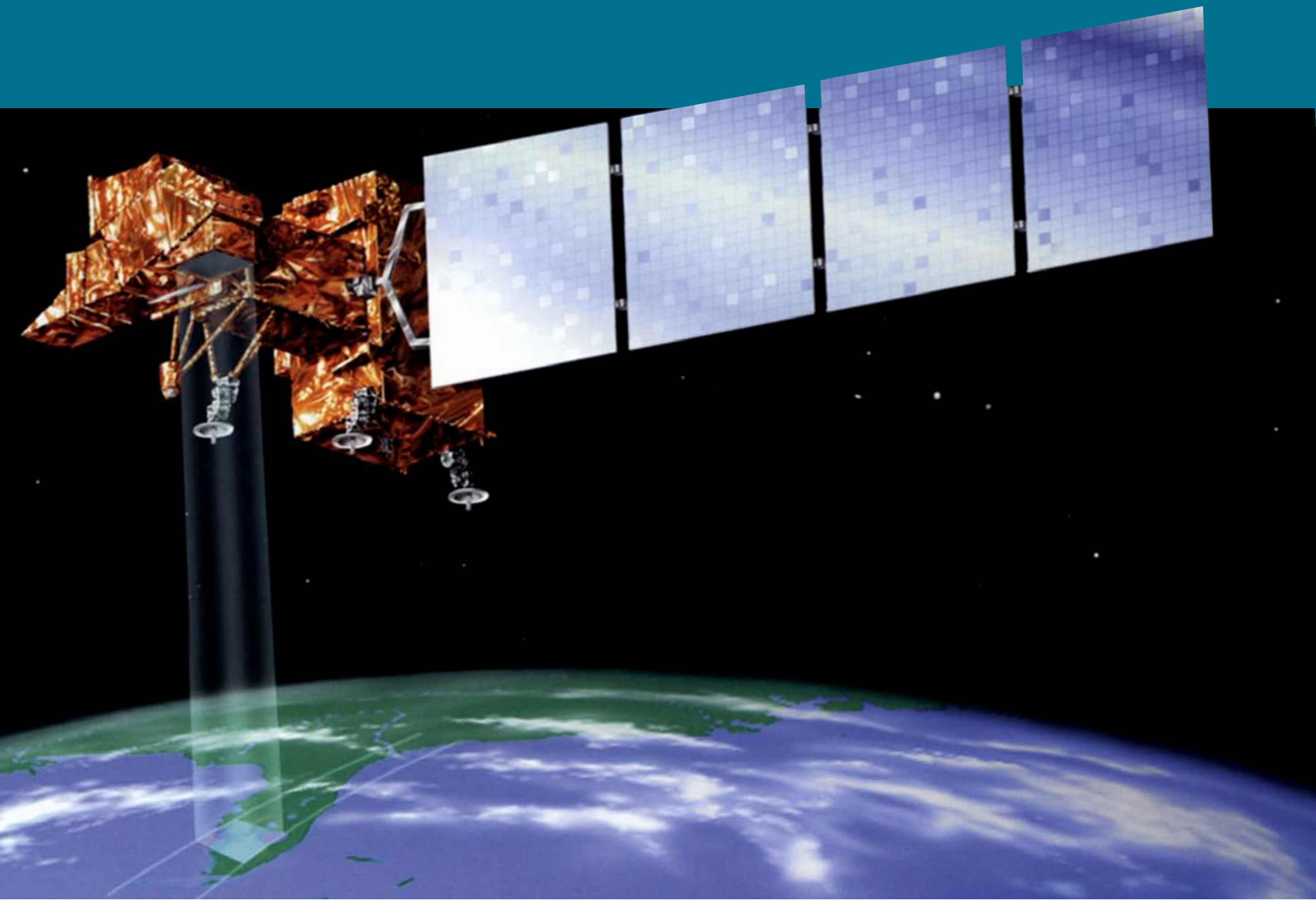
Australian Government
Geoscience Australia



Continuity of Earth Observation Data for Australia

Operational Requirements to 2015 for Lands, Coasts and Oceans

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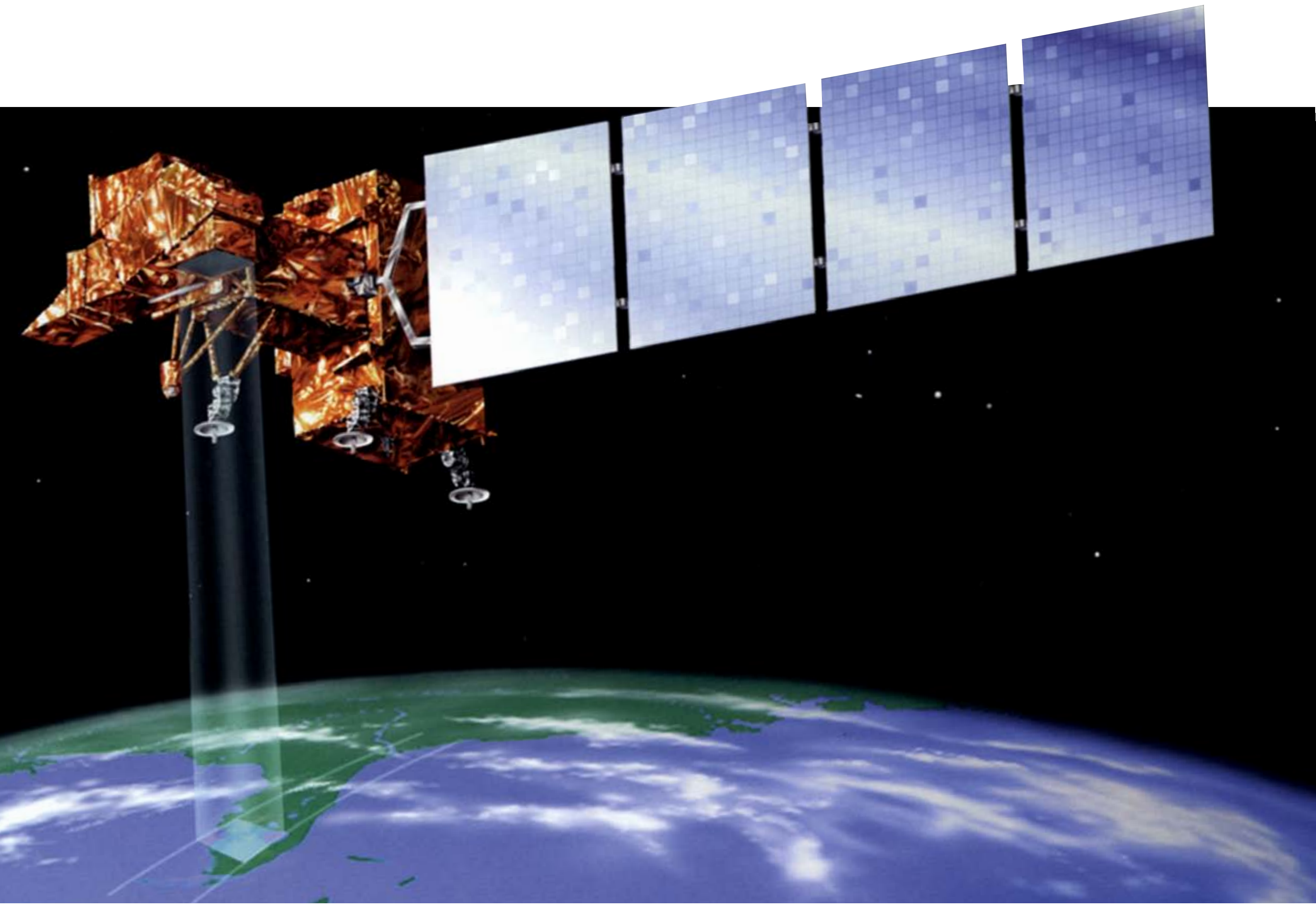

Continuity of Earth Observation Data for Australia

Operational Requirements to 2015 for Lands, Coasts and Oceans

DEPARTMENT OF RESOURCES, ENERGY AND TOURISM

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GEOSCIENCE AUSTRALIA

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Additional contributors are shown in Appendix B.

FRONT COVER

Landsat-7. **Landsat-5** and **Landsat-7** are the currently active satellites in the Landsat series. Landsat-5 is the oldest and most widely used EOS satellite in Australia. Launched by NASA in 1984, it had a three-year design life. It still supports an expanding range of operational EOS programs in Australia, including the National Carbon Accounting System (NCAS).

BACK COVER

Surface reflectance image of Australia in August 2011 using a 16 day composite from MODIS (Geoscience Australia)

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Key Points

1. Earth Observations from Space (EOS) data have become pivotal to most environmental monitoring activities being undertaken by federal and state governments in Australia.
2. Australia is totally reliant on foreign satellites for EOS data.
3. Of the 22 EOS sensors currently being used for operational programs in Australia, 19 (86%) are expected to cease functioning by 2015.
4. Australia has not secured access to any future space-based sensors that are relevant to observing the Australian land mass and its coastal regions.
5. Alternate, non satellite-based sources of data do not exist for most types of space-based EOS data, especially those used for environmental monitoring programs.
6. In contrast with the projected rapidly decreasing access to EOS data, Australia's EOS requirements are expected to increase significantly over the next decade. To support a sample set of 91 operational government programs, the total annual EOS data storage requirements in 2015 were conservatively estimated at 1.2 PB per year. This represents a twentyfold increase on current annual EOS data storage. These estimates do not include meteorological applications, research and development activities, or new sensor technologies.
7. Two data types, medium resolution optical and Synthetic Aperture Radar (SAR), are most at risk of data gaps before 2015 for land and marine applications.
8. Data continuity for low and high resolution optical data, and for passive microwave data, is also of concern, but improved access to these data types has a lower priority due to the availability of alternative data sources and/or current levels of data usage in land and coastal applications.
9. Urgent action is needed to ensure that the imminent and potentially damaging EOS data gaps are not realised.
10. Australia's participation in the Landsat Data Continuity Mission (LDCM) and ESA's Sentinel missions would significantly reduce the risk of the projected EOS data gaps in the high priority data types and should be the focus of immediate action. It should also be a priority to encourage an on-going Landsat program.
11. As a matter of priority Australia needs to formalise agreements with several upcoming EOS missions, and formulate a decadal infrastructure plan to safeguard the supply of EOS data.

Executive Summary

INTRODUCTION

Earth Observations from Space (EOS) describes a range of approaches that observe and measure Earth surface properties from space-based platforms. EOS data is used widely and to great advantage in Australia by numerous federal and state government agencies, research institutions, and the private sector, and have particular value in a large, sparsely populated country that needs to monitor a long coastline and a wide range of natural disasters. Australia's involvement in international agreements that require recording, monitoring and reporting on environmental change also necessitates the use of EOS data.

Australia has been utilising Earth Observations from Space (EOS) data for over five decades, with the first satellite imagery being received in 1960. In 2011, five organisations in Australia routinely acquire data from dozens of foreign satellites, through intergovernmental agreements and/or commercial contracts with overseas jurisdictions.

Australia's position, as a passive user relying on foreign satellite data, leaves its remote sensing industry and services in a vulnerable position (Lewis and Reddy, 2006). As an increasing number of land, water, disaster management and other activities become dependent on EOS data in Australia, it is increasingly important to address the risks associated with a lack of control over the supply of EOS data. These risks include cessation of satellite service or access rights, interruptions to data supply due to management priorities, incomplete spatial coverage for Australian areas of interest, and inferior system design or operation to meet Australian needs.

The current government expenditure on remote sensing in Australia approximates $100 million per annum (Geoscience Australia, 2010), with significant increases expected in future years. In a recent study by ACIL Tasman (ACIL Tasman, 2010), the GDP contribution of the Australian EOS sector was valued at $3.3 billion per annum. This equates to a return on investment of more than 30 to one.

PURPOSE AND SCOPE OF REPORT

This report, entitled 'Continuity of Earth Observation Data for Australia: Operational Requirements to 2015 for Lands, Coasts and Oceans (CEODA-Ops)', details the projected EOS data that will be required by Australian government agencies in 2015, and assesses the expected availability of EOS data in Australia to 2020. Only EOS applications that are relevant to terrestrial, coastal and ocean areas are considered. Research and development activities, and meteorological applications, are both outside the scope of this report.

Data requirements and availability are assessed for five categories of EOS sensors: low resolution optical, medium resolution optical, high resolution optical, synthetic aperture radar, and passive microwave.

Three primary questions are addressed:

1. What will Australia's EOS data requirements be in 2015?
2. What are Australia's EOS data continuity plans to 2020? and
3. What are the major factors and constraints that could restrict or impede access to Earth Observations from Space (EOS) data for Australian users?

In particular this study focuses on the data continuity required to maintain the most significant EOS programs that are being conducted by Australian governments as assessed through Geoscience Australia's

National Remote Sensing Technical Reference Group (NRSTRG) members. The seventh NRSTRG and Distributors' Meeting in February 2010 (Geoscience Australia, 2010) identified 92 federal and state programs that currently depend on EOS data. In this report, 91 of these operational programs are used as a sample set to conservatively forecast Australia's EOS data requirements in 2015[1]. Neither research and development requirements, nor meteorological requirements, have been considered in the CEODA-Ops projections.

