POSEIDON-3 (Jason-2)	Dec 2013	POSEIDON-3B (Jason-3)	June 2014 (launch Apr 2014)	POSEIDON-3 past 3-year design life
		ALT (HY-2A)	Currently flying	Data access and data quality uncertain
		AltiKa	June 2012 (launch Apr 2012)	CNES pushing ISRO for an open data policy, but uncertain
		SRAL (Sentinel-3)	Apr 2014 (Launch Nov 2013)	Strong continuity option; free and open data policy expected
RA-2 (Envisat)	Dec 2013	SRAL (Sentinel-3)	Apr 2014 (Launch Nov 2013)	Well past design life; recent orbit change has affected coverage
SIRAL (CryoSat-2)	Dec 2013	SRAL (Sentinel-3)	Apr 2014 (Launch Nov 2013)	Useful for operational continuity

The key current supply instruments are the POSEIDON instruments on the TOPEX/Jason missions. Jason-1 (launched 2001) and Jason-2 (launched 2008) are currently operational beyond their 3-year design life. Both are currently supported for extended operation through to late 2013.

It is generally considered that the availability of a single altimeter instrument is sufficient to ensure continuity of global mean sea level observations, provided that there is six to nine months overlap—depending on the technology involved—between successive missions. However, some researchers have suggested that a minimum of three or four operational altimeters are needed to meet the requirements for R&D in support of operational activities like marine safety and defence operations. In order to meet these latter requirements, surveyed projects are using the two POSEIDON sensors currently flying, and the altimeters on Envisat (RA-2, launched 2002, well into extended operations), and CryoSat-2 (launched 2010, projected operation until end 2013). Ocean current and topography monitoring, and forecasting (*c.f.* BLUELink, BoM), are the more demanding applications, requiring higher observational frequencies and latencies of just hours.

There is some risk to the continuity of global sea level measurements, with a possible gap (or, at least, a possible lack of required cross-calibration overlap) in the Jason series, with Jason-2 ending in December 2013 and Jason-3 scheduled for launch in April 2014. In practice, it is very possible that Jason-2 operations can be extended (Jason-1 has been flying for ten years) to close this gap. Furthermore, Sentinel-3A is scheduled to launch in December 2013 and could mitigate a possible gap (although not in the same class as the Jason series, it does share some common heritage). Conversely, Jason-3 funding shortfalls continue in the provider agencies and there remains a risk of launch delay.

There is also a very real risk that the minimum number of three to four operational altimeters required for near real-time monitoring and forecasting applications may not be sustained. Operational continuity is a major topic of discussion in this user community, particularly in support of applications including defence, weather and marine safety.

The **POSEIDON** series of instruments is the class-defining standard for Radar Altimeters. Continuity in this series, including the necessary temporal overlap in coverage, is an ongoing planning issue. Although tentative funding arrangements for the **Jason-3** mission were confirmed in early 2011, the potential for funding shortfalls remains a reality and a launch delay is a genuine risk. Of the future non-Jason altimeter missions, **SRAL**, on the **Sentinel-3 mission**, appears to be the best continuity option. The Sentinel-3 series is initially funded for at least two missions, Sentinel-3A (November 2013–2021) and Sentinel-3B (December 2014–2022), with the expectation of continuity for decades to come.

The **CryoSat-2** mission was successfully launched in April 2010, following the failed launch of CryoSat in 2005. As data from the SIRAL altimeter becomes available, developers of operational applications are beginning to make use of it. CryoSat-2 is a nominal 3-year mission, scheduled to end in December 2013, but likely to operate for longer. The Chinese **HY-2A** mission was launched in August 2011, and carries the ALT altimeter. While the Chinese have indicated that they will make data from this instrument available, it has not yet started to flow. The launch of **AltiKa** (SARAL) is planned for April 2012. It appears that AltiKa will be a high quality instrument. The data access policy, however, has not been finalised, with ISRO resisting the CNES preference for open access.

Europe (particularly France) has been the world leader in this data type for two decades, and has engaged in effective partnership with the USA to ensure Jason series continuity. The expected addition of SRAL on Sentinel-3 underscores the importance of European relationships in ensuring continuity of data access. The relationship with NOAA, on access to Jason data with low latency, also remains very important in this area. China and India may emerge as being important as alternative providers.

5.2.7 Hyperspectral Imagery

Current Data Sources and Life Expectancy

Hyperspectral imagery (also called "imaging spectroscopy") is considered by many of the surveyed groups as major step-change in optical remote sensing, as it is expected to offer an unprecedented operational capacity to better distinguish ("fingerprint") different terrestrial, atmospheric, man-made and aquatic chemicals and materials, as well as to provide physics-based quantitative measurement of their concentrations. There has long been interest and expertise in Hyperspectral imagery within the Australian science community, notably, following the announcement of the ARIES-1 mission in 1996. The benefits of this data type in resource exploration and agricultural applications are well known. As such, Australia, perhaps more than any other country, is positioned to derive significant benefit from an accessible, high quality Hyperspectral satellite data source. Australia's R&D community has benefitted greatly from access to one of the best airborne Hyperspectral imaging systems designed, built and operated in Australia (HyMap), as well as numerous other airborne Hyperspectral data providers operating overseas-built instruments. CSIRO scientists also have ongoing collaboration locally with DSTO and several mining companies, and internationally with Japan and Germany, and are members of the international science team for NASA's planned HyspIRI mission.

Hyperspectral imagery is deemed essential to ten of the 56 R&D projects covered by the present survey. The majority of these utilise commissioned aerial survey data from both Australian and overseas companies or agencies, while some also make use of experimental satellite data from the **Hyperion** (NASA) and **CHRIS** (Compact High Resolution Imaging Spectrometer, ESA) spaceborne sensors, to develop novel applications. The Hyperion sensor (Hyperspectral, with hundreds of individual spectral bands) and CHRIS sensor (Multispectral, up to 63 spectral bands) are still in operation and providing research data despite being well past their design life. Hyperion has been authorised for operations by NASA through to September 2013. The International Space Station also hosts a Hyperspectral payload for Ocean Colour studies (HICO), and this has been in operation since 2009.

There are a number of countries competing to provide the first new civilian Hyperspectral missions, with Hyperion (onboard EO-1) and CHRIS (onboard Proba) having been considered experimental, and without the signal-to-noise ratio, spectral or operational characteristics that are optimal for many applications. These new systems include: Italy, with **PRISMA** (likely to have a commercial focus); Germany, with **EnMAP**, a research mission possibly with some commercial interest; and Japan, with **HISUI** (formerly Hyper-X) onboard **ALOS-3** but with an unknown data access policy. The Italian PRISMA mission is scheduled to launch first (in 2014, see Table 5-8), followed by the launch of EnMAP (DLR) in 2015, which will provide a source of 30m resolution high-quality Hyperspectral imagery. ALOS-3 plans are uncertain and the project is yet to receive funding from either METI or JAXA, although a provisional date of 2014 is set for its launch.

HyspIRI (NASA) is the most ambitious of these missions, with an anticipated 19-day repeat cycle at 50 m resolution over all terrestrial and coastal areas, and 1000m resolution over all oceans, producing an anticipated 5 TB of raw, uncompressed data per day. The mission is presently under consideration for US funding, and not planned for launch before 2018-2020.

Table 5-8 Data Continuity Options: Hyperspectral Imagers

Current Sensor	Expected End of Life	Possible Substitute	Expected Availability	Comments
Hyperion (EO-1)	Well past design life – operations authorised until Sep 2013	HSI (EnMAP)	2015	Late 2013 or early 2014 launch
		HYC (PRISMA)	2014	Launch June 2014
		HISUI (ALOS-3)	2014	No firm launch date

Unless more comprehensive coordination initiatives are developed around Hyperspectral data exploitation, the risk remains that all Hyperspectral imagery available in the next decade will only be available through limited research agreements or commercial arrangements. This has significantly limited the uptake of other EO data types, such as X-band SAR data, in Australia (and elsewhere) in the past, and may have the same impact on the usage of Hyperspectral imagery. Furthermore, some of the larger research programs aiming to exploit these data may not be ready to receive, archive or process the massive amounts of data which these systems will produce once operational.

Australia's science heritage with Hyperspectral data, availability of high-quality airborne data, and our resource-oriented economy potentially position us to make the most of the opportunity provided by these multiple new planned data sources. Australian investment and/or participation (for example, through science team membership) in these missions would contribute to reducing the risk associated with ensuring Australian access to this data.

5.2.8 Lidar

Satellite Lidar was identified as essential by five of the 56 projects surveyed, and airborne Lidar by six projects, with one of these projects using both sources. There are two main applications for Lidar—atmospheric measurements for the study of aerosols, winds and clouds, and land measurements for topographic studies or vegetation and biomass estimation, such as canopy profiling in forestry. Amongst the projects surveyed for this study, most of the applications of Lidar were focused on land measurements, with the notable exception of CAWCR, which is involved in climate and weather modelling. Full-waveform Lidar is considered to be the most advanced and rich source of Lidar data in the forestry, cropping and biomass assessment and R&D sectors, as it provides unprecedented levels of detail in terms of the 3-dimensional structure of the aboveground vegetation.

At present there is only one Lidar satellite, NASA's **CALIPSO**, which is focused on atmospheric studies, and is funded to continue until September 2013 (although now beyond mission design life). NASA's ICESat mission did carry the GLAS Lidar instrument, which was only marginally suitable for land measurements due to its low spatial resolution. That mission, however, ended in August 2010. **ICESat-II** is being planned, and will carry a similar instrument, although it is not being considered for launch until 2016, and is still subject to programmatic approval.

With reference to Table 5-9, space-borne Lidar data will continue to be available only on an experimental or 'one-off' mission basis, rather than in any sustained fashion. The NASA ICESat and ICESat-II missions serve to illustrate the existing situation. Whereas the first ICESat mission carried an infrared laser, the ICESat-II mission will change technology and use a green laser. This will potentially require significant adjustment by researchers using the existing data stream, to re-tune and re-calibrate activities to make best use of the new data stream.

Table 5-9 Data Continuity Options: Lidar

Current Sensor	Expected End of Life	Possible Substitute	Expected Availability	Comments
CALIOP (CALIPSO)	Sept 2013	ALADIN (ADM-Aeolus)	Nov 2013	Should provide a good continuity option for CAWCR
		ATLID (EarthCARE)	Oct 2013	Significant schedule risk
		CO2 Lidar (ASCENDS)	2020+	Mission still under review, not yet approved
		HSRL (ACE)	2020+	Mission still under review, not yet approved
		HDWL (3D Winds)	2030+	Mission still under review, not yet approved
ICESat	Ended Aug 2010	ICEBridge	Currently available	NASA airborne campaign focused on providing continuity for polar ice study users
		ICESat-II	2016	Mission still under review, not yet approved
		Laser altimeter (LIST)	2030+	Mission still under review, not yet approved

NASA does have a number of mission concepts under review—ASCENDS, ACE, 3D WINDS—directed toward the study of atmospheric winds, aerosols, CO_2, *etc.*, but these are scheduled for launch beyond 2020, at the earliest.

The ESA **ATLID** sensor, planned for launch on the ESA-JAXA **EarthCARE** mission in October 2013, may provide a continuity option for the aerosol studies currently undertaken by CALIPSO.

An apparent one-off mission, the **ALADIN** instrument is approved to be flown on **ADM-Aeolus** (ESA) in November 2013. The mission will provide wind profile measurements for global 3D wind field products used in the study of atmospheric dynamics, including global transport of energy, water, aerosols, and chemicals.

ICESat, **ICEBridge**, and **ICESat-II**—ICESat is the most recent operational, satellite-based Lidar suited for land measurements. The mission, however, ended in August 2010. NASA has implemented an airborne program called ICEBridge, which is designed to continue critical ice sheet measurements in the period between active satellite missions. The ICESat-II mission is considered, but not yet approved.

5.2.9 Ocean Colour

Ocean Colour instruments were identified as essential to six of the 56 projects surveyed. While included earlier in this report in their more generic category of Low Resolution Optical sensors, several researchers noted that MODIS (Aqua and Terra) and MERIS (Envisat) have sufficient spectral information for use in Ocean Colour applications. Ocean Colour information is also available from the OCM instrument on the ISRO OCEANSAT-2 mission.

The most widely used current Ocean Colour instruments, MODIS and MERIS, are well beyond their design life times, but are expected to be continued in operation in the short-term, in order to provide cross-calibration opportunities for VIIRS and Sentinel-3 (see Table 5-9).

MODIS heritage will be continued with the launch of **VIIRS** (see Section 5.2.1). There is concern amongst some of the surveyed users that VIIRS, which was launched on NPP in October 2011, may not fully satisfy the needs of the Ocean Colour community, although its increased spatial resolution of 750 m is welcomed. Continuity is expected, however, assuming no delays to JPSS-1.

The **Sentinel-3A** mission is approved for launch in November 2013, with continuity assured by Sentinel-3B (2014) and beyond, although funding issues for the operation of the Sentinel missions is yet to be resolved. This makes the **OLCI** instrument a likely continuity option for MERIS. Prospects are good for a free and open data access policy by ESA/EC for this data type.

OCM was launched on **OCEANSAT-2** in 2009, and is expected to last until late 2014. Researchers contributing to the present survey indicated that while OCM was fundamentally a quality instrument, there were currently significant issues with calibration and validation of the data. Korea's **GOCI** is currently operational, and producing good data but is focused on the Korean peninsula and does not currently cover Australia. The **GCOM-C1** JAXA mission has been approved for launch in February 2014, with two follow-on missions planned—GCOM-C2 in 2018, and GCOM-C3 in 2022. This makes the **SGLI** instrument a strong continuity option. JAXA has a heritage in Ocean Colour instrumentation with OCTS and GLI.

NOAA will be the USA's long term provider of VIIRS data that will provide continuity in the SeaWiFS-MODIS data streams (although with a more limited spectral band set than MODIS). ESA and JAXA will be the providers of the two long-term and high-quality sources of Ocean Colour data, Sentinel-3 and GCOM-C respectively. ISRO continues to operate the OCEANSAT series and this has potential as a sustained data source, assuming data quality issues can be addressed.

Table 5-10 Data Continuity Options: Ocean Colour

Current Sensor	Expected End of Life	Possible Substitute	Expected Availability	Comments
MODIS (Aqua & Terra)	Sept 2013	VIIRS (NPP & JPSS)	Early 2012 (Oct 2011 launch with follow-ons planned in 2017 and 2023)	Some concern that the instrument does not have the technical capabilities to meet ocean colour community needs
		SGLI (GCOM-C)	Feb 2014	Follows on from ADEOS-II GLI
MERIS (Envisat)	Dec 2013	OLCI (Sentinel-3)	Early 2014 (Nov 2013 launch)	Strong continuity and open data policy
OCM (OCEANSAT-2)	Current	OCM (Oceansat-3 & -3a)	2014	Continuity of this dataset is planned. Data access uncertain.

5.3 Summary

The continuity risk to the main EO satellite data supply sources utilised by researchers responding to this survey is summarised in Table 5-11 for each of the nine Priority Data Types. The table also briefly indicates the current and future key providers of each data type, based on known programs and plans. The predominant latency requirement for each data type based on survey results is also indicated.

Table 5-11 Priority Data Types: Satellite 5-Year Supply Continuity Risk and Key Providers

Priority EO Data Type	5-year continuity risk	Current key providers (and missions)	Future key providers (and missions)	Predominant Latency Requirement
Optical – Low Resolution	Low	NASA (MODIS) NOAA/EUMETSAT (AVHRR) JMA (MTSAT series)	ESA/EC (Sentinel-3 series) NOAA (NPP/JPSS series) JAXA (GCOM-C series) JMA (MTSAT series)	Hours/Weeks
Optical – Medium Resolution	High	USGS (Landsat-5/-7)	USGS (LDCM) ESA/EC (Sentinel-2 series)	Days/Weeks
Optical – High Resolution	Low	USA commercial providers (Worldview, GeoEye) Airborne operators	USA & European commercial providers (Worldview, GeoEye, Pleiades) Airborne operators	Days/Weeks
SAR – C-band	Low	ESA (Envisat) CSA (Radarsat)	ESA/EC (Sentinel-1 series) CSA (Radarsat & RCM)	Weeks
SAR – L-band	No current supply	-	CONAE-ASI (SAOCOM-1A) JAXA (ALOS-2)	Weeks
SAR – X-band	Low	ASI (COSMO-SkyMed) DLR (TerraSAR-X)	ASI (COSMO-SkyMed series) DLR (TerraSAR-X series)	Weeks
Passive Microwave Radiometry	Medium	NASA (Aqua – just concluded) NOAA/DoD (DMSP series) JAXA/NASA (TRMM) ESA (SMOS)	JAXA/NASA (GCOM-W series) NASA (GPM, Aquarius, SMAP) NOAA/DoD (DMSP series) ESA (SMOS) ISRO (Megha-Tropiques, RISAT-3)	Hours
Radar Altimetry	Medium	EUMETSAT-NOAA (Jason series) ESA (Envisat)	EUMETSAT-NOAA (Jason series) ESA/EC (Sentinel-3 series)	Hours
Hyperspectral Imagery	High	NASA (EO-1)	DLR (EnMAP) ASI (PRISMA) METI/JAXA (ALOS-3)	Weeks
Lidar	High	NASA (CALIPSO)	ESA/JAXA (EarthCARE)	Weeks
Ocean Colour	Low	ESA (MERIS) NASA (MODIS) ISRO (OCEANSAT)	ESA/EC (Sentinel-3 series) JAXA (GCOM-C series) ISRO (OCEANSAT) NOAA (NPP/JPSS series)	Hours

The following summary conclusions are noted from Table 5.11 and the underlying information in this section:

1. Traditionally, Australia has a high dependence on US satellite data. Most of the anticipated gaps in the Priority Data Types identified will result from the retirement of ageing US satellites.
2. USGS, although mentioned only in the context of the Landsat series and management of several civilian US EO data archives, will continue to be regarded as a key provider, given the importance of that data in Australian R&D (although other Medium Resolution Optical data sources are likely to exist in future). Landsat-5 data acquisitions have been suspended as of November 2011 as USGS attempts to address a significant technical problem, increasing the likelihood of an imminent data gap for Medium Resolution Optical data.

3. NASA has long been the most important supplier of EO satellite data in support of the Australian R&D needs surveyed (largely thanks to its free and open data policy, and direct broadcast of data into Australian satellite stations). NASA is cited as a key current supplier six times in Table 5-11, across five different data types. In the list of key future data providers, NASA is only cited in a single category (Passive Microwave Radiometry data type) with GCOM-W (a JAXA mission) and GPM (a NASA-led international mission).
4. Provided that data access terms are favourable and the current GMES funding issues are resolved, Australia's relationship with ESA could potentially become very important for provision of EO satellite data for R&D needs in Australia in the next five years. ESA is identified as being a key current supplier for four data types. It is a key future supplier for seven data types (often in partnership with the EC), largely due to the GMES program and the five series of Sentinel satellite missions.
5. JAXA is expected to be an important partner in the future supply of EO data to Australia. JAXA is cited as a potential future supplier for six of the Priority Data Types. The data policy uncertainties in Japan for large volumes of data from land-imaging satellites such as the ALOS series will therefore continue to be a risk to the Australian terrestrial research community of practice. It is assumed that all but High Resolution Optical images of land surfaces will continue to be freely available, and that some free access to High and Medium Resolution Optical data would be still available under collaborative R&D arrangements (*e.g.* via JAXA's Kyoto Carbon Initiative).
6. ASI is cited as a potential future provider in three different data types (X-band SAR, Hyperspectral imagery, and L-band SAR as a CONAE partner), although these are mainly commercial.
7. DLR is a potential future provider for X-band SAR and Hyperspectral imagery data types.
8. ISRO missions may become more accessible and usable by Australian researchers in the future. It is cited as a possible supplier for Ocean Colour data (OCEANSAT series) and for Microwave data from Megha-Tropiques (launched October 2011).
9. China does not feature significantly in the future supplier table, simply due to a lack of information and heritage among Australian researchers utilising data from Chinese satellites. While there is uncertainty as to data policy and data access systems, Chinese agencies are planning to launch dozens of missions in coming years, some of these jointly with Brazil, spanning all or most of the Priority Data Types required for Australian research. The possibility of access to the data streams from these missions should not be overlooked.