AUSTRALIAN USAGE

EOS data are currently being used operationally for a wide range of applications in Australia, including modelling climate, forecasting weather, monitoring water usage 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, and navigation.

Australia's remote sensing sector has traditionally relied heavily on the routine acquisition of low-cost, public good satellite imagery. Commercial imagery has been utilised to a much lesser extent, due to its greater costs, less consistent coverage, less sophisticated instruments and more restrictive licensing conditions. Most of the public good satellite sensors now being used by the 91 programs, however, are already operating beyond their life expectancy, with Australia's most widely used satellite, Landsat 5, being 24 years beyond its design life of three years. There are currently no formal arrangements in place for Australia to receive data from the numerous sensors, both public good and commercial, that will be carried on missions planned during the next decade.

DATA REQUIREMENTS IN 2015

To adequately support the EOS needs of the 91 sample programs, it is expected that Australia-wide coverage will be required in 2015 for the five sensor types being considered. Frequency of coverage varies for each data type and region, from daily for low resolution optical data to triennially for SAR coverage of some marine areas. Coverage of Antarctica will also be required for medium resolution optical and SAR data.

The CEODA-Ops estimates for area of coverage and storage capacity that will be required for each sensor type in 2015 are summarised in **Table ES-1**. The total data storage required by the 91 sample programs in 2015 is conservatively estimated at 1.2 PB per year (1,192 TB), which represents an almost twentyfold increase from 2010 usage. This estimate is conservative and does not include new requirements that can be expected to arise in areas such as carbon farming, improved monitoring of forest biomass and ecosystem health, and overseas development aid for activities such as forest carbon assessments and disaster management.

1 Program 26 is not included in this sample due to insufficient EOS data usage.

Table ES-1 Summary of Projected EOS Data Requirements in 2015

Estimate	Sensor Type					TOTAL
	Optical			SAR	Passive Microwave	
	Low Spatial Resolution (> 80 m)	*Med. Spatial Resolution (10-80 m)*	*High Spatial Resolution (< 10 m)*			
Annual Area (Estimate Million km²/year)	143,895	2,910	17	16	197	147,035 TB
Annual Data Storage Estimate	202 TB	235 TB	747 TB	8 TB	15 MB	**1,192 TB**

DATA AVAILABILITY IN 2015

Australia currently uses EOS data from only 22 sensors, representing only 20% of those available[2], and acquisition arrangements have *not* been ratified for any upcoming sensors. Under the current arrangements, projections based on the expected end of life for current sensors indicate that less than 14% of the EOS data sets that were in use in 2010 will be available in 2015. The consequences are much more severe for individual data sets, with no EOS data being accessible from medium and high resolution optical, SAR, or passive microwave sensors in 2015, and less than a third of the currently used data sets being available from low resolution optical sensors.

PROGRAM IMPLICATIONS

The projected loss of these data sets in 2015 would prevent EOS data input to over half of the currently dependent programs, including the National Carbon Accounting System (NCAS), and severely reduce data input to many others. Many of the EOS dependent programs serve emergency management activities or contribute to international agreements. Thus, a deprivation of key data sets would be costly to Australia, and would also compromise the integrity of existing agreements that depend on these data sets.

Some, but not all, types of EOS data can be acquired from alternate sources, such as sensors carried by aerial platforms. There are no alternate sources for low or medium resolution optical data, the two most widely used data types in Australia. Similarly, the synoptic view offered by space-borne SAR and passive microwave sensors cannot be acquired from aerial platforms.

DATA STREAM IMPLICATIONS

Australia currently has no national strategy on EOS to ensure that its data needs will be satisfied into the future, or to coordinate Australian involvement in international activities related to EOS. In this context, data needs include both access to appropriate data sources and adequate archiving of imagery for potential future use.

Australia benefits primarily from EOS programs operated by the USA. A number of characteristics of these programs, such as technical quality, reliability of satellite systems, commitment to international collaboration and service, open data licensing, and nearcontinuous observation are crucial to the value proposition from these capabilities. Whilst there are many new EOS capabilities in space, and others are under development, they must be assessed against these factors to determine their potential value to Australia.

The availability and suitability of data from commercial sources is increasing and Geoscience Australia, together with Defence, has established a specialised supply panel to allow efficient and more coordinated

2 Please note that some potential sensors may not provide EOS data to an acceptable standard for operational use.

access to commercial data. It should be noted, however, that whilst datasets may be provided on a commercial model, all existing EOS systems are underwritten, either directly or through large assured contracts, by governments.

Table ES-2 presents a summary of risk ratings for each data type. These risk ratings consider the likelihood of data gaps before 2015, the availability of alternative data sources, and the current and projected data usage levels.

Table ES-2 Summary of Risk Ratings

	Sensor Type				
	Optical			SAR	Passive Microwave
	Low spatial resolution (> 80 m)	*Medium spatial resolution (10-80 m)*	*High spatial resolution (< 10 m)*		
Risk Rating[3]	Low	Very High	Medium	High	Low

The widespread usage of medium resolution optical data makes the potential shortage of this data type most alarming. To avoid likely data gaps, which could severely impact legislative monitoring programs, urgent commitment is required to secure Australian access to future sensors, especially the Landsat Data Continuity Mission (LDCM) and the Sentinel missions.

The potential of space-based SAR data also demands immediate attention to ensure its ongoing availability in Australia. While this data type is not yet used as widely as optical data, the inherent advantages of frequent coverage and independence from weather and daylight are expected to increase its usage in the future. These advantages will be particularly valuable for essential services such as disaster mitigation, search and rescue, and border protection.

While an imminent shortage of low resolution optical data for Australia is not anticipated, only a modest infrastructure upgrade would be required to ensure access to the expanded range of such sensors planned before 2020. Future access to space-based passive microwave and high resolution optical sensors should also be investigated.

PRIORITIES FOR ACTION

The collective opinion of GA, CSIRO, BOM and DIGO has established that the EOS supply chain can be characterised by five space investment areas (Australian Government, 2011):

- Coordination and cooperation;
- Securing future Earth observations;
- Investment in ground infrastructure and communications;
- Extracting value; and
- Sustained capability to deliver.

These investment areas underpin the ongoing accessibility, delivery, and effectiveness of EOS data in Australia.

3 Ratings are based on the relative severity of the projected data access situation, with respect to its impact on the 91 sample programs within state and federal agencies, and the complexity of gaining access to new data of this type.

CONCLUSION

A continuous supply of EOS data is required to adequately service both current and future EOS programs in Australia. This supply can only be ensured through appropriate strategic planning, with consideration to the five space investment areas, and formal commitments to secure data access. Given the lead time necessary to ratify acquisition agreements and establish infrastructure, these issues need to be addressed without delay to avoid the projected disruptions to Australian EOS data access.

As a matter of priority Australia needs to formalise agreements with several upcoming EOS missions, and formulate a decadal infrastructure plan to safeguard the supply of EOS data.

Section 1
Introduction

1.1 EARTH OBSERVATIONS FROM SPACE (EOS)

Earth Observations from Space (EOS) describes a range of approaches that observe and measure Earth surface properties from space-based platforms. EOS offers a unique source of Earth surface data by recording:

- Accurate geo-locations for contiguous target areas;
- Objective, consistent measurements of physical properties of the land surface that can be interpreted to define its features and condition; and
- Repeated coverage to enable detection of changes in features and/or their condition.

EOS analyses increasingly combine different types of measurements, such as radar and optical imagery, to more accurately discriminate Earth surface features and changes. The expanding archive of EOS imagery now enables time series analyses, which are being used to further quantify landscape dynamics, highlight the environmental drivers in natural processes, monitor compliance with resource usage regulations, and address issues related to climate change.

For the purposes of this report five simplified EOS data types are defined (as detailed in **Section 2**)—low resolution optical, medium resolution optical, high resolution optical, synthetic aperture radar (SAR), and passive microwave.

1.2 EOS IN AUSTRALIA

1.2.1 USAGE

EOS data are used widely and to great advantage in Australia by numerous federal and state government agencies and research institutions, as well as the private sector. The benefits of EOS data are particularly valuable in a large, sparsely populated country that needs to monitor a long coastline and a broad range of natural disasters.

Australia has established EOS expertise in a diverse range of applications, including:

- Weather forecasting;
- Climate change and atmospheric studies;
- Natural disaster mitigation;
- Cartography, positioning and navigation;
- Mineral and resources exploration;
- Infrastructure planning and reporting;
- Natural resource management;
- Water availability and usage monitoring;
- Ocean surveillance and monitoring; and
- Bathymetry and water quality in coastal areas.

In particular, EOS is fundamental to Australia's climate science, with over half of the 50 internationally recognised Essential Climate Variables (ECVs) being dependent on EOS data (CEOS, 2010; see **Appendix G** for a full list of ECVs). Furthermore, Australia has achieved international prominence and influence in climate change negotiations through its use of EOS for measuring, reporting and verifying carbon stores in living forests (see **Section 1.3.2** for more details). Additionally, Australia's involvement in international agreements necessitates the use of EOS data for recording, monitoring and reporting on environmental change (ATSE, 2009).

The Australian Academy of Technological Sciences and Engineering (2009) outlined the collective vision and aspirations of the space science community in Australia as:

Earth Observations from Space (EOS) are the single most important and richest source of environmental information for Australia. … EOS provides a level of information coverage otherwise unattainable on the state of the atmosphere, ocean, coasts, rivers, soil, crops, forests, ecosystems, natural resources, ice, snow and built infrastructure and their change over time.

They enable a wide range of essential services to be given to the community, with multi-billion dollar annual benefits to the nation as a whole. … The coverage, density and volume of information cannot be matched by any other observational system. ... Australia cannot do without EOS data if we want to sustain and improve our current economic status and standard of living.

1.2.2 ECONOMIC VALUE

The direct contribution of EOS to Australia's Gross Domestic Product (GDP) has been estimated at $1.4 billion in 2008-09 (ACIL Tasman, 2010). This estimate considered the combined value of imagery, technology and skilled labour within the 92 federal and state government programs reported by Geoscience Australia (2010) to be using EOS data. Given the growing dependency on EOS for information on Climate Change, Environmental Reporting and Compliance, and Natural Resource Management, this figure is expected to exceed $4 billion by 2015. Tangible outcomes from the use of EOS in these areas are reduced environmental degradation (for example, reduced salinity and increased sustainability of fishing stock), increased biodiversity, and improved usage of resources, such as water.

Additionally, the related productivity benefits to the Australian economy, that is the impacts of EOS information on productivity in other market sectors[4], were estimated at $1.9 billion in 2008-09, and projected to be worth $2.5 billion by 2015 (ACIL Tasman, 2010).

Further benefits of EOS, totalling $1 billion, were estimated by ACIL Tasman (2010) for providing enhanced information relating to:

- Climate Change—$200 million;
- Natural Resource Management—$500 million; and
- Emergency Management—$200 million.

These estimates do not include government EOS usage in Defence, national security, police, or local government applications, and thus should be considered to be conservative. Private sector usage is also excluded from these estimates.

By contrast, the current government expenditure on remote sensing in Australia approximates $100 million per annum (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.

4 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).

1.3 APPLICATIONS AND BENEFITS OF EOS

1.3.1 NATIONAL CHALLENGES REQUIRING EOS

EOS is currently being used operationally for a wide range of applications in Australia, including modelling climate, forecasting weather, monitoring water usage 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, and navigation.

The Australian Academy of Technological Sciences and Engineering (2010) 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.

1.3.1.1 Climate Change

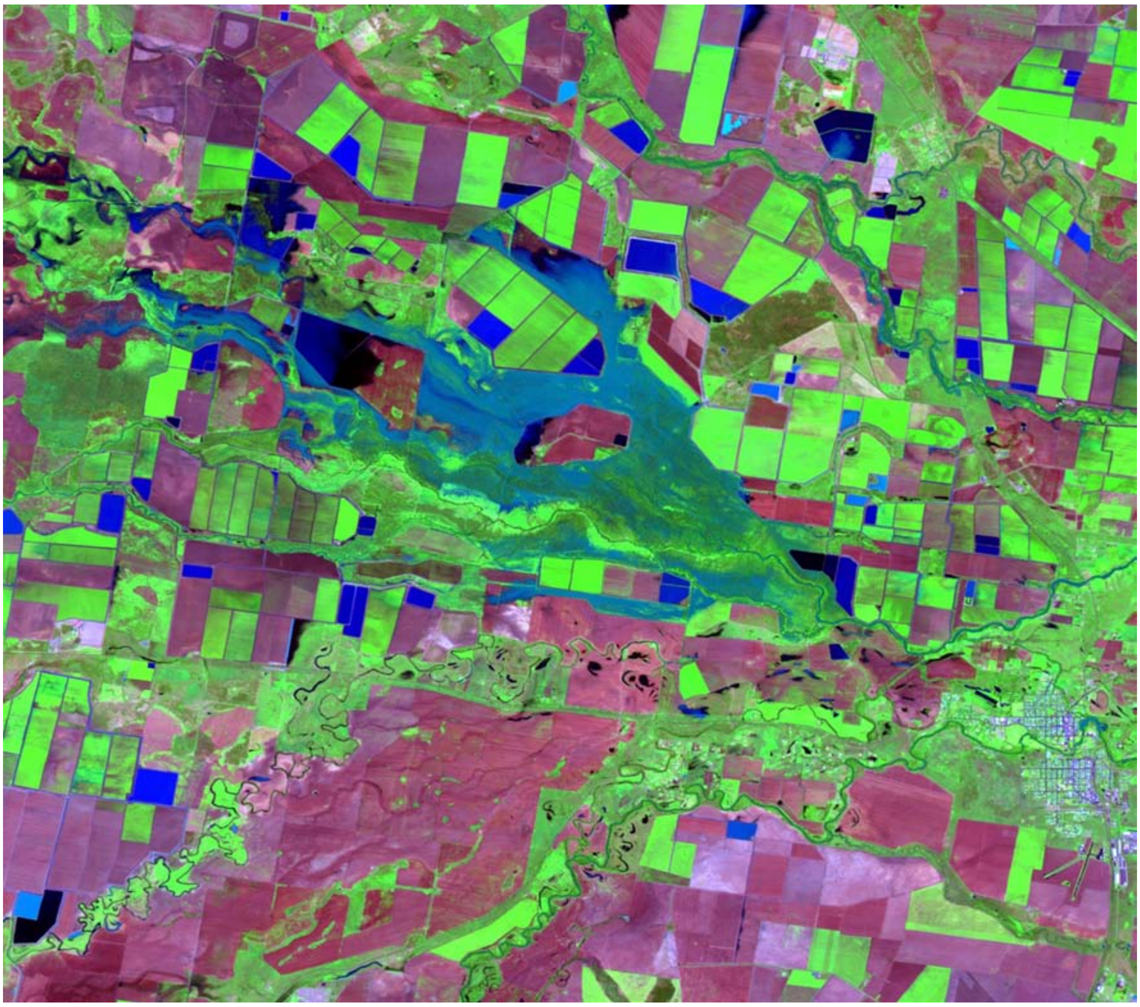
Monitoring the variability and impact of both global and regional climate change relies heavily on EOS-derived information about carbon sinks, sources and storage, trends in temperature, rainfall and other climate variables, and changes in ocean circulation, sea level and the Antarctic ice sheet. This information is being used by federal, state and local governments, academic and research organisations, and private companies.

Research in this area includes integrating EOS data with dynamic models of atmospheric, oceanic and terrestrial processes. The goals of this work include long term forecasts (months ahead) for ocean and seasonal weather as well as very long term forecasts (50 years ahead) for climate change scenarios.

1.3.1.2 Water Availability

EOS data are being used to map and monitor wetlands, water courses and water storage in terms of water level, water quality and the extent of water bodies (See image 1.1). An increasing number of government and private agencies are using this data source to determine current and future water availability in Australia.

Image 1.1 Landsat-5 Thematic Mapper satellite image (acquired September 2004) of the Gwydir Raft wetland and surrounding agricultural landscape near Moree, NSW.



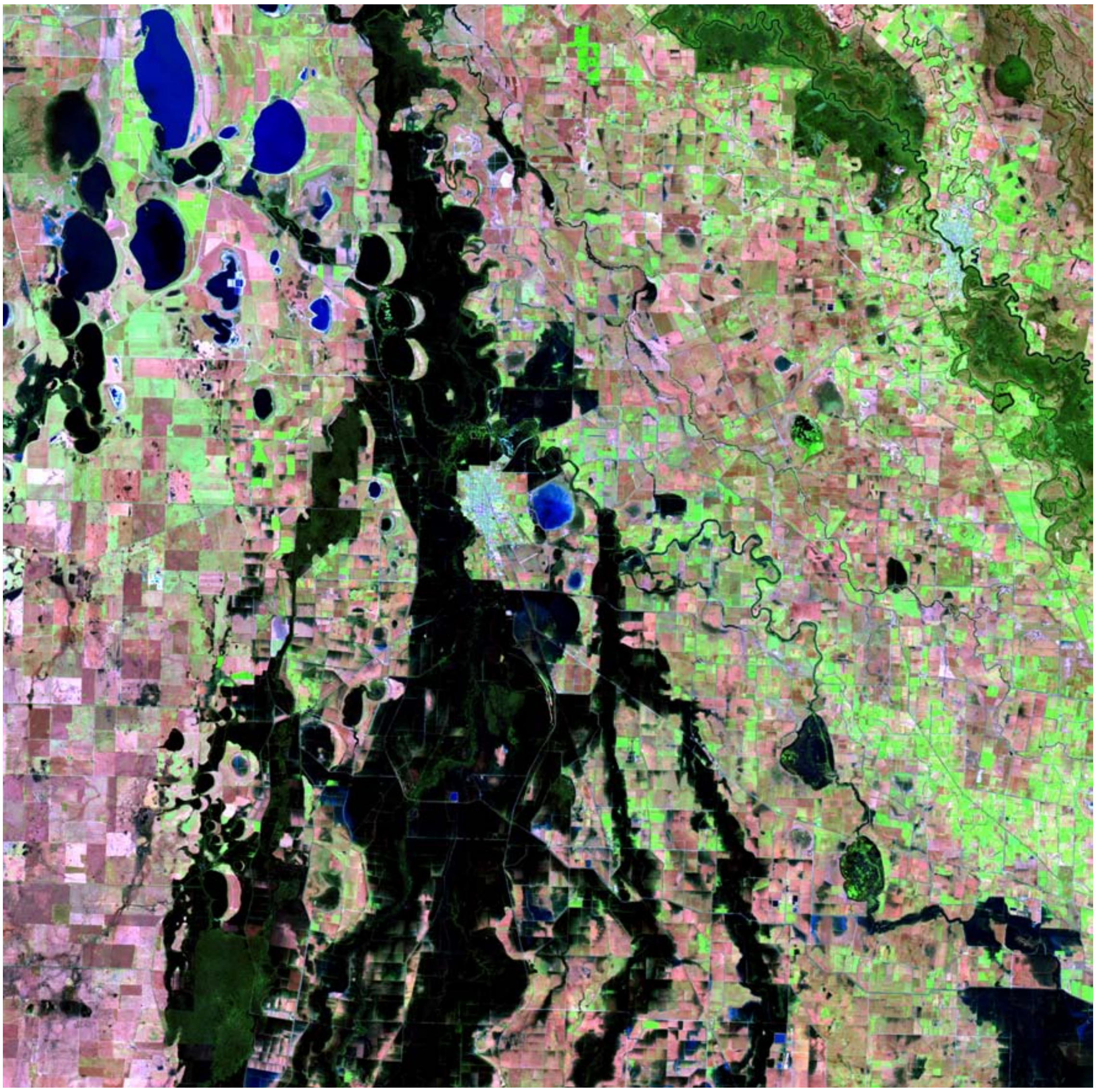
This false colour image (short-wave infra-red, near infra-red and green bands displayed as red, green and blue) shows vegetation in shades of green, soil in shades of pink and water in shades of blue to black. This image formed part of a time series study to monitor irrigation water storage and correlate water usage with crop productivity.

Management of water availability involves using a range of EOS sensors to provide data on rainfall, surface soil moisture, surface temperature, snow cover, and evapotranspiration. Hydrologic models also use EOS-derived products including those related to vegetation type, vegetation greenness, solar radiation, surface albedo and fire scarring. Research currently focuses on using EOS data to improve catchment scale hydrologic models for more efficient use of water, more reliable estimates of water availability and use for irrigation, and improved flood control and forecasts. Developments in this area include the use of gravity observations from satellites to estimate changes in groundwater storage, the use of remote sensing to study the interactions between groundwater and surface water (such as groundwater recharge during floods) and the operational use of remote sensing to measure the water used by irrigated crops.

1.3.1.3 Natural Disaster Mitigation

Federal, state and local governments use EOS data in all phases of emergency management, namely planning, preparedness, response and recovery, for bushfires, cyclones, severe thunderstorms, floods, tsunamis, droughts, earthquakes and their aftereffects (See image 1.2). Developments in this application area involve improved timeliness of imagery and integration of EOS data with other geospatial data sets.

Image 1.2 Landsat-5 Thematic Mapper satellite image (acquired January 2011) showing the extent of flooding around Kerang, Victoria.



This false colour image (short-wave infra-red, near infra-red and green bands displayed as red, green and blue) shows vegetation as shades of green, soil as shades of pink and water as shades of blue to black. This composite image maximises the contrast between water and land, and was used to determine flood extent for emergency services. It has also be used for studies of water quality.

1.3.1.4 Safe and Secure Transport

The daily operations of road, rail, air and sea transport have become reliant on EOS data through the Global Navigation Satellite Systems (GNSS) and satellite-based weather information. Extreme weather warnings are invaluable for planning road and rail transport and search and rescue operations. Air transport also benefits from satellite-based hazard warning systems such as the Volcanic Ash Advisory Service while sea transport benefits from EOS-derived information on sea ice.

1.3.1.5 Energy and Resources Security

Environmental information derived from EOS data is used by energy and resources companies to identify geothermal and marine petroleum sources of energy, mineral deposits, potential locations for wind and solar energy generators, and also to estimate production levels in solar power plants. The potential impact of tropical cyclones, tsunamis and storm surges on offshore oil and gas facilities is also being reduced using EOS data.

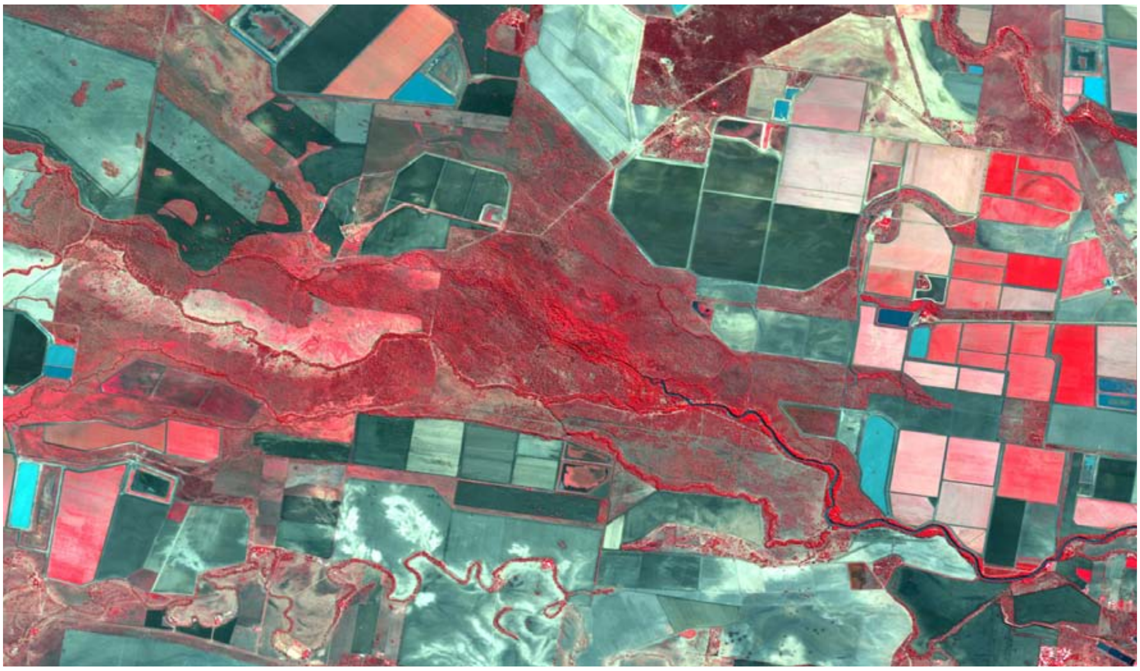
EOS data enable government regulatory agencies to observe the impact of industry operations on the environment. Research into the underlying structure and dynamics of our planet also rely heavily on EOS data sources.

1.3.1.6 Agriculture, Forestry and Ecosystems

Federal and state governments, as well as private companies, are increasingly dependent on EOS data to monitor agriculture, forestry and the natural environment for food and fibre products, legislative regulations and international agreements.

Agricultural uses of EOS data in Australia include prediction of crop and pasture production, early detection of crop stress, monitoring of irrigation usage, and modelling crop productivity in relation to soil type and/or management practices (See image 1.3). EOS data are also being used to evaluate drought conditions, monitor locust plagues, and control the spread of animal health epidemics such as foot and mouth disease.

Image 1.3 ALOS AVNIR2 satellite image (acquired May 2007) of the Gwydir Raft wetland and surrounding agricultural landscape near Moree, NSW.



In this standard false colour composite, shades of red indicate vegetation, green areas show bare soil and cyan areas are water-covered. This composite maximises the contrast between irrigated cotton crops and native vegetation and was used to map land cover.

Forestry derives benefits from EOS-based information for increasingly sophisticated estimates of biomass, detection of tree stress conditions, and assessment of catchment condition and wildlife habitat, especially after bushfires.