6 PRIORITIES FOR ACTION

6.1 Major Data Continuity Risks

As discussed in previous sections, the risk of EO data gaps are high for several Priority Data Types, namely Medium Resolution Optical, L-band SAR, Hyperspectral and Lidar. From this group, the recent malfunction of Landsat-5 and the current gap in L-band SAR data both warrant close attention. In addition, the widespread reliance on the ageing MODIS sensor, and little preparatory work amongst R&D teams on alternatives such as VIIRS and Sentinel-1, merits further consideration. The implications of these potential data continuity risks on current EO-related R&D in Australia were discussed in Section 5.2.

When addressing alternatives to avoid future data gaps, a combination of favourable technical characteristics, coverage, distribution systems and data access policies are all needed to satisfy the needs of the Australian EO R&D community. Additionally, it must be stressed that the migration of research or operational procedures from one EO data source to another, or source shifting, is both expensive and time-consuming; the overheads involved in understanding, calibrating and validating, and adapting processing and analysis systems for each new data source make researchers unlikely to change data sources readily or frequently, and this must be recognised as a major influence on usage patterns.

The overall cost of a critical EO data gap to the Australian economy, including any consequent source shifting, has been estimated at more than $100 million with increasing costs for longer data gaps (ACIL Tasman, 2010). This estimate encompasses:

- Costs associated with source shifting—should alternative datasets be available;
- Selective use of commercial data in place of open access data;
- Potential under-utilisation of government resources if alternative data is not available.

Should no alternative data sources be available or affordable, EO data gaps could disrupt several critical operational programs, including legislative monitoring and emergency management, and delay the development and implementation of multiple research outcomes.

6.2 Priorities for Action

The *CEODA-Ops* Report discussed five investment areas (or 'Priorities for Action') that support the EOS data supply chain in Australia. These areas were determined as the collective opinion of GA, CSIRO, BoM and DIGO (Australian Government, 2011):

- Coordination and Cooperation—governance structures to encourage collaboration, and coordinate EO data access;
- Securing Future Earth Observations—ensuring access to international public good EO sources and efficient use of commercial capabilities, through co-investment where necessary;
- Investment in Ground Infrastructure and Communications—strategic planning for EO data reception and distribution, with minimum latency;
- Extracting Value—systems for data processing, scientific analysis and information delivery, including Cal/Val activities; and
- Sustained Capability to Deliver—investment in Australian EOS skills to ensure ongoing capability to process, calibrate, interpret and apply EOS data streams.

The findings of the *CEODA-R&D* survey will be discussed in terms of these five investment areas.

6.2.1 Coordination and Cooperation

The Australian EO sector has largely developed as a synergistic community, with 95% of researchers surveyed through the CEODA-R&D study being actively involved in collaboration with domestic and/or international organisations. The current extent of domestic interaction (see Section 2.3.5) not only ensures efficient use of local resources and maximum benefit from available expertise, but also underpins Australia's strength in the international EO scene. Collaborative facilities such as IMOS and TERN have further streamlined the acquisition, standardisation and dissemination of EO-related data and skills, and this trend should be supported and extended to other EO applications areas.

As the EO data type most used by Australian researchers, Low Resolution Optical data are being acquired concurrently by several R&D centres, predominantly from the on-line MODIS and AVHRRR archives, and via the Australian national facilities for direct broadcast reception and redistribution. The opportunity exists to rationalise these replicated access efforts with a more efficient infrastructure for the reception, processing and distribution of commonly used datasets like the MODIS 16-day composites. The national processing facility for MODIS/AVHRR/VIIRS data is a significant step in this direction. Given that Australia does not contribute to the funding of any of these satellite systems even though it is amongst the world's heaviest users, a more coordinated approach to data acquisition would also minimise Australia's impact on the provider agency systems.

While the Australian EO R&D community is technically very strong, it requires more serious institutional support to help maintain international linkages to collaborators, and have more active participation in international initiatives such as those of the Committee on Earth Observation Satellites (CEOS) and the Group on Earth Observations (GEO), and involvement at the science team level in the development of new satellite technology in order to tailor systems/products to suit Australian requirements. Such support would permit continued development of innovative applications for EO data, and also maintain access to key EO datasets, which is not always provided through operational government programs.

6.2.2 Securing Future Earth Observations

Australia has no EO satellite capability of its own. It has contributed sub-systems to important payloads, notably the AATSR instrument of Envisat, in the past, and is currently contributing hardware to NASA's GRACE Follow-on mission. EO data usage in Australia is characterised by a preference for sources that are freely available from foreign providers.

The Australian EO R&D sector has discovered efficient ways to access key EO datasets, often via strategic relationships established by individuals with overseas science collaborators or space agencies. More than 40 different satellites are identified as necessary for data supply continuity across the nine Priority Data Types for Australian researchers. ESA and JAXA are important potential future EOS data suppliers across a large number of the Priority Data Types. The current data supply continuity outlook for many EOS missions is dependent on *ad hoc* relationships between different individual Australian researchers and/or agencies. To increase access and adoption of more advanced next generation EO data streams, it would be advisable that stronger inter-institutional data agreements with key data providers be established at the Federal government level, as well as guaranteed access to bandwidth, and time allocation for use of current satellite downlink infrastructure for these science missions. The need for a national negotiating position may be exacerbated in future if the main EO data supply agencies continue their trend towards centralised Internet-based data distribution systems that may not meet Australian latency requirements. Local support for Australian membership of international EO mission science teams, which is often locally unfunded, would be a basis for a clearer Australian contribution to international efforts.

A number of CEODA-R&D survey respondents commented that the expectation of continued goodwill through (typically) free supply of data from 59 different satellite instruments provided by other countries is a high risk strategy, particularly considering the current economic positions of some of these countries relative to Australia.

Some survey respondents advocated that Australia should make an increased and visible contribution to the space segments of the EO capabilities on which we depend as a nation. This could take the form of an instrument contribution to the increasing number of virtual constellations (coordinated but separate observing missions of several countries), or co-investment in a collaborative international mission. Furthermore, high altitude unmanned aerial platforms may also be considered as an alternative option for acquiring critical EO data.

The trend towards international virtual constellations of spacecraft towards a particular measurement objective represents a cost-effective opportunity for Australian participation in a way that could secure continued goodwill and data access by the multitude of contributing partners. Many of these constellations have been emerging through the CEOS framework (*e.g.* Ocean Colour, Ocean Surface Topography, Precipitation) and others (such as the COSMIC GPS Radio Occultation system) are based on inter-governmental agreements between a number of countries (principally Taiwan and USA in the case of COSMIC).

Three EO data types have particular importance to Australian researchers, and warrant special consideration for potential investment:

SAR

The 2009 Defence White Paper (Department of Defence, 2009a) states that the Department of Defence intends to acquire a Synthetic Aperture Radar satellite. SAR data are a high priority for the Australian research community surveyed, and there are few prospects for open access to L-band and X-band systems for the foreseeable future, with both anticipated to be commercially controlled in most (or all) cases. L-band SAR data is the most productive in support of vegetation studies, like forest and biomass mapping for policy initiatives such as REDD+ or IFCI, disaster monitoring and operational programs such as the National Carbon Accounting System (NCAS). But X-band SAR data also have a role here, and the inclusion of suitable wide area imaging and polarisation modes may permit, for example, wall-to-wall forest mapping as needed for national reporting activities, or mapping of damage to infrastructure or crops after severe storms or cyclones. If the proposed Defence SAR capability could include both Defence and civil applications, this would have significant benefits for the Australian research community.

C-band data may see increased future use with Sentinel-1 data (ESA/EC) and possibly the RCM data (Canada) becoming freely available from 2013.

Hyperspectral

The CEODA-R&D survey identified an increasing need for spectral information and higher sensor quality, including Hyperspectral imagery, for quantitative material detection and mapping in key economic sectors including resource exploration, agriculture and legislated monitoring programs. Australia has a strong heritage in the manufacture and operation of airborne Hyperspectral imaging systems (*e.g.* the Australian Hymap sensor), and has long considered a domestic capability in Hyperspectral imaging from space, notably the ARIES-1 mission studies in the 1990s. The 2009 Defence Capability Plan (Department of Defence, 2009b) also identifies Hyperspectral capabilities as a priority for the Department of Defence, and states that there may be opportunities for collaboration with Australian industry (assumed to include the research sector) in developing these capabilities.

The first wave of Hyperspectral satellite imagers is expected to emerge from 2014, and Australian researchers have been working closely with the various countries developing these systems (particularly the US, Germany, Italy and Japan) to promote Australia as the ideal laboratory to test, calibrate and develop accurate information products from these data for a variety of applications . Partnerships between Australia and one or more of the leading countries in this sector would be a high priority for future space capability development, especially if a niche technology can be captured, such as Hyperspectral thermal infrared imaging technology.

Short Wave and Thermal Infrared

Both short wave and thermal infrared (SWIR and TIR) multi-spectral data from Low Resolution Optical sources such as MODIS, AVHRR and AATSR are important for broad-area monitoring of sea and land surface temperature, as well as in support of vegetation and other land surface studies which feed into modelling of groundcover, climate and evapotranspiration. Thermal spectroscopy data from Hyperspectral imagers is important for mineral mapping. The first 'geoscience-tuned' EO system capable of mapping land surface composition, especially its mineral content, was the Japanese ASTER sensor with multi-spectral coverage at SWIR and TIR wavelengths. Australia was the first to develop national geoscience maps from these data.

There is concern that the most-used EO instruments, MODIS and Landsat-7 ETM+, will lose SWIR and TIR capabilities in the next generation of satellites, and there are no plans to develop a follow-on ASTER instrument. To date, the only Hyperspectral satellite SWIR imaging sensor is the US Hyperion, which was not designed for operational use. There are no satellite TIR imaging sensors currently collecting moderate to high spatial resolution imagery. Thus, the future data supply for SWIR and TIR data is uncertain, and the current usage of these data warrants attention at the national level to ensure security of supply.

6.2.3 Investment in Ground Infrastructure and Communications

The most common supply channel for EO data used by Australian researchers is the Internet. Researchers typically utilise the servers of the supply agencies (*e.g.* NASA, USGS) or their data processing partners to secure their routine data needs.

Landsat-8 (LDCM) is known to be moving towards a centralised data architecture, with less dependence on overseas ground stations, and a central on-line repository at the USGS-operated EROS Data Centre. The GMES Sentinel series data architecture is not fully defined but is likely to follow a similar model. Further, the distributed ALOS Data Node concept, which involved local downlink and processing in Australia (at GA), will not be repeated and JAXA is understood to be moving towards a centralised data distribution model. In combination, these missions are likely to represent the majority of data usage by Australian researchers and will have major implications for the routes through which data flows.

BoM has indicated that the next generation of geostationary meteorological satellites of Japan will also distribute data by Internet only. Himawari-8 data volumes are estimated to be 50 TB/annum based on current specifications, compared with ~0.6 TB/annum from the current MTSAT missions. BoM's Internet will need to be capable of 13 Mbits/s sustained by 2015, in order to transfer data from JMA to BoM every 10 minutes.

This trend will be compounded if there is a continued move to higher spatial and spectral resolution data (as indicated by the survey), including High Resolution Optical, Hyperspectral and Lidar data types. In the next five years, however, the majority of Hyperspectral and Lidar data needs will continue to be satisfied by airborne supply sources.

Some researchers noted the current distortion in data flows resulting from the way in which Internet bandwidth is paid for by State Governments, but not by researchers who are using academic networks. Relationships between the Governments and the researchers are being exploited to route data through academic networks and then to physically ship data for the final stage of the journey to the State user.

Seven of the R&D projects surveyed that now use large volumes of EO data collectively acquire around 29 TB per year. With data volumes expected to double annually, in 2016 these seven projects could be acquiring close to 1 PB each year. If researchers access the same datasets independently and in parallel, there will be significant inefficiencies in the use of international network bandwidth. Moves towards centralised data access and archiving in Australia would greatly reduce these inefficiencies. The move to Internet-based supply models has significant implications for national data networks and computing infrastructure with regard to data transmission, storage, pre-processing and provision, and will require national coordination.

Recent science infrastructure roadmaps have recognised the need for increased central investment into space-related and EO-related infrastructure, particularly in relation to network bandwidth, high-performance EO data processing and management infrastructure, Cal/Val activities, and quality assurance/control activities. The research community has expressed the need for this investment to ensure continued effective supply and management of data.

6.2.4 Extracting Value

Calibration and Validation

As more and more applications rely on EO data for quantitative measurements of land, atmosphere and water characteristics, the need for careful calibration and data correction (for atmospheric effects, imaging directionality and topography) is increasingly critical. The trend towards legislative monitoring based on EO data will necessitate systematic, national Cal/Val programs. Topical examples of this trend from among the surveyed projects include monitoring of carbon emissions and inland water quality.

National infrastructure to support radiometric Cal/Val is considered by many researchers to be a fundamental element of ensuring EO data stream quality. International links, such as involvement with global Cal/Val teams, has helped to ensure the quality of relevant data products in Australian conditions, especially in those cases when Australia is the only contributor to such activities in the Southern Hemisphere.

This was generally seen as a role for the Federal government, tied to the provision of calibrated, validated and standardised datasets, especially for optical datasets. An organisation with formal responsibility for quantifying these attributes for all EO data types in Australia would help to ensure data quality.

As discussed in Section 2.3.5, Australian scientists are active participants in the science teams for various international EO missions. This involvement is viewed as essential by many researchers, providing good leverage for Australian users to access EO data and share Cal/Val data with other international research teams. Australia's unique geography and position in the Southern Hemisphere makes it ideally suited for the collection of valuable Cal/Val data, including both surface and atmospheric measurements. Many researchers considered that this to be one of the most significant contributions Australia could and should continue to make to the international EO community.

National EO Product Standards

The MODIS model for publishing and delivering a suite of specialised information products derived from calibrated radiance, reflectance, emissivity and temperature data has helped initiate the establishment of standards. Even though many MODIS products are not optimised for Australian conditions they are readily taken up by the user community as such products are much easier to integrate. This model is now being adopted for other sensors and applications, including the National Carbon Accounting System and the Australian ASTER geoscience map, for which the underpinning processing methods were developed in Australia and are now being extended to other regions internationally. The process for establishing national information product standards is not yet established, however, and many research organisations are competing for recognition and support. The Australian user community requires that such standards be established to improve the accuracy and useability (value) of EO data.

Historical Data Archives

A further key priority is the preservation, rigorous pre-processing and seamless availability of the historical archive of EO data for Australia. This consists of near-complete High Resolution (30m) Optical datasets going back to 1985 and Low Resolution Optical datasets going back to 1981, but also includes Ocean Colour and surface temperature data for the surrounding oceans. This historical archive of multi-resolution datasets is important for the establishment of environmental baselines/retrospective state, and for analysis of trends, anomalies and environmental change in the presence of both climate change and variability.

The existing archive is a relatively short record, given the temporal resolution of certain events on decadal or longer timescales (e.g. cycles of drought driven by El Nino events, the subsequent influence on the occurrence of flood events, changes in ground cover and on inland and coastal water quality). The archive provides an important historical calibration for models developed for the prediction of current or future events at both the regional and continental scales, and is also important in framing rapid response (e.g. to contemporary flooding and bushfire events); for example, being able to calibrate river models on historical data for such things as flood events.

6.2.5 Sustained Capability to Deliver

Like many fields of Australian science, the EO sector has a legacy of being supported by resourceful and committed scientists who are passionate about their research. This high level of commitment has enabled Australian EO scientists to achieve international prominence with very limited resources, and to develop a wide range of EO applications that significantly benefit the nation. Without adequate official support and investment, however, commitment alone is not sufficient to safeguard existing expertise, ensure its dissemination to future scientists, and maximise its benefit to Australia.

Many of the research projects surveyed in the CEODA-R&D study are currently operating with minimum staffing and budgetary levels. Few areas of EO research are continuously funded, and as a consequence, these R&D activities lack continuity. Transient and/or inadequate funding has yielded inadequately documented results and high staff turnover, resulting in a loss of expertise. Several of the projects surveyed involve staff with decades of experience in EO research whose current resources do not allow them to access future data sources to extend their research. Without appropriate support to pass on their expertise, when these individual scientists leave the workforce, much of their experience and networks will be lost.

The history of remote sensing in Australia has fostered remarkable goodwill and cooperation amongst researchers and permitted the establishment of key facilities for mutual benefit. In future, however, these facilities must be strategically managed to ensure their effective operation beyond the tenure of specific individuals and their personal networks. To develop a sustained capability to deliver high quality EO products that currently make an estimated annual GDP contribution of $3.3 billion, Australia must ensure continuity of capability through strategic planning, resourcing and succession planning.

6.3 Conclusions

The conclusions and recommendations are presented below, structured to be consistent with the study objectives.

Importance of EO data in support of R&D outcomes

The *CEODA-R&D* survey identified 217 EO-related R&D projects in Australia, of which 187 were considered for inclusion in the survey, and ultimately 56 projects from 31 organisations were sampled in detail. The size and scope of these projects varies considerably. Altogether, the 56 projects employ 190 full-time equivalent staff and share a total annual budget of nearly $35 million.

The sampled R&D projects collectively use 59 different satellite instruments that are considered to be 'essential' to the research outcomes. Of these 59 instruments, 17 are used uniquely by CAWCR/BoM in support of their NWP and application research projects.

Airborne data usage was also considered, but in less detail, with supply sources typically being specially commissioned flights or in-house systems. Since airborne image acquisition is not systematic, continuity for airborne data sources cannot be predicted in the same way (although other uncertainties obviously apply to the execution of space data sources).

National significance of the R&D activity

Apart from providing important scientific advances and innovations, the majority of surveyed projects also support a range of social, security, environmental and economic outcomes and needs within Australia. They encompass a broad range of objectives and applications. Over 70% of the surveyed projects are linked to current operational EO-dependent programs in Australia, with research results contributing to a wide range of application areas, including large area monitoring and/or modelling of environmental resources, national weather and ocean forecasting, and emergency management. The most common societal benefit areas cited were ecosystems, agriculture, climate and water. National benefits and operational outcomes include: improved weather forecasting and public safety; improved climate models; Antarctic monitoring and surveillance; ocean forecasting and surveillance; national and international carbon accounting capabilities; water resource management capabilities; agricultural resource efficiency and improved productivity; improved resource exploration; disaster mitigation and response capabilities – amongst many others.

Data types of special importance to the R&D sector

Nine Priority Data Types, regarded as essential by Australian researchers, were identified in Section 3.3, based upon their criticality in support of research outcomes, and their widespread usage across multiple projects. These are (in decreasing order of usage):

- Low Resolution Optical;
- Medium Resolution Optical;
- High Resolution Optical;
- SAR (C-, L- and X-band);
- Passive Microwave Radiometry;
- Radar Altimetry;
- Hyperspectral Imagery;
- Lidar; and
- Ocean Colour.