Environmental management in Australia relies heavily on EOS data to map and monitor land cover, land use, ecosystems, and land degradation. National inventories, such as the National Carbon Accounting System (NCAS), and the National Forest Inventory (NFI) depend on EOS data to derive estimates of vegetation cover, condition and change.

1.3.1.7 Coasts and Oceans

EOS data are used routinely to map and monitor Australia's extensive coastal waters and oceans as well as Antarctica. Observations of sea surface temperature, sea height, chlorophyll concentration, and icebergs assist the fishing and shipping industries. The quality of coastal waters is inferred from estimates of phytoplankton concentration, turbidity, temperature and water colour (See image 1.4). The location and health of coral reefs are now regularly monitored using EOS data, and sea surface temperatures are constantly monitored from satellites as an indicator of coral bleaching events. Marine pollution, including oil spills, is also monitored by EOS.

Image 1.4 Landsat-5 Thematic Mapper satellite image (acquired January 2011) showing flood waters from the Brisbane River discharging into Moreton Bay, Queensland.

This true colour image highlights the water quality problems associated with flood water discharge (flood waters appearing as shades of brown). This image was used to determine the extent of flood plumes for emergency services during these recent floods.

1.3.1.8 National Security

Both classified and unclassified EOS information underpin national security activities within the Australian Defence Force (ADF), the Defence Imagery and Geospatial Organisation (DIGO), the Defence Science and Technology Organisation (DSTO), the Border Protection Command (BPC), and the Directorate of Oceanography and Meteorology (DOM). EOS-based surveillance supports situational awareness, and exposes illegal fishing, and unauthorised maritime activities.

1.3.2 INTERNATIONAL AGREEMENTS

As well as numerous domestic applications of EOS, Australia has formal obligations to contribute to international agreements that have been designed to monitor global environmental resources.

The National Carbon Accounting System (NCAS) was established by the Federal Government in 1998 to provide a complete accounting and forecasting system for human-induced sources and sinks of greenhouse gas emissions from Australian land-based activities (http://www.climatechange.gov.au/government/initiatives/national-carbon-accounting.aspx). The system is using thousands of satellite images to monitor land use changes across Australia since 1972, as well as relevant ancillary information relating to climate, soils and vegetation.

Australia is now a recognised world leader in carbon accounting and shares this expertise with the global community through agreements such as the International Forest Carbon Initiative (IFCI), a Reducing Emissions from Deforestation and Forest Degradation (REDD) demonstration activity. Australia is also prominent in the efforts by the Group on Earth Observation (GEO) to develop a Global Forest Observation Initiative (GFOI).

1.3.3 THE GLOBAL EARTH OBSERVATION SYSTEM OF SYSTEMS (GEOSS)

The Group on Earth Observations (GEO) is an international body established in 2002 to encourage its member governments to coordinate projects, strategies and investments for Earth Observation. Since 2005, GEO has been implementing the Global Earth Observation System of Systems (GEOSS) ten year plan to advance and demonstrate the societal benefits of Earth Observation in nine Societal Benefit Areas (SBA):

- **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, and carbon and biomass estimation;
- **Biodiversity**—assess condition and extent of ecosystems, distribution and status of species, and genetic diversity in key populations, as well as tracking invasive species;
- **Climate**—model, mitigate, adapt and assess risks of climate change for atmosphere, lands and oceans;
- **Disasters**—predict and monitor earthquakes, floods, landslides, cyclones, volcanic eruptions, and wildfires;
- **Ecosystems**—monitor and evaluate ecosystem health, function and change in coastal and near-shore marine systems, forests, inland water, oceanic islands and archipelagos, tundra, and watersheds;
- **Energy**—assess viability of renewable energy sources, including hydropower, wind power, bioenergy, solar power, geothermal power;
- **Health**—monitor aeroallergens, air quality, and infectious diseases, and provide early warning for public health risks such as heat waves and epidemic pre-conditions;
- **Water**—monitor terrestrial hydrology of surface waters, ground waters, forcings, water quality, and water usage; and
- **Weather**—improve weather information, forecasting and warning using numerical weather prediction (global and regional), synoptic, aeronautical and agricultural meteorology, and atmospheric chemistry.

GEO (2010) identified critical Earth observation priorities that are common to many of the GEO Societal Benefit Areas (SBA). This analysis focused on the observation needs of Earth Observation (EO) users internationally, and included ground, airborne, in-situ and space-based observations that are currently being used, or desired, by resource managers, scientific researchers and policy makers[5].

5 In this context, 'Earth observation' referred to "parameters and variables (eg. physical, geophysical, chemical, and biological) sensed or measured, derived parameters and products, and related parameters from model outputs that describe the Earth's land, oceans, and atmosphere as well as factors related to human dimensions" (GEO, 2010).

The Earth observations that ranked as critical to all Societal Benefit Areas were three Essential Climate Variables (ECVs): *precipitation, soil moisture* and *surface air temperature*. Those observations that were considered critical to over half of the Societal Benefit Areas were: *surface wind speed, land cover, surface humidity, vegetation cover, surface wind direction, normalised difference vegetation index, sea surface temperature, urbanisation, vegetation type, land surface temperature, surface atmospheric pressure, leaf area index, upper level humidity, elevation* and *snow cover extent*. This list also includes many Essential Climate Variables (ECV; see **Appendix G**). The inference drawn from these results in the GEOSS plan is that actual, derived or modelled estimates of these 'critical' parameters from EOS data would have the greatest benefit to the international EOS user community, and thus warrant greater emphasis in strategic planning and design of EOS data sensors.

1.4 EOS DATA

EOS imagery from satellites has been available for over five decades, starting with the first meteorological satellite, TIROS-1, in 1960. Both the quality and quantity of imagery has greatly increased during this period, with an estimated 70 operational EOS satellites currently providing public good (that is non-commercial) imagery and several hundred more planned to become operational before 2025 (ATSE, 2009). The extent of operational use of EOS data internationally has enabled an increasing number of commercial companies to manage satellite platforms, with several dozen commercial satellites now supplying EOS data.

To ensure access to EOS data, several smaller countries are becoming involved in satellite constellations, that is, groups of satellites with similar sensors that collectively provide daily global coverage. In some arrangements, such as the Disaster Monitoring Constellation (DMC) operated by Algeria, China, Nigeria, UK and Spain, each satellite is owned and controlled by a separate nation and the owners agree to freely provide a small percentage of each day's imagery for disaster monitoring.

Each source of EOS data is released with specific licensing arrangements that define how the data can be shared. A 'Creative Commons Acquisition Licence' permits unrestricted sharing of raw EOS data and derived products. This is also known as an open data policy and applies to many, but not all, forms of EOS data. By limiting the number of users who can access purchased and processed data, licence restrictions effectively increase the costs of those data sets to government projects.

1.4.1 AVAILABILITY AND ACCESS IN AUSTRALIA

Australia does not currently have its own Earth Observation (EO) satellite. Its access to EOS data sets is enabled via cooperative agreements with foreign jurisdictions and corporations and the establishment of appropriate local infrastructure. At present, over 70 federal and state organisations regularly acquire and/or utilise EOS data from satellites controlled by China, France, Germany, India, Italy, Japan, Korea, Nigeria, UK, USA or the European Commission (Geoscience Australia, 2010).

Australia's lack of forward plans for access to satellite data for terrestrial and coastal applications, and many ocean applications, leaves its remote sensing industry in a vulnerable position (Lewis and Reddy, 2006). As an increasing number of land, water and disaster management solutions become dependent on EOS data, the risks associated with this position, that is, a passive reliance on foreign data sources, also increase. These risks include cessation of satellite service or access rights, interruptions to data supply due to management priorities, incomplete spatial coverage for Australian areas of interest, and inferior system design or operation to meet Australian needs.

Australia's remote sensing sector has traditionally relied heavily on the routine acquisition of low-cost, public good satellite imagery. A critical dependence has developed on EOS data from the USA, the European Union, Japan and Canada for a range of operational applications. Due to its greater costs and more restrictive licensing conditions, commercial imagery has been utilised to a much lesser extent, although this usage in Australia is increasing.

Many public good satellite sensors currently being used in Australia are already operating beyond their life expectancy, with Australia's most widely used satellite, Landsat 5, being 24 years beyond its design life of three years. In spite of this, there are currently no formal arrangements in place for Australia to receive data from the numerous sensors, both public good and commercial, that will be carried on missions planned during the next decade.

The National Earth Observation (NEO) group (formerly the Australian Centre for Remote Sensing, ACRES) within Geoscience Australia (GA) has been collecting imagery from the Landsat series of satellites since 1979. The popularity and low-cost of this imagery has led to a significant reliance on the current Landsat 5 and Landsat 7 satellites by local, state and national agencies (Phinn *et al.*, 2008). Both Landsat 5 (launched 1984) and Landsat 7 (launched 1999), however, have far exceeded their life expectancies. While the Landsat Data Continuity Mission (LDCM) is planned to replace these satellites, it will not be launched until December 2012 (and a further six months of on-board testing is scheduled before its imagery will be routinely available). Further, the failure of the scan-line corrector in Landsat 7 in 2003 has limited the utility of data available from that satellite. The capacity of Landsat 5 has also been limited by its age and, since it has no reserve system, failure of that sensor would create an immediate gap in Landsat imagery. Imagery from this satellite is already severely limited during winter months due to problems with its solar panel and battery.

Another important consideration is that access to new data sets, such as those that were available from the Advanced Land Observing Satellite (ALOS), are typically governed by short-term Memoranda of Understanding (MOU). GA's MOU with Japan for initial ALOS acquisition, for example, ended in January 2011 and commercial rates now apply to usage of any data acquired from that mission.

1.4.2 MANAGEMENT OF EOS DATA IN AUSTRALIA

The acquisition, dissemination and archiving of EOS data within Australia are shared between several organisations. Australian satellite receiving stations are primarily operated by GA, CSIRO and the Bureau of Meteorology (BOM). These agencies provide both raw and processed EOS data, acquired from foreign satellites, to a range of public and private users in Australasia. Other agencies that regularly acquire satellite data include the Australian Institute of Marine Science (AIMS), the Defence Imagery and Geospatial Organisation (DIGO), the Western Australian Satellite Technology and Applications Centre (WASTAC)[6], and the Tasmanian Earth Resources Satellite Station (TERSS)[7]. Some EOS data are also freely available via the internet.

There is currently no wholistic, national strategy on EOS to ensure that Australia's data needs will be satisfied into the future, through access to available data sources and/or adequate archiving of current imagery for potential future use, nor is there any strategy to coordinate Australian involvement in international EOS-related activities.

1.4.3 CURRENT GOVERNMENT EOS PROGRAMS IN AUSTRALIA

Geoscience Australia (2010) identified 92 EOS-dependent programs that are currently operated by government agencies in Australia (see **Appendix E** for details). These programs were selected for their national significance, but only represent a subset of current EOS applications in Australia. A sample set of 91 of these 92 programs is analysed to determine the projected requirements of EOS data for Australia (see **Section 3** below)[8].

6 Current members of WASTAC are: Curtin University of Technology, Murdoch University, WA Land Information Authority, BoM, GA and CSIRO.

7 Current members of TERSS are: University of Tasmania, Australian Antarctic Division, CSIRO, GA, BoM, and CSST.

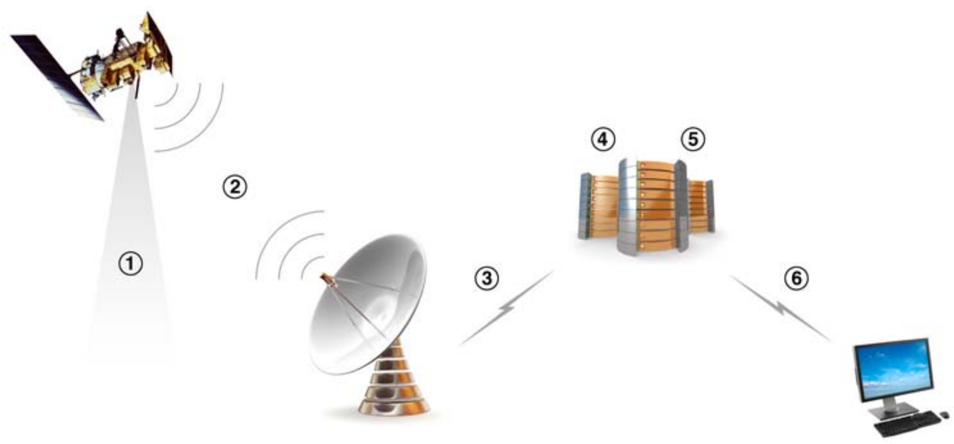
8 Program 26 is not included in this sample due to insufficient EOS data usage.

1.4.4 RECEPTION AND DISTRIBUTION

Acquisition of EOS data generally involves several steps that are dependent on appropriate infrastructure. As illustrated in **Figure 1-1**, the generic process includes the following sequence:

- Satellite-borne sensor scans Earth's surface;
- Scanned measurements are transmitted to a satellite dish at a receiving station as telemetry data;
- Telemetry data are transmitted by high speed communications link to a processing facility;
- Telemetry data are decoded and calibrated to create a raw data image
- The raw data image is further processed to create an image product; and
- The image product is transmitted to the user by a communication link or digital media.