No weighting has been applied to account for data volumes or to suggest relative importance of one research activity over another.

Of these, the Low and Medium Resolution Optical data are by far the most widely used, with Low Resolution Optical data being used by around half of the surveyed projects. SAR data sources (three bands in combination) represent the next most widely used.

Survey respondents assess that these Priority Data Types will not change significantly over the next five years (see Section 4), although EO data sources with higher spatial and spectral resolutions are anticipated. Several have indicated an increasing need for Hyperspectral and Lidar data types, yet many do not expect their future requirements for these two data types to be fully met by satellite sources. The future supply scenarios outlined in Section 5 indicate that there will be few satellite missions, available on terms suitable to Australian researchers, for these data types. It is presumed that researchers expect their requirements for Hyperspectral and Lidar data to be met by airborne data sources.

Supply Outlook for the Priority Data Types

Section 5 documents considerable detail on future EO data supply scenarios, and explains the global supply context, prospects of each of the major supply agencies, and specifics for each of the nine Priority Data Types. The summary table is repeated as Table 6-1.

Of the top four Priority Data Types, there is one actual and current data gap for SAR (L-band), and a high risk of a data gap for Medium Resolution Optical data. The Landsat continuity gap is dependent on the ongoing health of Landsat-5 and Landsat-7. Landsat-5 acquisitions are currently suspended and this could indicate the end of its 27-year life. If a data gap occurs (as seems likely), the many R&D teams (and operational programs) in Australia using this data will incur a significant cost to transition their Landsat-based algorithms and methodologies to other multi-spectral optical data. The economic impact to Australia of losing access to Landsat data has been assessed as $100 million in the first year of a data gap, with a flow on effect in subsequent years for the duration of that gap (ACIL Tasman, 2010).

Use of MODIS data is so widespread in Australian R&D and government programs that a very significant financial and technical cost will be incurred when MODIS data is no longer available, estimated to be on the same scale as the costs estimated for the Landsat data gap.

Numerous operational national programs and legislated monitoring activities will be severely affected by loss of Landsat and MODIS data.

The L-band SAR data gap has significantly affected the Australian R&D community, including those supporting forest carbon and vegetation studies using radar.

Of the remaining five Priority Data Types, only one (Ocean Colour) might safely be described as having a low risk to data continuity in the next five years.

Table 6-1 Priority Data Types: Satellite 5-Year Supply Continuity Risk and Key Providers

Priority EO Data Type	5-year continuity risk	Current key providers (and missions)	Future key providers (and missions)	Predominant Latency Requirement
Optical: Low Resolution	Low	NASA (MODIS) NOAA/EUMETSAT (AVHRR) JMA (MTSAT series)	ESA/EC (Sentinel-3 series) NOAA (NPP/JPSS series) JAXA (GCOM-C series) JMA (MTSAT series)	Hours/Weeks
Optical: Medium Resolution	High	USGS (Landsat-5/-7)	USGS (LDCM) ESA/EC (Sentinel-2 series)	Days/Weeks
Optical: High Resolution	Low	USA commercial providers (Worldview, GeoEye)	USA & European commercial providers (Worldview, GeoEye, Pleiades) Airborne operators	Days/Weeks
SAR: C-band	Low	ESA (Envisat) CSA (Radarsat)	ESA/EC (Sentinel-1 series) CSA (Radarsat & RCM)	Weeks
SAR: L-band	No current supply	-	CONAE-ASI (SAOCOM-1A) JAXA (ALOS-2)	Weeks
SAR: X-band	Low	ASI (COSMO-SkyMed) DLR (TerraSAR-X)	ASI (COSMO-SkyMed series) DLR (TerraSAR-X series)	Weeks
Passive Microwave Radiometry	Medium	NASA (Aqua – just concluded) NOAA/DoD (DMSP series) JAXA/NASA (TRMM) ESA (SMOS)	JAXA/NASA (GCOM-W series) NASA (GPM, Aquarius, SMAP) NOAA/DoD (DMSP series) ESA (SMOS) ISRO (Megha-Tropiques, RISAT-3)	Hours
Radar Altimetry	Medium	EUMETSAT-NOAA (Jason series) ESA (Envisat)	EUMETSAT-NOAA (Jason series) ESA/EC (Sentinel-3 series)	Hours
Hyperspectral Imagery	High	NASA (EO-1)	DLR (EnMAP) ASI (PRISMA) METI/JAXA (ALOS-3)	Weeks
Lidar	High	NASA (CALIPSO)	ESA/JAXA (EarthCARE)	Weeks
Ocean Colour	Low	ESA (MERIS) NASA (MODIS) ISRO (OCEANSAT)	ESA/EC (Sentinel-3 series) JAXA (GCOM-C series) ISRO (OCEANSAT) NOAA (NPP/JPSS series)	Hours

Critical relationships for EO data supply continuity

NASA has been the single most important supplier of EO satellite data in support of Australian R&D needs over the last decades, but the future supply prospects for the Priority Data Types identified suggest that a larger number of suppliers will become important to Australia over the coming years. This has implications for both the planning and prioritisation of key relationships and infrastructure in support of these supply arrangements.

ESA could emerge as an important provider of EO satellite data for R&D needs in Australia, provided that GMES funding issues are resolved and the data access terms are favourable. ESA (and in some cases the EC) is identified as a possible future supplier for up to seven Priority Data Types data types, based on data from the GMES program and the five series of Sentinel satellite missions. A formal data sharing agreement with ESA is considered to be a high national priority.

JAXA is anticipated to be an important partner in the future supply of EO data to Australia (and data from the geostationary meteorological missions of Japan continues to be critical for both Australian research and operations). USGS (Landsat), ASI (X-band SAR, Hyperspectral imagery and L-band SAR), DLR (X-band SAR and Hyperspectral imagery), and ISRO (Ocean Colour data and Passive Microwave data) will also be important data supply partners. Additionally, Chinese agencies are planning many EO missions in future years, which could become supply sources for Australia.

Given the significant and extended interest within Australia in the potential of Hyperspectral imagery from space, and the known disposition of DLR with regard to supplying data from EnMap for research purposes, a formal agreement with DLR on Hyperspectral data supply is proposed to be another national priority.

More than 40 different satellites are identified as necessary for the continuity of data supply across the nine Priority Data Types for Australian researchers.

Greater involvement with key international coordination bodies, such as CEOS and GEO, could help to compensate for the Australian tradition of depending on goodwill from international EO data suppliers.

Infrastructure implications

The most common supply channel for EO data used by Australian researchers is the Internet, with the majority of data being derived from international sources. As more suppliers use this avenue of dissemination, and data volumes increase (the survey suggested an increase of two to ten times current data volumes is expected over the next five years – more in some domains), efficient on-line access will be critical to minimise both cost and latency. This has significant implications for national computing infrastructure both in data storage and provision, and will require national coordination.

The need for careful, systematic calibration and validation (Cal/Val) of EOS datasets is urgently needed to support the growing number of operational programs relying on these data, especially in areas of legislative monitoring. A national infrastructure to support radiometric Cal/Val is considered by many researchers to be a fundamental element in ensuring EO data stream quality. It is also considered to be one of the major contributions that Australia could and should make to the international EO community.

SAR data and Hyperspectral imagery were both identified as future priority data types for the R&D community. In the short term, future missions, such as Sentinel-1 and -2 (ESA/EC, May 2013) and EnMap (DLR, Apr 2015) offer significant opportunities for available data streams of high value to the research community. Adequate planning for the reception, processing, archiving and distribution of these specialist data types will be essential if maximum national benefit is to be derived.

Sustaining capacity

The international prominence of Australian R&D achievements in EO is founded on the outstanding commitment of a relatively small number of resourceful, and often under-resourced, scientists. With the first generation of EO scientists reaching retirement, Australia is poised to lose decades of undocumented experience and numerous international connections. Similarly, the history of EO in Australia has fostered a unique level of goodwill and cooperation in many areas, including data management. Such functions have readily become dependent on generous individuals rather than adequately resourced facilities.

6.4 Recommendations

1. **A formal coordinated national strategy to ensure continuity of supply for the Priority Data Types identified, particularly Medium Resolution Optical data, is strongly recommended as a matter of priority, both with regard to international agreements as well as nationally coordinated EO infrastructure planning.** The outlook for continuity of supply of the more than 40 EOS missions that are critical for Australian R&D outcomes is largely dependent on a range of *ad hoc* relationships between different individual Australian researchers and/or agencies. As also concluded by the *CEODA-Ops* Report, a big-picture understanding of the full extent of the relationships between Australian EO data users and the suppliers is essential. An increasing number of supply agencies are of importance to Australia and this needs to be recognised and planned for.
2. **In addition to traditional US data suppliers, ESA and JAXA are identified as two significant emerging future suppliers of EO data for Australian R&D. Formalised national agreements with these agencies should be explored as a priority to guarantee access to these critical data (Sentinel-1,-2,-3, GCOM-C, -W, ALOS-2,-3, MTSAT, GPM) on terms consistent with researcher requirements for latency etc.** Further priority agreements should also be explored in relation to the supply of L-band SAR data (from JAXA and from CONAE) and the supply of Hyperspectral data (from DLR).
3. **A data gap for Medium Resolution Optical data appears to be imminent with the suspension of Landsat-5 data acquisition in November 2011. Rather than allow a costly plethora of uncoordinated interim arrangements to be negotiated and paid for by the multitude of research and operational users in Australia, it is recommended to undertake an immediate review of the data gap mitigation options and costs, and to seek to negotiate a coordinated solution at minimum overall cost to the nation.**
4. **The replication and operational continuity of the nationally coordinated EO data access and processing efforts being pioneered under prototype research infrastructure initiatives such as TERN and IMOS should be explored for all Priority Data Types.** The trend towards Internet-based data supply by all of the key supply agencies has significant implications for national computing infrastructure both in data storage and provision, and will require national coordination. Furthermore, given that Australia does not contribute to the funding of the satellite systems, but is amongst the world's heaviest users of EOS data, a more coordinated approach to data acquisition would also minimise Australia's impact on the provider agency systems by providing an effective interface to them. The establishment of national EO Data Centres for processing, archival and distribution of key datasets and derived standard products (*e.g.* for terrestrial, for climate and atmospheric, and for marine and coastal data), which are downloaded once from the international supplier, calibrated, processed, mirrored and held at networked repositories, and then distributed nationally, would rationalise significantly the myriad *ad hoc* data access arrangements that currently exist in Australia, and save significantly on the overhead and cost of international Internet traffic related to future EO data supply.

5. **The Australian Government should invest in strong links to, and participation in, the key international coordination bodies related to EO data supply and applications (CEOS, GEO, CGMS)** as a worthwhile and cost-effective investment to counter the 'high-risk' strategy of assuming continued free access to the systems developed by other nations. International space agencies should continue to be encouraged and supported as they move towards free and open data access policies.
6. **National infrastructure to support radiometric Cal/Val should be explored. This is a fundamental element in ensuring EO data stream quality and is essential to support the growing number of operational programs relying on these data, especially in areas of legislative monitoring.** It is also considered to be one of the major contributions that Australia could and should make to the international EO community.
7. **The Australian Government should consider formalised support for Australian membership of international science teams related to priority EO missions and Essential Climate Variables.** Such participation is often locally unfunded, and is another opportunity for a clearer Australian contribution to international efforts.
8. **Three areas are recommended for further exploration as high priority candidates for an Australian space segment capability: SAR, Hyperspectral imagery, and Short Wave and Thermal Infrared.** A cost-effective way to contribute could be through Australian participation in the increasing number of international virtual constellations.
9. **The CEODA Report series provides a basis for a national consultation process to determine long-term future EO supply priorities.** The *CEODA-R&D* Study survey process does not provide the full picture as to which future EOS data streams should be studied in more detail as to their potential to contribute to national information needs and societal benefits. Furthermore, several relatively new sensor systems, which may not be widely used currently, merit more attention in terms of continuity and critical data gaps across a range of new science and application fields important to Australia. Similar processes undertaken in Europe and the USA could provide a helpful model for a follow-on consultation activity.

REFERENCES

ACIL Tasman (2010). *Report on Economic Value of Earth Observation from Space – A Review of the Value to Australia of Earth Observation from Space*. ACIL Tasman.

ATSE (2009). *An Australian Strategic Plan for Earth Observation from Space.* Prepared for the Australian Academy of Science and Australian Academy of Technological Sciences and Engineering. Australian Academy of Science.

Australian Government (2011). *Earth Observations from Space (EOS) National Infrastructure: Priorities for Australia's Space Policy*. Draft V2.4, June 2011.

CEOS (2011). *Earth Observation Handbook*. ESA, Nov 2011. http://database.eohandbook.com/

Department of Defence (2009a). *Defending Australia in the Asia Pacific Century: Force 2030 – Defence White Paper 2009.* Department of Defence. http://www.defence.gov.au/whitepaper/

Department of Defence (2009b). *Defence Capability Plan*: Public Version. Department of Defence. http://www.defence.gov.au/dmo/id/dcp/dcp.cfm

DIISR (2011). *2011 Strategic Roadmap for Australian Research Infrastructure.* Department of Innovation, Industry Science and Research.

Dyce, P., Woolner, J., and Marks, A. (2005) *Technical Implementation of the Sentinel Hotspots Web-Based Pilot Wildfire Mapping System in Australia*. CSIRO Land and Water unpublished report. http://www.aprsaf.org/data/malaysia_tecshop_data/Part1_Sentinel_Implement.pdf http://www.aprsaf.org/data/malaysia_tecshop_data/Part2_Sentinel_Implement.pdf

Euroconsult (2008). *World Prospects for Government Space Markets, 2008 Edition.*

Geoscience Australia (2010). *A National Space Policy: Views from the Earth Observation Community*. National Earth Observation Group, Geoscience Australia.

Geoscience Australia (2011). *Continuity of Earth Observation Data for Australia: Operational Requirements to 2015 for Lands, Coasts and Oceans.* Commonwealth of Australia (Geoscience Australia). http://www.ga.gov.au/image_cache/GA19990.pdf

Held, A., and Kaku, K. (2007) Sentinel Asia: An outline delivery system for satellite imagery and disaster support in the Asia-Pacific region. *Proc. International Symposium of Remote Sensing of Environment*, Costa Rica.

National Research Council of the National Academies (2007). *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond.* Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future. National Research Council, USA.

National Research Council of the National Academies (2011). *Assessing requirements for Sustained Ocean Color Research and Operations*. National Academies Press.

ISBN 978-0-309-21044-7 http://www.nap.edu/catalog.php?record_id=13127

Northern Sky Research (2009). *Global Satellite-Based Earth Observation, 2nd Edition.*

Space Foundation (2011). *The Space Report, 2011 Edition.*

Space Policy Unit (2010). *Analysis of Australian Government Space Activities*. Department of Innovation, Industry, Science and Research, Australia.

GLOSSARY

AAD	Australian Antarctic Division
AARNet	Australian Academic and Research Network
AATSR	Advanced Along-Track Scanning Radiometer
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABI	Advanced Baseline Imager
ACBPS	Australian Customs and Border Protection Service
ACCESS	Australian Community Climate and Earth System Simulator
ACLUMP	Australian Collaborative Land Use Mapping Program
ACT	Australian Capital Territory (territory of Australia)
ACTPLA	ACT Planning and Land Authority (Australia)
AEB	Agência Espacial Brasileira (Brazilian Space Agency)
AEC	Australian Electoral Commission
AEISS	Advanced Electronic Image Scanning System
AERONET	Aerosol Robotic Network (NASA)
AFMA	Australian Fisheries Management Authority
AGD	Attorney-General's Department
AGRIC	WA Department of Agriculture and Food (Australia)
AGSNET	Aerosol Ground Stations Network (CSIRO)
AIMS	Australian Institute for Marine Science
AIRS	Atmospheric Infra-Red Sounder
ALI	Advanced Land Imager
ALISEO	Aerospace Leap-frog Imaging Stationary interferometer for Earth Observation
ALOS	Advanced Land Observing Satellite (JAXA, Japan)
AltiKa	Ka-band Altimeter (CNES)
ALUM	Australian Land Use and Management System
AMAZÔNIA-1	Brazilian satellite named for the region in Brazil
AMI/SAR/Image	Active Microwave Instrumentation/Synthetic Aperture Radar/Image Mode
AMSR-2	Advanced Microwave Scanning Radiometer-2
AMSR-E	Advanced Microwave Scanning Radiometer – EOS
ANU	Australian National University
ANZLIC	Australian and New Zealand Land Information Council
Aqua	NASA mission collecting data on Earth's water cycle (USA)

Aquarius	NASA Instrument comprising three L-Band radiometers and a scatterometer
ASAR	Advanced Synthetic Aperture Radar
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
Astrium	SPOT Image parent company, a subsidiary of EADS
ATSR	Along Track Scanning Radiometer
AusAID	Australian Government overseas aid program
AVHRR	Advanced Very High Resolution Radiometer (NOAA)
AWFI	Advanced Wide Field Imager
AWiFS	Advanced Wide Field Sensor
AWiFSSAT	Advanced Wide Field Sensor Satellite
Beijing-1	China DMC+4 microsatellite
BFCRC	Bushfire Cooperative Research Centre (Australia)
BJ-1	See Beijing-1
BNSC	British National Space Centre
BoM	Bureau of Meteorology (Australia)
BRLK	ROSHYDROMET Synthetic Aperture Radar
BRS	Bureau of Rural Science (Australia)
BSRN	Baseline Surface Radiation Network
Bushfires NT	Team responsible for Bushfire Act in NT Department of Natural Resources, Environment, the Arts and Sport (Australia)
C3DMM	WA Centre of Excellence for 3D Mineral Mapping (Australia)
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
Cal/Val	Calibration and Validation of EO data
Cartosat	Series of satellites maintained by ISRO for cartographic applications (India)
CAST	China Academy of Space Technology
CAWCR	Centre for Weather and Climate Research (Australia)
CBERS	China-Brazil Environmental Remote Sensing satellite
CCD	Charged Coupled Device
CDTI	Centro para el Desarrollo Tecnológico Industrial (Center for Development of Industrial Technology, Spain)
CEODA-Ops	Continuity of Earth Observation Data for Australia: Operational Requirements to 2015 for Lands, Coasts and Oceans (Geoscience Australia, 2011)
CEOS	Committee on Earth Observation Satellites: established in 1984 to coordinate Earth Observation provided by satellite missions; members and associates from civil agencies responsible for developing international Earth Observation programs and/or managing related ground facilities.