Figure 1-1 EOS Data Acquisition Process[9]



1. Satellite measurements; 2 Telemetry transmitted to Earth; 3.Telemetry transmitted to processing facility; 4. Telemetry processed into raw data image; 5. Raw data image processed to image product; 6. Image product transmitted to user.

There are several critical infrastructure components in this sequence, all of which need to be fully operational to ensure timely product delivery to EOS users:

- Receiving station needs appropriate technology to continuously acquire the transmitted format, volume and frequency of telemetry data;
- High speed communications link must have adequate capacity to continuously transmit the necessary volume of acquired data without delay;
- Processing facility needs ample storage capacity to record and archive telemetry data, raw data imagery and image products;
- Processing facility needs to have agreed processing capacity to accommodate expected volume of raw data imagery and process image products without delay; and
- Communication link with users requires sufficient capacity to distribute required volume of data in a timely manner.

Each component in this sequence must operate continuously, or services based on EOS data are compromised. Additionally, an archive of raw and processed imagery must be maintained to supply future data requirements. Efficient access to this archive also requires ongoing management of data storage facilities and distribution networks.

The total archive of raw data imagery, from 1979 to 2010, that is being maintained by GA comprises approximately 500 TB. Nearly half of this archive was acquired from the Landsat series of satellites.

9 Copyright credits: Computer workstation—Dmitry Rukhlenko/shutterstock.com; 3D Servers—Konstantinos Kokkinis/shutterstock.com; Satellite dish 3d—Maxx-Studio/shutterstock.com

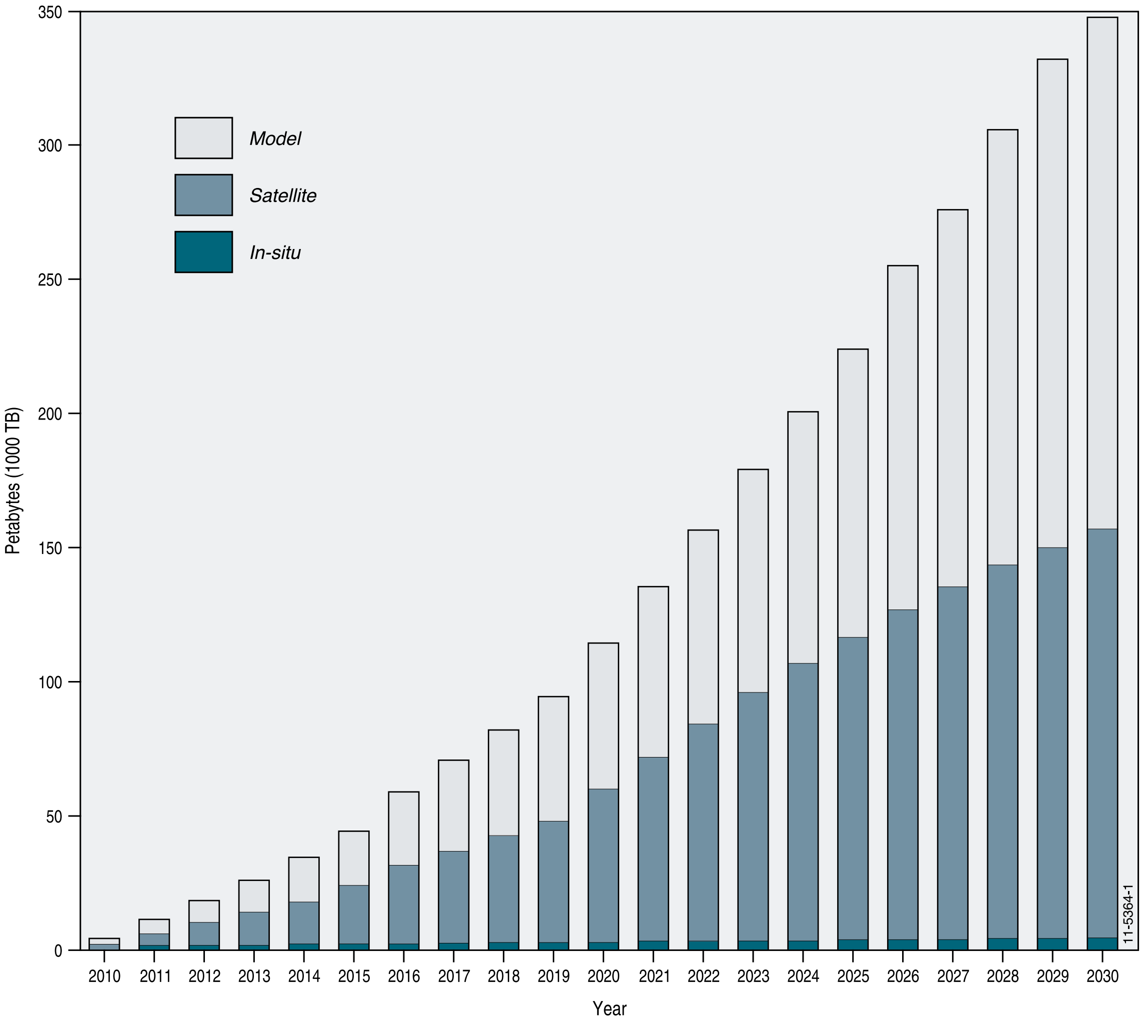
Raw EOS data are typically processed several times to correct for radiometric and geometric distortions. Before distribution to users, most satellite imagery acquired by GA, for example, has been processed three to five times, with each processing stage requiring access to additional data storage. A conservative estimate of the storage required to process raw EOS data is three times the raw data volume.

Between July 2009 and June 2010, approximately 19 TB of raw EOS data were acquired by GA from 11 sensors carried by eight satellites. The current annual data volume acquired from all EOS sources in Australia is estimated at 20 TB. This volume of data would require 60 TB of storage to allow conversion of the raw data into standard image products.

The volume of available EOS data is expected to increase dramatically in future decades. As illustrated in **Figure 1-2**, for climate models alone, Overpeck et al. (2011) estimate more than a fiftyfold increase in the volume of EOS data over the next decade, with a 150 times increase expected by 2030. Ongoing strategic planning is essential to ensure that the necessary infrastructure is in place to support the anticipated future volume of EOS data.

Australia has the lowest population density in the developed world, yet is responsible for a disproportionately large area of land and water in the Southern Hemisphere. Effective management of the Australian land mass, offshore jurisdictional limits and Antarctic region will increasingly rely on EOS data sources. The extent of Australia's resource management responsibilities, relative to its population density, makes access to EOS data more critical for Australia than for most other developed countries.

Figure 1-2 Expected Volume of Climate Data



Adapted from: Overpeck *et al.* (2011)

1.5 ALTERNATIVE DATA SOURCES

Earth observation (EO) data can also be acquired from non space-borne platforms such as aircraft, balloons, flux towers, hand-held instruments and ground sensors. These data sources provide essential calibration and validation information for space-borne sensor data and also offer valuable information in their own right.

Unlike the formal arrangements required for use of EOS data, access to these alternative data sources is largely governed by opportunity and cost. As such, they are not within the scope of the present report, but have been included here for completeness.

1.5.1 AIRBORNE SENSORS

Various forms of EOS sensors have been carried on airborne platforms for over a century and are now widely used to acquire detailed imagery of Earth surface features. Airborne platforms are also used to simulate and validate satellite-borne sensors.

The acquisition of EOS data from airborne sensors has the advantage of flexibility in timing, instrumentation and coverage. This flexibility ensures that the acquired data coincide with favourable atmospheric conditions and optimal target discrimination over the region of interest. This is particularly advantageous for natural disasters, such as bushfires or floods, where timely information is required to both direct the response effort and record the severity of the event. Timely information is also valuable for monitoring agricultural production and national security. Airborne EOS data are generally more expensive than data acquired from satellite borne sensors, and provide a reduced area of coverage. Licensing arrangements for most airborne EOS data, however, are generally more relaxed and favourable to 'creative commons' licensing than those that apply to some sources of space-borne imagery.

In some circumstances airborne sensors can replace the service provided by EOS capabilities, for example in high-resolution images of major cities. However there are also substantial disadvantages to airborne sensors including mobilisation costs, inconsistent timing of observations, limited coverage, difficulties obtaining repeat observations, and calibration of observations. As the industry matures, these problems will be reduced but not altogether removed.

1.5.2 *IN-SITU* SENSORS AND CALIBRATION DATASETS

The calibration and validation (CalVal) of EOS data, and validation of information derived from the data, are increasingly reliant on data from *in-situ* sensors installed at strategically located field sites. In Australia these sites are often designed to satisfy international scientific standards. Field sites enable collaboration with international EOS researchers and are an important mechanism for interaction with satellite operators. Calibration sites at stable target locations ensure that the accuracy of airborne and EOS data is known for specific conditions.

Instrumentation at CalVal sites record measurements continuously, or at regular intervals, for relevant physical parameters of the Earth surface and the atmosphere. *In-situ* sensors are being used to record a wide range of measurements related to vegetation and carbon dynamics, soil moisture, gravity fields, topography, bathymetry, ocean colour, water quality, sea ice, and meteorology. An international network of over 500 flux towers has been established to provide continuous, long-term micrometeorological measurements for global ecosystem monitoring, with a focus on understanding energy, carbon and water exchange between the atmosphere and key ecosystems.

Calibration data are also necessary to accurately locate observations on the ground. These data take many forms including reflective targets, satellite laser ranging (to improve knowledge of the location of the satellite), reference images and digital elevation models. Other forms of ground-based data are collected to calibrate, validate and supplement space-borne and airborne data, including datasets of atmospheric properties, hand-held sensors, vehicle-mounted sensors, and temporary ground-based sensors. Improved satellite and instrument design can reduce reliance on ancillary data.

1.6 EOS SENSORS

The range of EOS sensors is technically diverse, having been designed to collect different types of data at differing scales.

1.6.1 DATA RESOLUTION AND EXTENT

Resolution refers to the intensity or rate of sampling, while extent refers to the overall coverage of a data set. Extent can be seen as relating to the largest feature, or range of features, which can be observed, while resolution relates to the smallest.

For a feature to be distinguishable in the data, the resolution and extent of the measurement need to be appropriate for the measurable properties of the feature. For a feature to be separable from other features, these measurements must also be able to discriminate between the differences in reflectance from those features.

Resolution and extent can be seen to operate in four 'dimensions' of EOS data acquisition:

- **Spectral**—resolution relates to the width of wavelength channels, while extent describes the number and spectral range of channels in the image;
- **Spatial**—resolution relates to the pixel size, while extent relates to the overall image coverage;
- **Radiometric**—resolution relates to the energy difference which determines different radiance (or brightness) levels in an image, while extent relates to the number of levels detected; and
- **Temporal**—resolution relates to the repeat cycle or interval between successive acquisitions, while extent relates to the total period over which imagery is available.

1.6.2 SENSOR TYPES

Various types of EOS sensors are available for use on satellite and aerial platforms. Passive sensors measure solar radiation that has been reflected or emitted by Earth's surface or atmosphere. Active sensors, such as radar and lidar, transmit an energy pulse and record the returned energy.

International EOS capabilities and plans, of both satellite missions and sensors, are documented comprehensively by the Committee on Earth Observation Satellites (CEOS) in *The Earth Observation Handbook* (CEOS, 2010), commonly known as 'The CEOS Handbook'. Details of most sensors and satellites cited in the present report have been derived from its 2010 web update[10].

The CEOS Handbook identifies 14 instrument or sensor categories, only seven of which are relevant to terrestrial, coastal and ocean applications (see **Appendix D** for the full list of instrument categories used by CEOS):

- **High resolution optical sensors**—passive panchromatic and multispectral sensors that record visible and infrared wavelengths from the Earth's surface with pixel sizes less than 100 m. CEOS (2010) lists 44 current and planned high resolution optical sensors;
- **Imaging multispectral radiometers** (visible/infrared)—passive multispectral radiometers that record visible and infrared wavelengths from the Earth's surface and atmosphere with pixel sizes greater than 100 m. CEOS (2010) lists 70 current and planned imaging multispectral visible and infrared radiometers;
- **Imaging multispectral radiometers** (passive microwave)—passive sensors that measure microwave emittance (1-40 GHz and 80-100 GHz) from the Earth's surface at low spatial resolutions. CEOS (2010) lists 28 current and planned passive microwave radiometers;
- **Imaging microwave radars**—active sensors that measure backscattered signals from transmissions in the range 1-10 GHz with spatial resolution less than 100 m. CEOS (2010) lists 21 current and planned imaging microwave radars;
- **Lidars**—active sensors that measure radiation from the Earth's surface or atmosphere when illuminated by a laser source. CEOS (2010) lists five current and planned lidars;
- **Radar altimeters**—active sensors that use radar to measure the topographic profile of the Earth's surface (land and ocean). CEOS (2010) lists 11 current and planned radar altimeters; and
- **Ocean colour instruments**—passive radiometers and imaging spectrometers designed to measure radiance from marine waters in visible and near infrared wavelengths (400-800 nm), typically with high spectral resolution and low spatial resolution. CEOS (2010) lists nine current and planned ocean colour sensors.

10 http://www.eohandbook.com/eohb2010//PDFs/EOHB%202010%20key%20tables.pdf
Note that instruments classified as 'TBA', 'Proposed', 'Prototype' or 'No longer operational' have not been considered in the present report. Further, multiple radar modes of any relevant sensors have not been considered as separate sensors.

For the purposes of this report five simplified EOS data types, based on both spectral and spatial characteristics of sensors, are used:

- Low resolution optical;
- Medium resolution optical;
- High resolution optical;
- Synthetic aperture radar (SAR); and
- Passive microwave.

These data types are defined in **Section 2** of this report.

1.6.3 SENSOR SELECTION AND DATA QUALITY

EOS sensors for terrestrial, coastal and ocean monitoring primarily measure electromagnetic radiation from the Earth's surface and vary in terms of resolution and extent. Different sensors are receptive to different regions of the electromagnetic spectrum, with individual sensors typically measuring multiple discrete regions. The sensitivity of a sensor to radiation is designed to optimise the detection of specific target features, and as a result is a characteristic that varies between sensors. Sensors also vary in their spatial resolution (or pixel size) and temporal resolution (or repeat cycle for subsequent measurements).

The most suitable sensor will vary for different applications, in different situations. Some EOS data, such as measurements of visible and infrared wavelengths, are affected by atmospheric conditions, including clouds, rain and dust, while others, such as measurements in the microwave regions, are unaffected by weather conditions.

The designed resolution and extent of a sensor contribute to the quality of data it can collect. Other factors that impact data quality are instrument maintenance, preprocessing, calibration, and validation. Some agencies supplying data also offer more reliable acquisition and distribution procedures than others.

Specific uses of EOS are generally adapted to the characteristics of particular sensors. While other sensors may offer similar characteristics in terms of both resolution and extent, the use of substitute sensors generally requires changes to data processing procedures and may impact the continuity of ongoing monitoring programs.

It should also be noted that a given sensor may be carried on two or more concurrent platforms. A sensor being carried on multiple satellites, that follow identical orbits within a single mission series (such as the Landsat TM sensor on the Landsat 5 and Landsat 7 satellites), is specifically designed and calibrated to produce comparable image values from each satellite. Some sensors are also carried by multiple satellite missions. This is the case for MODIS (MOderate Resolution Imaging Spectroradiometer), which operates on both the Terra and Aqua satellites (modis.gsfc.nasa.gov). These satellites follow different orbits to allow acquisition of MODIS data up to four times per day. Image acquisition at different times in the diurnal cycle, however, can result in image value differences that are directly attributable to changes in sun position and view angle, rather than changes in the properties of the imaged surface. Advanced correction procedures are applied to such data sets to ensure their image values are comparable for digital analyses.

Section 2
Context of CEODA-Ops Report

2.1 OBJECTIVES

This report, entitled 'Continuity of Earth Observation Data for Australia: Operational Requirements to 2015 for Lands, Coasts and Oceans (CEODA-Ops)', aims to identify:

1. Australia's EOS data requirements in 2015;
2. Australia's EOS data continuity plans to 2020; and
3. The major factors and constraints that could restrict or impede access to EOS data for Australian users.

The first objective is addressed in **Section 3,** the second in **Section 4**, and the third is discussed in **Section 5**.

2.2 SCOPE

This report considers both current EOS data usage in Australia and the projected usage in 2015. In the context of this report, the term 'EOS data' is limited to data derived from space-based sensors.

To avoid duplication with the comprehensive documentation produced by the meteorological community, satellites and sensors that are exclusively used for atmospheric studies, and EOS data used for atmospheric correction of other imagery, are not included in this report. Thus, the main focus of this report is on satellites and sensor classes that are relevant to observing the Australian land mass and its current offshore jurisdictional limits (continental shelf extents). For particular regions of interest, some attention is given to satellites and sensors that cover territories outside Australia's jurisdiction.

The National Remote Sensing Technical Reference group (NRSTRG; see **Appendix A**) was established by Geoscience Australia as an advisory panel in 2004. It comprises EOS data users from government, academia and the private sector, and as such, represents a cross-section of the remote sensing community in Australia. The present report addresses recommendations made by the Seventh NRSTRG and Distributor's Meeting, held in February 2010, as documented by Geoscience Australia (2010).

In particular this study focuses on the data continuity required to maintain the most significant EOS programs that are being conducted by NRSTRG members. Geoscience Australia (2010) identified 92 federal and state government programs that currently depend on EOS data. In this report, 91 of these ongoing, operational programs are used as a sample set to conservatively forecast Australia's EOS data requirements in 2015[11].

The use of EOS data for current or future research and development activities is not considered in this report.

Contributors to the CEODA-Ops report are listed in **Appendix B**.

11 Program 26 is not included in this sample due to insufficient EOS usage.

2.3 CEODA-OPS DATA CATEGORY DEFINITIONS

EOS sensors have been categorised in many ways with most classification systems being based on spectral and/or spatial characteristics. The CEOS instrument categories described in **Section 1.6.2**, for example, primarily classify sensors on the basis of their spectral characteristics.

For the purposes of this report, EOS sensor data are considered in terms of five data types:

- Low resolution optical;
- Medium resolution optical;
- High resolution optical;
- Synthetic aperture radar (SAR); and
- Passive microwave.

Throughout this report, these sensor data types will be referred to as the CEODA-Ops Data Categories. Each of the CEODA-Ops Data Categories relates to one or more CEOS instrument categories (see **Section 1.6.2**). Because of the importance of spatial scale in Australian applications, the optical data group has been sub-divided into three categories that relate to subsets of the CEOS categories.

A number of data types are not included in the CEODA-Ops Data Categories because, despite their increasing importance, there was insufficient data to reliably project their usage in 2015. Omitted data types include sensors that are being used in terrestrial, coastal and ocean applications to directly measure surface elevation and properties, namely lidar and radar altimetry instruments. Lidar (LIght Detection And Ranging) instruments, also known as laser altimetry, can be used to determine the elevation and structure of a target surface. Such surfaces can include bare earth for topographic mapping, tree canopies for forest height surveys, and water body surface height for water resources management. Radar (RAdio Detection And Ranging) altimetry sensors are used to derive surface elevation information for global and regional sea level monitoring, wave height measurement, wind velocity, and tides, as well as the topography and dynamics of ice sheets and the ocean surface.

While an increasing number of lidar and radar altimeters, and other instruments such as gravity sensors, are being carried on satellite platforms, these data sources are not being used operationally in Australia at this stage.

2.3.1 LOW RESOLUTION OPTICAL SENSORS

Low resolution optical sensors are broadly classified as 'regional scale' sensors that record reflectance in the visible and infrared (including thermal) wavelengths, and have a geometric pixel size greater than 80 m. This data type comprises subsets of three CEOS instrument categories: *high resolution optical sensors, imaging multispectral radiometers (visible/infrared)* and *ocean colour instruments* (see **Section 1.6.2** for CEOS category definitions). Such sensors include NOAA AVHRR and MODIS.

Most low resolution sensors are operated for public good. Their data are widely used for operational support in meteorology, oceanography, fire monitoring, disaster management, climate and water cycle modelling, and broad area land cover monitoring.

2.3.2 MEDIUM RESOLUTION OPTICAL SENSORS

Medium resolution optical sensors record visible and infrared (including thermal) wavelengths with a geometric pixel size greater than 10 m and less than or equal to 80 m. They are commonly considered as 'paddock scale' sensors. This data type comprises subsets of three CEOS instrument categories: *high resolution optical sensors, imaging multi-spectral radiometers (visible/infrared)* and *ocean colour instruments* (see **Section 1.6.2** for CEOS category definitions).

These sensors, such as Landsat TM, have traditionally been operated for public good and scientific observation purposes, although a number of commercial sensors, such as SPOT MSS, are now available in this category. Data from Medium Resolution Optical sensors can be used for a wide range of applications including agriculture, forestry, carbon accounting, disaster mapping, regional geology and lithology, and environmental monitoring and management. Landsat TM data are being increasingly used for mapping inland and estuarine water quality, coastal habitats, seagrass and coral reefs (Arnold Dekker, *pers. comm.*). The range of uses of medium resolution optical sensors is continually expanding.

2.3.3 HIGH RESOLUTION OPTICAL SENSORS

High resolution optical sensors record optical (visible and infrared, including thermal) wavelengths with a geometric pixel size up to 10 m. This 'urban scale' data type also comprises subsets of three CEOS instrument categories: *high resolution optical sensors, imaging multi-spectral radiometers (visible/infrared)* and *ocean colour instruments* (see **Section 1.6.2** for CEOS category definitions).

Unlike the coarser data sensors, high resolution optical sensors, such as Quickbird and Ikonos, are usually operated as commercial ventures. High resolution optical data can be used in a wide range of applications, including civil planning, enforcement, defence and security analyses, digital terrain modelling, mineral mapping, hydrology, cartography and cadastral mapping, emergency response, asset evaluation, demographic studies, change detection, precision agriculture, agricultural forecasting, and monitoring water quality.

2.3.4 SYNTHETIC APERTURE RADAR SENSORS

Synthetic Aperture Radar (SAR) sensors, also known as imaging microwave radars, are active radar systems that transmit pulses of radio waves at a target and measure the echo waveforms returned to the sensor. Different wavelengths and polarisations are used to discern particular target properties.

EOS SAR sensors are useful for atmospheric studies, physical oceanography, geological surveys, topographic mapping, measurement of surface movement following earthquakes, direct measurement of above-ground biomass, and mapping of flood areas and storm damage. SAR data have particular application to studies of ice motion and dynamics and in determining soil moisture content. Radar observations have the advantage of being relatively unaffected by illumination and weather conditions (including cloud and smoke), so useful data can be acquired at any time. This feature is particularly advantageous in tropical and other persistently cloudy environments.

2.3.5 PASSIVE MICROWAVE SENSORS

Passive microwave sensors detect microwave radiation that is naturally emitted by the Earth's land, seas and atmosphere as a result of thermal heating. The values and variations in brightness temperatures measured by passive microwave detectors can be correlated with different physical properties and states of materials, and are especially useful to indicate moisture content. Microwaves can be used to detect surface properties regardless of cloud cover and diurnal cycles.

These sensors can be used for physical oceanography, meteorology, climatology, topographic mapping, vegetation structure studies, atmospheric dynamics, geophysics and geoid studies, and monitoring ice and snow. Derived data sets include soil moisture and temperature for hydrologic modelling, plant growth monitoring and flood prediction, ocean salinity, sea surface temperature, and snow depth and melt conditions.

Space-borne passive microwave sensors have been used since 1972 and now provide daily updates for most sea ice-covered regions around the globe (http://nsidc.org/seaice/study/passive_remote_sensing.html). As such, this data category has particular significance for monitoring Australia's Antarctic region.

2.4 CEODA-OPS DATA COVERAGE CATEGORIES

2.4.1 SPATIAL COVERAGE

For the purpose of this report, EOS data coverage for Australia is considered in terms of the following spatial categories:

- Six coastal and marine zones based on Integrated Marine and Coastal Regionalisation of Australia (IMCRA) v4.0, plus the extended continental shelf entitlement declared by UNCLOS in 2008[12];
- Twelve terrestrial regions based on Surface Water Divisions; and
- All urban locations, defined by cities and towns with at least 2,000 inhabitants.

The data coverage categories are detailed and illustrated in **Appendix C**.

2.4.2 TEMPORAL COVERAGE

Temporal requirements are considered in terms of six categories (see **Appendix C** for details):

- Hourly: new imagery every hour;
- Daily: new imagery every day;
- Monthly: new imagery every month;
- Quarterly: new imagery every three months;
- Annually: new imagery every year; and
- Triennially: new imagery every three years.

12 http://www.ga.gov.au/ausgeonews/ausgeonews200903/limits.jsp

Section 3

EOS Data Requirements

3.1 INTRODUCTION

The following projections of EOS data requirements for Australia are based on 34 federal and 57 state and territory remote sensing programs identified in Geoscience Australia (2010). These 91 ongoing, operational programs are summarised in **Appendix E**. It should be noted that programs requiring *ad hoc* image data for specific events, for example search and rescue operations, are not included in this sample. Local government requirements have also been excluded. Thus, these projections are conservative estimates of Australia's future EOS data needs.

As detailed in **Section 2**, both Research and Development activities, and meteorological applications, are out of scope for this report.