CEOS MIM	CEOS Missions, Instruments and Measurements database
CEOS WGCV	CEOS Working Group on Cal/Val
CGMS	Coordination Group for Meteorological Satellites
CHRIS	Compact High Resolution Imaging Spectrometer
CNES	Centre National d'Etudes Spatiales (French Space Agency)
COCTS	China Ocean Colour and Temperature Scanner
COMDISPLAN	Commonwealth Disaster Plan (Australia)
COMS	Communications, Oceanography and Meteorology Satellite (Korea)
CONAE	COmision Nacional de Actividades Espaciales (Argentina)
COSI	COrea SAR Instrument (KOMPSAT-5, Korea)
COSMIC	Constellation Observing System for Meteorology, Ionosphere and Climate
COSMO	COnstellation of small Satellites for the Mediterranean basin Observation
COSMO-SkyMed	COSMO satellite series
CPR	Cloud Profiling Radar
CRC	Cooperative Research Centre (Australia)
CRCSI	Cooperative Research Centre for Spatial Information (Australia)
CRESDA	Centre for Resources, Satellite Data and Application (China)
CSA	Canadian Space Agency
CSG	COSMO-SkyMed Second Generation
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
CSST	CSIRO Space Sciences and Technology (Australia)
CZI	Coastal Zone Imager
DAFF	Department of Agriculture, Fisheries and Forestry (Australia)
DAFWA	WA Department of Agriculture and Food (Australia)
DCCEE	Department of Climate Change and Energy Efficiency (Australia)
DEC	WA Department of Environment and Conservation (Australia)
DECCW	NSW Department of Environment, Climate Change and Water (Australia)
DEH	Department of Environment and Heritage (Australia)
DEM	Digital Elevation Model
DERM	Queensland Department of Environment and Resource Management (Australia)
DEWHA	Department of the Environment, Water, Heritage and the Arts (Australia)
Deimos-1	DMI satellite, part of the DMC (Spain)
DFAT	Department of Foreign Affairs and Trade (Australia)
DigitalGlobe	Private USA satellite system operator and digital image product provider (formerly EarthWatch, and WorldView Imaging Corporation)
DIGO	Defence Imagery and Geospatial Organisation (Australia)

DIISR	*Former* Department of Innovation, Industry, Science and Research (Australia)
DIISRTE	Department of Industry, Innovation, Science, Research and Tertiary Education (Australia) – formerly DIISR
DIPE	NT Department of Infrastructure, Planning and Environment (Australia)
DLR	Deutsche Zentrum für Luft- und Raumfahrt (German Space Agency)
DMAC	DubaiSat-1 Medium Aperture Camera
DMC	Disaster Monitoring Constellation (Consortium of European and African countries)
DMCii	DMC International Imaging (UK)
DMI	Deimos Imaging, part of the Deimos Space Group (Spain)
DMSP	Defense Meteorological Satellite Program (USA)
DNRM	Queensland Department of Natural Resource Management (Australia)
DPI (Vic)	Victorian Department of Primary Industry (Australia)
DPI (WA)	WA Department of Primary Industry (Australia)
DPIWE	Tasmanian Department of Primary Industry, Water and Environment (Australia)
DoD	Department of Defense (USA)
DOW	WA Department of Water (Australia)
DSE	Victorian Department of Sustainability and Environment (Australia)
DubaiSat	EIAST satellite, with receiving station in Dubai (United Arab Emirates)
DWLBC	SA Department of Water, Land, Biodiversity and Conservation (Australia)
EADS	European Aeronautic Defence and Space Company
EarthCARE	ESA cloud and aerosol mission (Europe)
EC	European Commission
ECV	Essential Climate Variable
ECMWF	European Centre for Medium-Range Weather Forecasts
EHC	Electronic Housing Code (Australia)
EIAST	Emirates Institution for Advanced Science and Technology (United Arab Emirates)
EMA	Emergency Management Australia
EnMAP	Environmental Mapping and Analysis Program (Germany)
Envisat	Environmental Satellite (ESA)
EO	Earth Observation
EOS	Earth Observations from Space
ERIN	Environmental Resources Information Network (Australia)
EROS	Earth Resources Observation and Science

ERS	European Remote Sensing satellite (ESA)
ERSDAC	Earth Remote Sensing Data Analysis Centre (Japan)
ERTS	Earth Resource Technology Satellite (renamed to Landsat)
ESA	European Space Agency
ETM+	Enhanced Thematic Mapper Plus
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FCI	Flexible Combined Imager
FMCW	Frequency Modulated Continuous Wave (Radar)
FORMOSAT	Series of satellites managed by NSPO (Taiwan)
FY	FengYun (wind and cloud) polar orbiting meteorological satellite series (China)
GA	Geoscience Australia
GAC	Global Area Coverage
GB	Gigabyte (10^6 KB)
GCOS	Global Climate Observing System
GCOM-C1	Global Change Observation Mission – Climate series (Japan)
GCOM-W1	Global Change Observation Mission – Water series (Japan)
GDE	Groundwater Dependent Ecosystems
GEO	Group on Earth Observations: Intergovernmental body established in 2002 that encourages members to coordinate projects, strategies and investments for Earth observation.
GeoEye	Private USA company providing satellite and aerial imagery and services
GEOSS	Global Earth Observation System of Systems: Being developed by GEO based on 10 year plan from 2005 to advance and demonstrate societal benefits of Earth observation in nine specific areas: Disasters, Health, Energy, Climate, Agriculture, Ecosystems, Biodiversity, Water and Weather.
Geoton-L1	ROSKOSMOS high resolution imaging Vis/IP radiometer
GFOI	Global Forest Observation Initiative
GFZ	GeoForschungZentrum Potsdam (National German Research Centre for Earth Science)
GIS MS	GeoEye Imager System – Multispectral
GIS PAN	GeoEye Imager System – Panchromatic
GISTDA	Geo-Informatics and Space Technology Development Agency (Thailand)
GLAS	Geoscience Laser Altimeter System
GMES	Global Monitoring for Environment and Security (ESA)
GOCI	Geostationary Ocean Colour Imager (Korea)
GOES-R	Geostationary Operational Environmental Satellite R-Series (NOAA)

GOES-S	Geostationary Operational Environmental Satellite S-Series (NOAA)
GPM	Global Precipitation Measurement mission
GPS	Global Positioning System (USA)
GRACE	Gravity Recovery and Climate Experiment (NASA)
GRDC	Grain Research and Development Corporation (Australia)
GSD	Ground Sampling Distance
GSQ	Geological Survey of Queensland (Australia)
GSWA	Geological Survey of WA (Australia)
GTS	Global Telecommunication System (WMO)
HHI	Hyperion Hyperspectral Imager
HICO	Hyperspectral Imager for the Coastal Ocean
HiRI	High Resolution Imager
HISUI	Hyperspectral Imager Suite, ALOS-3 (Japan)
HJ	Huan Jing (environment) satellite series (China)
HPC	High Performance Computing
HPCCC	High Performance Computing and Communications Centre
HPSC	High Performance Scientific Computing facility (CSIRO)
HRG	High Resolution Geometrical
HRPIC	High Resolution Panchromatic Imaging Camera
HRS	High Resolution Stereoscope
HRTC	High Resolution Technological Camera (Panchromatic)
HRVIR	High Resolution Visible and Infra-Red
HSC	High Sensitivity Camera
HSI	Hyperspectral Imager
HSTC	High Sensitivity Technological Camera
HY	HaiYang (ocean) satellite series (China)
HYC	HYperspectral Camera
HySI	Hyperspectral Imager
HyspIRI	Hyperspectral Infrared Imager
IASI	Infrared Atmospheric Sounding Interferometer
IFCI	International Forest Carbon Initiative
IKONOS	Lockheed Martin / GeoEye commercial satellite—after the Greek word *eikōn*, meaning 'image'
Imager (INSAT)	Very High Resolution Radiometer (ISRO)
IMCRA	Integrated Marine and Coastal Regionalisation of Australia
IMOS	Integrated Marine Observing System (Australia)
IMS-1	Indian MicroSatellite – 1

INCAS	Indonesian National Carbon Accounting System (Indonesia)
Ingenio	Also knowns as SEOSAT, Satélite Español de Observación de la Tierra (Spanish System for Earth Observation Satellite) (CDTI, ESA)
INPE	Instituto Nacional de Pesquisas Espaciais (Institute of Spatial Research, Brazil)
INSAT	Indian National Satellite System
IR	Infrared
IRS	Infrared Sounding instrument
IRS-P6	Indian Remote Sensing satellite, also known as RESOURCESAT-1
ISA	International Space Agency
ISRO	Indian Space Research Organisation
ITT	International Telephone & Telegraph (corporation, USA)
iVEC	WA collaborative supercomputing, storage and visualisation centre
JAXA	Japan Aerospace Exploration Agency
JMA	Japan Meteorological Agency
JMR	Jason-1 Microwave Radiometer (successor to TMR)
JPSS	Joint Polar Satellite System (NASA)
KALPANA-1	Meteorological satellite named for the Indian-born American Astronaut Dr Kalpana Chawla (India)
KARI	Korea Aerospace Research Institute
KaRIN	Ka-band Radar INterferometer
KB	Kilobyte (2^{10} bytes)
KMSS	ROSHYDROMET MultiSpectral Imager (VIS)
KOMPSAT	KOrea Multi-Purpose SATellite
Landgate	WA Statutory Authority responsible for Land Information and Geographic Data (Australia)
Landsat	Originally known as the Earth Resource Technology Satellite, renamed in 1975 (USA)
LDCM	Landsat Data Continuity Mission, also Landsat-8 (USA)
LISS-III	Linear Imaging Self Scanner - III
LISS-IV	Linear Imaging Self Scanner - IV
LoSaMBA	Law of the Sea and Maritime Boundaries Advice (Australia)
LPDAAC	Land Products Distributed Active Archive Centre, USGS
LPMA	NSW Land and Property Management Authority (Australia)
MB	Megabyte (10^3 KB)
MBEI	Multi-Band Earth Imager
MCSI	Multiple Channel Scanning Imager

MDA	MacDonald Dettwiler and Associates (Canada)
MDBA	Murray-Darling Basin Authority (Australia)
MERCI	MERIS Catalogue and Inventory
MERIS	Medium-Resolution Imaging Spectrometer
MERSI	Medium-Resolution Spectral Imager
Meteor-M	Series of Russian meteorological satellites
METI	Ministry of Economy, Trade and Industry (Japan)
Metop	Meteorological Operational—Series of polar-orbiting meteorological satellites (EUMETSAT/NOAA)
MIOSAT	MIssione Ottica su microSATellite (Italy)
MIR	Mid-infrared
MIRAS	Microwave Imaging Radiometer using Aperture Synthesis
MIREI	Mid-InfraRed Earth Imager
MMRS	Multispectral Medium Resolution Scanner
MODIS	MODerate-Resolution Imaging Spectroradiometer (NASA)
Monitor-E	Monitor Experimental (Russia)
MoU	Memorandum of Understanding
MS	Multispectral (Camera or Imager)
MSC	MultiSpectral Camera
MSI	MultiSpectral Imager
MSMR	Multifrequency Scanning Microwave Radiometer
MSS	MultiSpectral Scanner
MSU-MR	Multispectral Scanning Imager–Radiometer (visible/IR)
MTG-I1	Meteosat Third Generation – Imager Mission 1
MTSAT	Series of Japanese meteorological satellites (JMA)
MUX	Multispectral Camera
MVIRS	Moderate Resolution Visible and Infra-Red Imaging Spectroradiometer
MVISR	Multispectral Visible and Infra-Red Scan Radiometer
MWR	Microwave Radiometer
MWRI	Microwave Radiation Imager
MxT	Multi-spectral CCD Camera
NASA	National Aeronautics and Space Administration (USA)
NASRDA	National Space Research and Development Agency (Nigeria)
NCAS	National Carbon Accounting System (Australia)
NCI	National Computing Infrastructure
NDVI	Normalised Difference Vegetation Index
NEDF	National Elevation Data Framework (Australia)

NEO	National Earth Observation group within Geoscience Australia (formerly the Australian Centre for Remote Sensing, ACRES)
NEON	National Ecological Observatory Network
NigeriaSat	Nigeria Satellite series
NIR	Near Infrared (electromagnetic radiation with wavelength near the red end of the visible spectrum)
NIRST	New Infrared Sensor Technology
NLWRA	National Land and Water Resources Audit (Australia)
NMP EO-1	New Millennium Program Earth Observing mission 1
NOAA	National Oceanic and Atmospheric Administration (USA)
NPOESS	National Polar-orbiting Operational Environmental Satellite System (USA)
NPEI	National Plan for Environmental Information
NPP	NPOESS Preparatory Project (USA)
NRSCC	National Remote Sensing Center of China
NRSTRG	National Remote Sensing Technical Reference Group (Australia)
NSAU	National Space Agency of Ukraine
NSPO	National Space Program Office (Taiwan)
NSW	New South Wales (state of Australia)
NT	Northern Territory (territory of Australia)
NT DNREAS	Northern Territory Department of Natural Resources, Environment, the Arts and Sport
NTLIS	NT Land Information System (Australia)
NVIS	National Vegetation Information System (Australia)
NWP	National Weather Program (BoM, Australia)
OCEANSAT	OCEAN SATellite series (India)
OCM	Ocean Colour Monitor
OCS	Ocean Colour Scanner
OLCI	Ocean and Land Colour Imager
OLI	Operational Land Imager
OOW	NSW Office of Water (Australia)
ORBIMAGE	Orbital Imaging Corporation, now GeoEye (USA)
OrbView	OrbImage/GeoEye satellite series (also known as SeaStar)
ORFEO	Optical and Radar Federated Earth Observation (France & Italy)
PAN	Panchromatic (Camera or Imager)
PAZ	Also known as SEOSAR, Satélite Español de Observación SAR (SAR Observation Spanish Satellite) (CDTI)
PB	Petabyte (10^{12} KB)
PM&C	Department of the Prime Minister and Cabinet (Australia)

PMR	Passive Microwave Radiometer
POAMA	Predictive Ocean Atmosphere Model for Australia
PPP	Public-Private Partnership
PRISMA	Precursore IperSpettrale della Missione Operativa (Italy)
PROBA	PRoject for OnBoard Autonomy (ESA)
PSA	A panchromatic imager (aka Gamma-L) (Russia)
QLUMP	Queensland Land Use Monitoring Program (Australia)
QuickBird	High resolution satellite owned and operated by DigitalGlobe (USA)
R&D	Research and Development
RADAR	RAdio Detection And Ranging
RADARSAT	RADAR SATellite (Canada)
RADARSAT C	RADAR SATellite Constellation (Canada)
RapidEye	German geospatial information provider (now Canadian-owned)
RASAT	Microsatellite imaging mission of Tubitak-Uzay; After the Turkish word meaning 'observation' (Turkey)
RCM	Radarsat Constellation Mission (Canada)
RCM	DERM Reef Catchment Monitoring (Australia)
RDSA	A multispectral imager (aka Gamma-C) (Russia)
REDD	Reducing Emissions from Deforestation and Forest Degradation
RESOURCESAT	RESOURCE SATellite (India)
Resurs DK1	Resurs – High Resolution 1 (Russia)
Resurs P	Resurs P Environmental Satellite (Russia)
RET	Department of Resources, Energy and Tourism (Australia)
RGB	Red Green Blue (generally refers to visible light)
RISAT	Radar Imaging SATellite (India)
ROSHYDROMET	Russian Federal Service for Hydrometeorology and Environmental Monitoring
ROSKOSMOS	Russian Federal Space Agency
RSI	Remote Sensing Instrument (Taiwan)
S-Band SAR	S-Band Synthetic Aperture Radar
SA	South Australia (state of Australia)
SAC-C	Satelite de Aplicaciones Cientificas – C (Satellite for Scientific Applications – C, Argentina)
SAC-D	Satelite de Aplicaciones Cientificas – D (Satellite for Scientific Applications – D, Argentina)
SAGNAC	For French physicist George Sagnac (*cf.* Sagnac interference)
SANSA	South African National Space Agency

SAOCOM	SAtélite Argentino de Observación COn Microondas (Argentine Microwaves Observation Satellite)
SAR	Synthetic Aperture Radar
SAR 2000	Synthetic Aperture Radar – 2000
SAR-2000 S.G.	SAR–2000 Second Generation
SAR-L	L-Band Synthetic Aperture Radiometer
SAR-X	X-Band Synthetic Aperture Radiometer
SARAL	Satellite with ARgos and ALtiKa
SBA	Societal Benefit Area, defined by GEOSS
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
Sentinel	Radar imaging satellite missions supporting GMES
Severjanin	X-band Synthetic Aperature Radar (Russia)
SGLI	Second generation GLobal Imager (Japan)
Sich-2	Small ocean observation satellite (Ukraine)
SIRAL	SAR Interferometer Radar Altimeter
SLATS	Statewide Landcover and Tree Study (Queensland, Australia)
SLIM-6	Surrey Linear IMager – 6 channel
SLIP-EM	WA Shared Land Information Platform Emergency Management (Australia)
SLSTR	Sea and Land Surface Temperature Radiometer
SMAP	Soil Moisture Active Passive (NASA)
SMOS	Soil Moisture and Ocean Salinity (ESA)
SNSB	Swedish National Space Board
SOE	State of Environment (Australia)
SPOT	Système Probatoire d'Observation de la Terre (France)
SPU	Space Policy Unit (Australia)
SRAL	SAR Radar Altimeter
SSM/I	Special Sensor Microwave Imager
SST	Sea Surface Temperature
SumbandilaSat	Sumbandila Satellite (from a Venda word, chosen by school children, meaning 'lead the way') (South Africa)
SumbandilaSat Imager	A 6 spectral band (visible range) line scanner
SWIR	Short-wave Infrared
SZS	Shore Zone Scanner
TanDEM-X	TerraSAR-X add-on for Digital Elevation Measurement (Germany)
TB	Terabyte (10^9 KB)
TERN	Terrestrial Ecosystem Research Network (Australia)

Terra	A multi-national NASA scientific research satellite, from the Latin word for "earth"
TerraSAR-X	Satellite acquiring X-band SAR data (Germany)
TERSS	Tasmanian Earth Resource Satellite Station (Australia)
TES	Technology Experiment Satellite (India)
TES-HYS	TES Hyperspectral Imager
THEOS	THailand Earth Observation Satellite (Thailand)
TIR	Thermal Infrared Radiometer
TIRS	Thermal InfraRed Sensor
TM	Thematic Mapper
TMI	TRMM Microwave Imager
TMPA	TRMM Multi-satellite Precipitation Analysis
TMR	TOPEX Microwave Radiometer (predecessor to JMR)
TopSat	Tactical Optical Satellite (UK)
TPM	Topex-Poseidon Mission
TRMM	Tropical Rainfall Measuring Mission (USA & Japan)
TSX-SAR	TerraSAR-X SAR
Tubitak	Space Technologies Research Institute / The Scientific and Technological Research Council of Turkey
TVMMP	Tasmanian Vegetation Mapping and Monitoring Program (Australia)
UAdel	University of Adelaide (Australia)
UAV	Unmanned Aerial Vehicles
UK-DMC	UK Disaster Monitoring Constellation (UK)
ULTRAPAN	(Cartosat-3) Panchromatic sensor
UNCLOS	United Nations Convention on the Law of the Sea
UNSW	University of NSW (Australia)
USGS	USA Geological Survey (USA)
UTS	University of Technology Sydney (Australia)
UWA	University of Western Australia (Australia)
VENμS	Vegetation and Environment monitoring on a New micro-Satellite (France & Israel)
VHRR	Very High Resolution Radiometer
VIIRS	Visible/Infrared Imager Radiometer Suite
VIRR	Multispectral Visible and Infra-Red Scan Radiometer
VSC	Venus Superspectral Camera
WA	Western Australia (state of Australia)
WALIS	Western Australian Land Information System (Australia)

WASTAC	Western Australian Satellite Technology and Applications Consortium (Australia)
WFC	Wide Field Camera
WFI	Wide Field Imager
WIRADA	Water Information Research and Development Alliance (Australia)
WMO	World Meteorological Organisation
WorldView	Commercial satellite (*cf.* QuickBird) owned and operated by DigitalGlobe (USA)
WV110	WorldView-110 camera (combined panchromatic and 8-band multispectral scanners)
WV60	WorldView-60 camera (panchromatic imager only)
X-Band SAR	X-Band Synthetic Aperture Radar

Contact Us
Phone: 1300 363 400
+61 3 9545 2176
Email: enquiries@csiro.au
Web: www.csiro.au

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