3.1.1 ESTIMATING DATA COVERAGE REQUIREMENTS IN 2015

Based on the current usage of EOS data by the sample programs, and the increasing trend toward greater reliance on EOS data in related applications, the expected EOS data requirements in 2015 have been estimated for the collective set of 91 programs. Expected data requirements are presented in **Section 3.2** within each of the five CEODA-Ops data categories (defined in **Section 2.3**) as maps showing the temporal coverage required by each spatial coverage category (defined in **Section 2.4**). These maps are based on the seven marine, 12 terrestrial and the numerous urban regions illustrated in **Figures C-1** and **C-2** **(see Appendix C).**

3.1.2 ESTIMATING DATA STORAGE REQUIREMENTS IN 2015

The data storage required to support the expected coverage of each data category has been estimated using the following criteria and process:

1. A **typical sensor** was selected to be indicative of the data category;
2. The number of data channels and the image pixel size(s) of the typical sensor were used to estimate **data density**, as KB/km^2, for the selected sensor (assuming 2 bytes per pixel);
3. Using the projected temporal coverage requirement maps below, and the area of each spatial category, an estimate for the area required for each temporal category was determined. This is referred to as the **temporal area estimate** and measured in km^2.
4. The temporal area estimates were converted to **annual area estimates**, km^2/year, by considering the frequency of coverage required for each temporal category;
5. An annual **volume estimate** of data, as MB/year or TB/year, was derived from the data density and the annual area estimates;
6. On the assumption that most images need to be stored in three formats (namely raw telemetry from the satellite, initial processing to create the raw data image, and higher level processing to create the image product), the annual **data storage estimate** was computed as three times the volume estimate and expressed as TB/year.

Using this procedure, the projected data storage required in 2015 was derived for each of the five CEODA-Ops data categories, as detailed in **Section 3.2.1** to **Section 3.3.5** below. This estimate reflects the file storage capacity that will be required, and should be indicative of the additional data handling overheads associated with processing and distribution of the data (see **Section 1.4.4** for an outline of the EOS data supply chain).

3.2 CEODA-OPS DATA CATEGORY REQUIREMENTS

3.2.1 LOW RESOLUTION OPTICAL

These 'regional scale' sensors (pixel size > 80 m) are widely used for a range of applications in Australia. The AVHRR and MODIS sensors service most Australian needs for low resolution optical data. This data type is currently being used by 44 of the 91 sample programs for several essential monitoring activities, including:

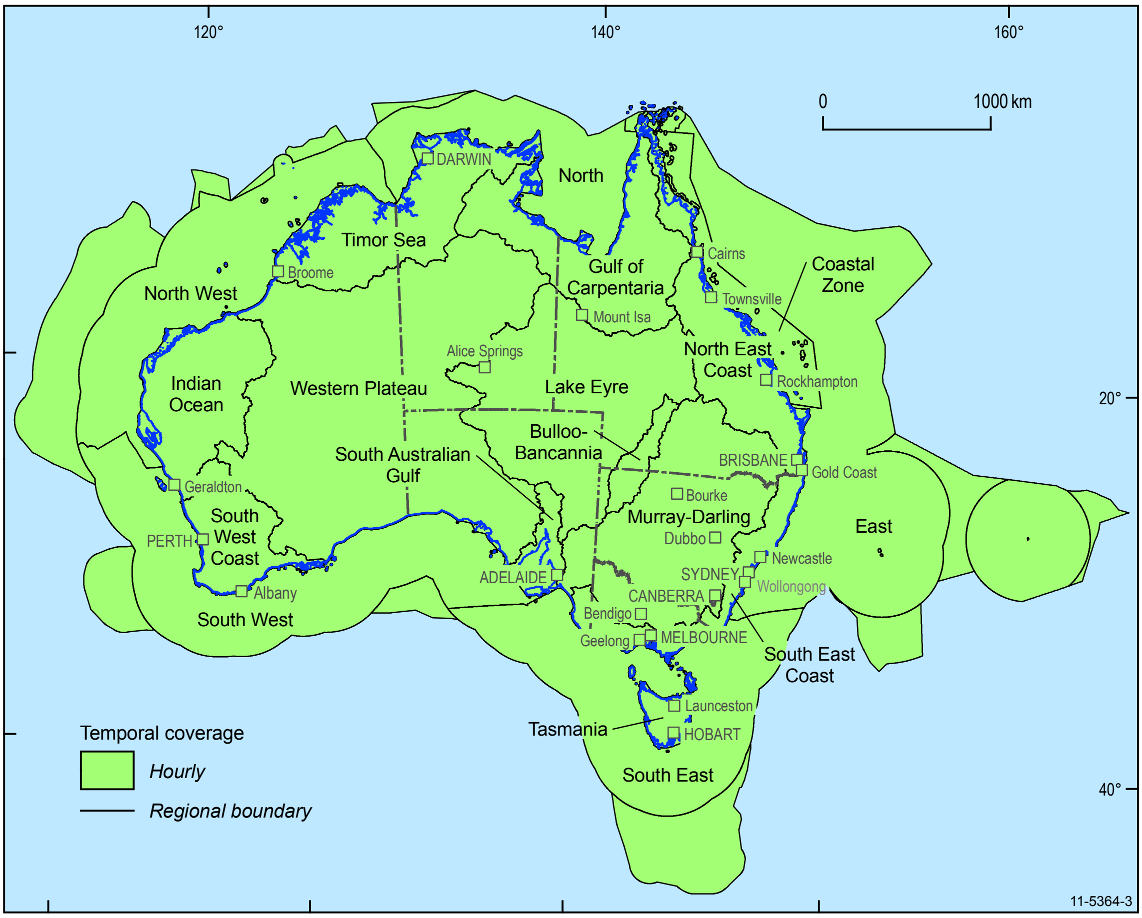
- Disaster mitigation and management, including bushfires, earthquakes, floods, and storms;
- Monitoring land use, land cover, ecosystems, native vegetation, salinity, water resources, wetlands, grassland curing, crop production, pasture growth, dust;
- Managing fisheries, reefs, floodplains and environmental degradation;
- International agreements;
- Glaciology, oceanology, and climate studies; and
- Carbon accounting.

Products derived from low resolution optical imagery include hotspot mapping of active fires, ocean colour and temperature maps, regional landscape mapping, flood mapping, land use and land cover monitoring, and estimating greenhouse gas emissions. Given that the users of these products include essential services, it is imperative that alternative data sources be available should one of the current sensors cease operation.

From July 2009 to June 2010, 5.9 TB of MODIS imagery were acquired by GA in approximately 5000 passes. Only 300 GB of AVHRR data were archived during this period. The total volume of unique low resolution optical data currently being acquired in Australia is estimated at 6 TB per year. To produce standard image products from this raw data, approximately 18 TB of data storage would be required.

The expected spatial and temporal coverage of low resolution optical data in 2015 is shown over all relevant sample programs in **Figure 3-1**. This indicates that low resolution optical data will be required for all areas of Australia at hourly intervals (see **Section 2.4.2**). To maximise spatial resolution, it is expected that these data will be acquired from polar-orbiting satellites.

Figure 3-1 Expected Data Requirements in 2015: Low Resolution Optical



Using the procedures described in **Section 3.1.2** above, and the projected coverage derived from **Figure 3-1**, the volume of low resolution optical data that is expected to be required by the sample programs in 2015 was estimated as follows:

1. The Ocean and Land Colour Instrument (OLCI; planned for Sentinel-3, with 21 channels and 300 m pixels) was selected as the **typical sensor**;
2. The **data density** for the typical low resolution optical sensor
   = (21 / (0.3 × 0.3)) × 2
   ~ 0.47 KB/km^2;
3. From **Figure 3-1**, the **temporal area estimate** for hourly low resolution optical data = 16,426,326 km^2;
4. The **annual area estimate**
   = 16,426,326 × 24 × 365
   ~ 1.44 E11 km^2/year;
5. The **annual volume estimate** of data to cover the required area
   = 1.44 E11 × 0.47
   ~ 67.2 TB/year; and
6. The **annual data storage estimate** was determined as 67.2 × 3
   ~ 202 TB/year.

This annual data storage estimate for low resolution optical data in 2015, 202 TB per year, represents more than an elevenfold increase on the current storage requirements for this data type at GA (namely 18 TB per year).

3.2.2 MEDIUM RESOLUTION OPTICAL

These 'paddock scale' sensors (10–80 m pixels) are the most commonly used category of sensors internationally. For several decades the Landsat series of satellites have provided the majority of medium resolution optical imagery for operational programs in Australia.

Medium resolution optical sensors have traditionally been operated for public good, although the number of commercial sensors is increasing. Data from medium resolution optical sensors are used by 72 of the 91 government programs for a wide range of applications including:

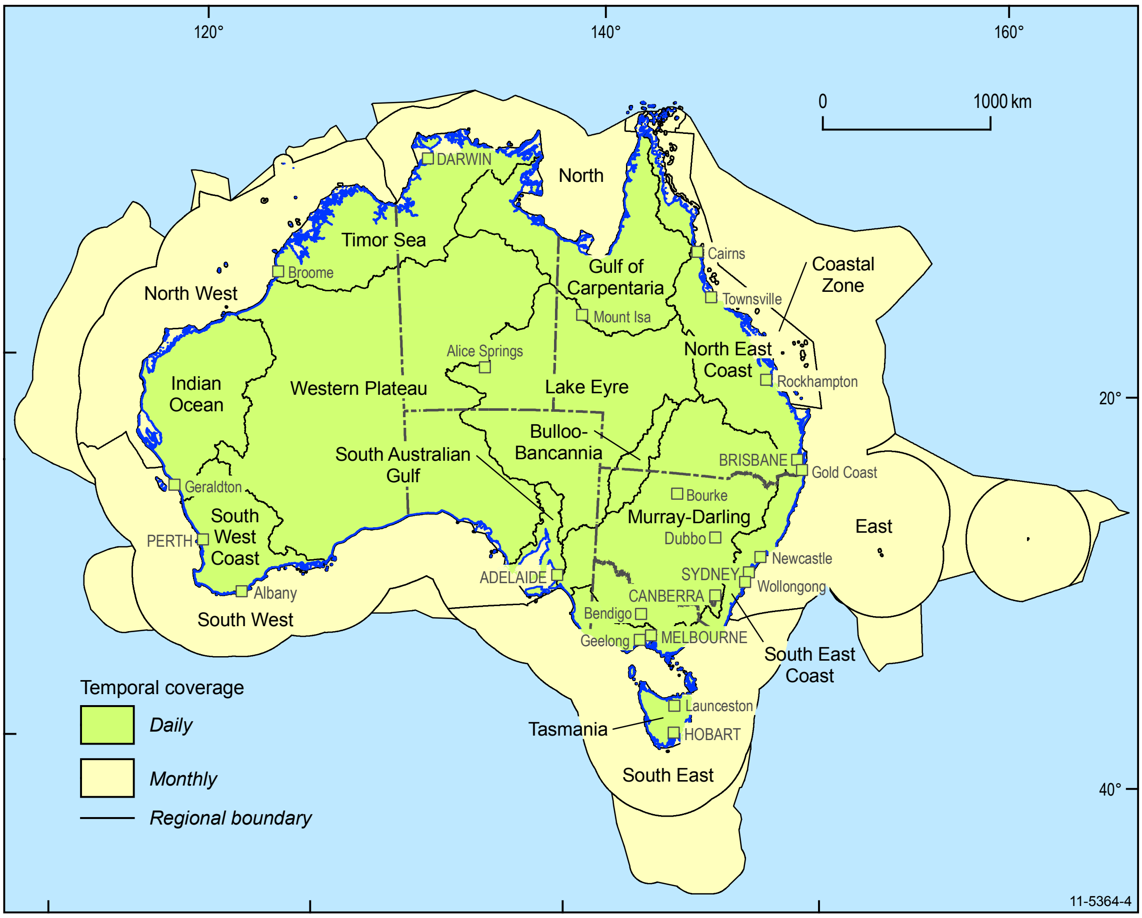
- Emergency management of floods, earthquakes, bushfires and storms;
- Mapping and monitoring land use, natural resources, biodiversity, water usage, drought, pollution, evapotranspiration, biomass, minerals, water quality, wetlands, groundwater dependent ecosystems, hydrocarbon seepage, land clearing, floodplains, crop acreage and growth, remnant vegetation, land degradation, irrigation, dryland salinity, and vegetation dynamics;
- Management of forests, rivers, fisheries, catchments and agriculture;
- National inventories of forests, greenhouse gases, endangered species, maritime boundaries, land cover, topography, and carbon sinks;
- Verification of residential housing development applications, rural taxation valuations, and environmental compliance; and
- Specific research areas: Antarctica, Great Barrier Reef, and hyperspectral imaging.

Between July 2009 and June 2010, approximately 9.6 TB of medium resolution optical data were acquired and archived by GA from the Landsat 5, Landsat 7, and ResourceSat–1 (IRS-P6) satellites. The current volume of medium resolution optical data being acquired in Australia is estimated at approximately 10 TB per year. The storage required to process this data into image products would be 30 TB per year.

The expected coverage of medium resolution optical data over Australia, based on the projected usage of the sample programs, is illustrated in Figure 3-2. This indicates that medium resolution optical data will be required at:

- Daily intervals for all terrestrial areas, including all urban areas; and
- Monthly intervals for all coastal and marine areas.

Figure 3-2 Expected Data Requirements in 2015: Medium Resolution Optical



Following the procedure described in **Section 3.1.2** above, and using the coverage derived from **Figure 3-2,** an estimate of the volume of medium resolution optical data that will be required in 2015 was computed as follows:

1. The Landsat Data Continuity Mission (LDCM) sensor MSI (which will have eight channels with 30 m pixels, one channel with 15 m pixel, and two channels with 120 m pixels), was selected as the **typical sensor**;
2. The **data density** for the typical medium resolution optical sensor
   = (8 / (0.03 × 0.03)) + (1 / (0.015 × 0.015)) + (2 / (0.12 × 0.12)) × 2 / 1000
   ~ 27 KB/km^2;
3. From **Figure 3-2**, the **temporal area estimates** were derived as:
   7,687,717.11 km^2 for daily data and
   8,738,609.19 km^2 for monthly data;
4. The **annual area estimate**
   = 7,687,717.11 × 365 + 8,738,609.19 × 12
   = 2,910,880,055 km^2/year;
5. The **annual volume estimate** of data to cover the required area
   = 2,910,880,055 × 27
   ~ 78.4 TB/year; and
6. The **annual data storage estimate** was determined as 78.4 × 3
   ~ 235 TB/year.

This annual data storage estimate for medium resolution optical data in 2015, 235 TB per year, is nearly eight times the volume that is currently being acquired and processed by GA (namely 30 TB per year).

3.2.3 HIGH RESOLUTION OPTICAL

High resolution optical sensors (pixels size < 10 m), or 'urban scale' sensors, are primarily operated by commercial enterprises. There is an increasing number of these sensors available for both satellite and airborne platforms and an ever-expanding range of applications that use them.

In Australia, data of this type are currently being used by 40 of the 91 operational programs for a diversity of reasons:

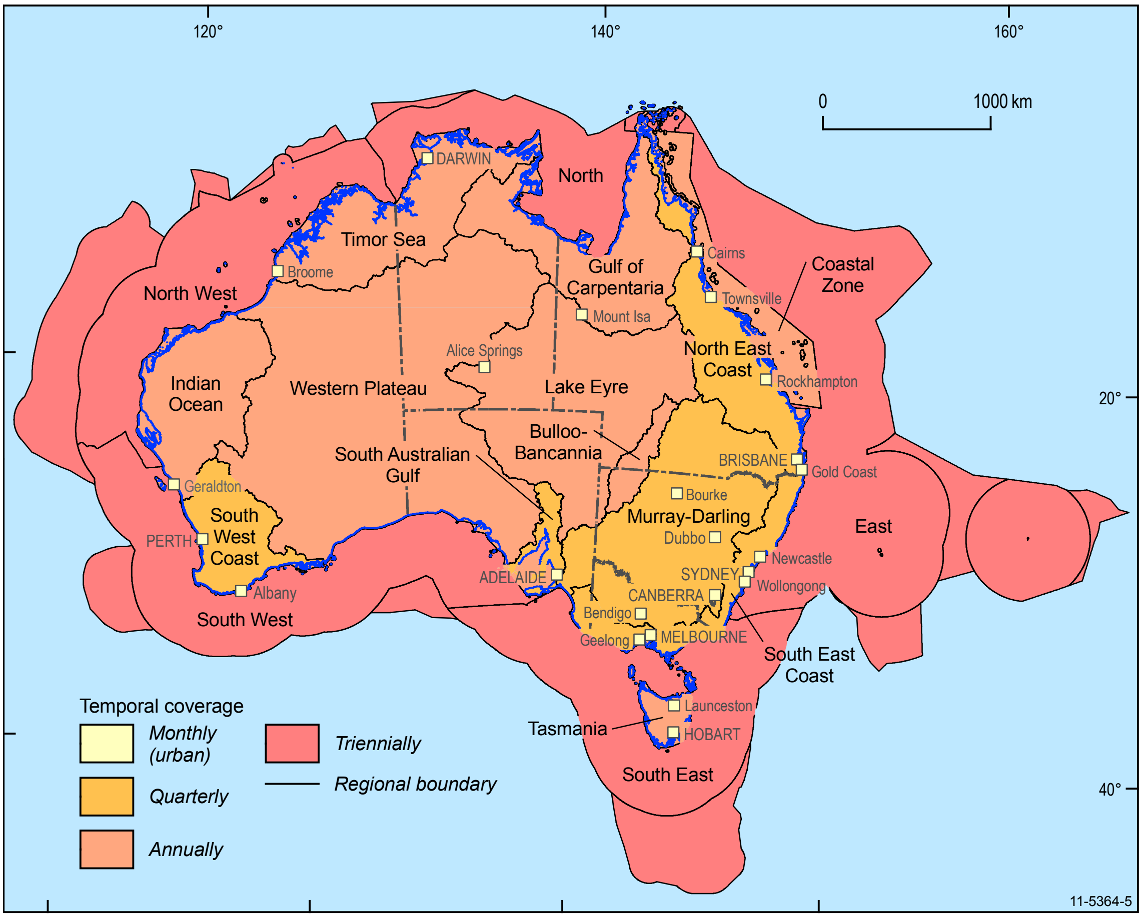
- Monitoring active and/or recent fires, floods, storms, and subsidence;
- Estimating biomass for carbon accounting, native vegetation mapping, and agriculture;
- Managing conservation areas (land and marine), environmental resources, estuaries and coastal waterways, marine jurisdiction, electoral boundaries, floodplains, and dryland salinity;
- Mapping geoscience resources, topographic features, shallow water bathymetry, wetlands, and plant stress; and
- Auditing environmental compliance, urban water use, and urban development.

As more frequent updates of high resolution optical data become available, it is expected that demand will increase rapidly for monitoring inland water quality, reservoir storage and flood levels (Arnold Dekker, *pers. comm.*).

The expected spatial and temporal coverage that will be required in 2015 for High Resolution Optical Data is illustrated in **Figure 3-3**, namely:

- Monthly coverage for some urban areas;
- Quarterly coverage for:
- Perth and the Southwest Coast surface water division;
- Adelaide and the South Australian Gulf surface water division;
- Other urban areas in Eastern Australia; and
- Southeast Coast, Murray-Darling and Northeast Coast surface water divisions;
- Annual coverage for other terrestrial and urban categories and the Coastal marine region; and
- Triennial coverage for other marine areas.

Figure 3-3 Expected Data Requirements in 2015: High Resolution Optical



Following the procedure described in **Section 3.1.2**, and using the coverage information given in **Figure 3-3**, an estimate of the expected volume of high resolution optical data required in 2015 was computed as follows:

1. The Worldview-2 sensor (which has one channel with 46 cm pixels and eight channels with 1.85 m pixels) was selected as the **typical sensor**;
2. The **data density** for the typical high resolution optical sensor
   = (1 / (0.00046 × 0.00046)) + (8 / (0.00185 × 0.00185)) × 2 / 1000
   ~ 14 MB/km²;
3. From **Figure 3-3**, the **temporal area estimates were determined as:**
   5,660.67 km² for monthly data
   2,166,572.43 km² for quarterly data
   6,195,749.23 km² for annual data and
   8,058,343.97 km² for triennial data;
4. The **annual area estimate** =
   = 5,660.67 × 12 + 2,166,572.43 × 4 + 6,195,749.23 + 8,058,343.97 / 3
   ~ 17,600,000 km²/year;
5. The **annual volume estimate** of data volume to cover the required area
   = 17,600,000 × 14
   ~ 249 TB/year; and
6. The **annual data storage estimate** was determined as 249 × 3
   = 747 TB/year.

This annual data storage estimate for high resolution optical data in 2015, 747 TB per year, is significantly higher than the storage currently required for this data type.

3.3.4 SYNTHETIC APERTURE RADAR

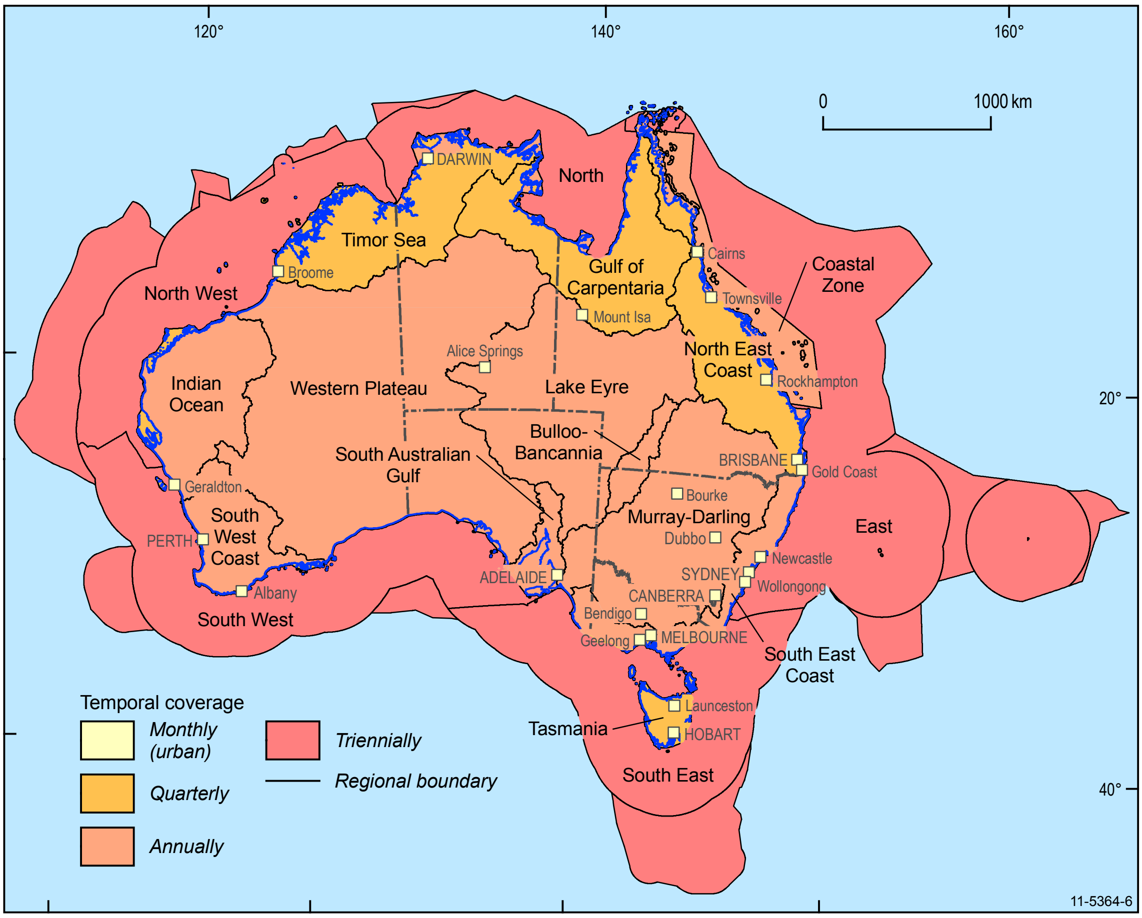
SAR data are not widely used in Australia at present, but usage is likely to increase with greater data availability and increasing knowledge of applications to key areas such as biomass estimation and emergency response. Within the 91 sample programs, SAR data are currently used by 14 programs to map and monitor natural disasters, land use, forest carbon, sea ice, marine borders, mineral resources, sea level, subsidence, woody vegetation and soil moisture.

Being unaffected by illumination and weather conditions, SAR data are particularly useful for monitoring tropical areas in northern Australia and cloudy areas, such as Tasmania.

The expected 2015 requirements for SAR data are illustrated in Figure 3-4, namely:

- Monthly coverage for some urban areas, plus Tasmania and northern Australia;
- Annual coverage for coastal areas and other terrestrial areas; and
- Triennial coverage for other marine areas.

Figure 3-4 Expected Data Requirements in 2015: Synthetic Aperture Radar



As described in **Section 3.1.2** above, and using the coverage derived from **Figure 3-4,** an estimate of the volume of SAR data that will be required in 2015 was computed as follows:

1. The Sentinel-1 C-band SAR sensor (with two polarisations of 5 m pixels) was selected as the **typical sensor**;
2. The **data density** for the typical SAR sensor
   = (2 / (0.005 × 0.005)) × 2 /1000
   = 160 KB/km^2;

3. From **Figure 3-4**, the **temporal area estimates were determined as:**
   5,660.67 km^2 for monthly data
   1,876,385.56 km^2 for quarterly data
   6,485,936.1 km^2 for annual data and
   8,058,343.97 km^2 for triennial data;
4. The **annual area estimate**
   = 5,660.67 × 12 + 1,876,385.56 × 4 + 6,485,936.1 + 8,058,343.97 /3
   ~ 16,700,000 km^2;
5. The **annual volume estimate** of data volume to cover the required area
   = 16,700,000 × 160
   ~ 2.67 TB/year; and
6. The **annual data storage estimate** was determined as 2.67 × 3
   ~ 8 TB/year.

This annual data storage estimate for SAR data in 2015, 8 TB per year, is also much higher than the current volume of SAR data being acquired and processed in Australia.

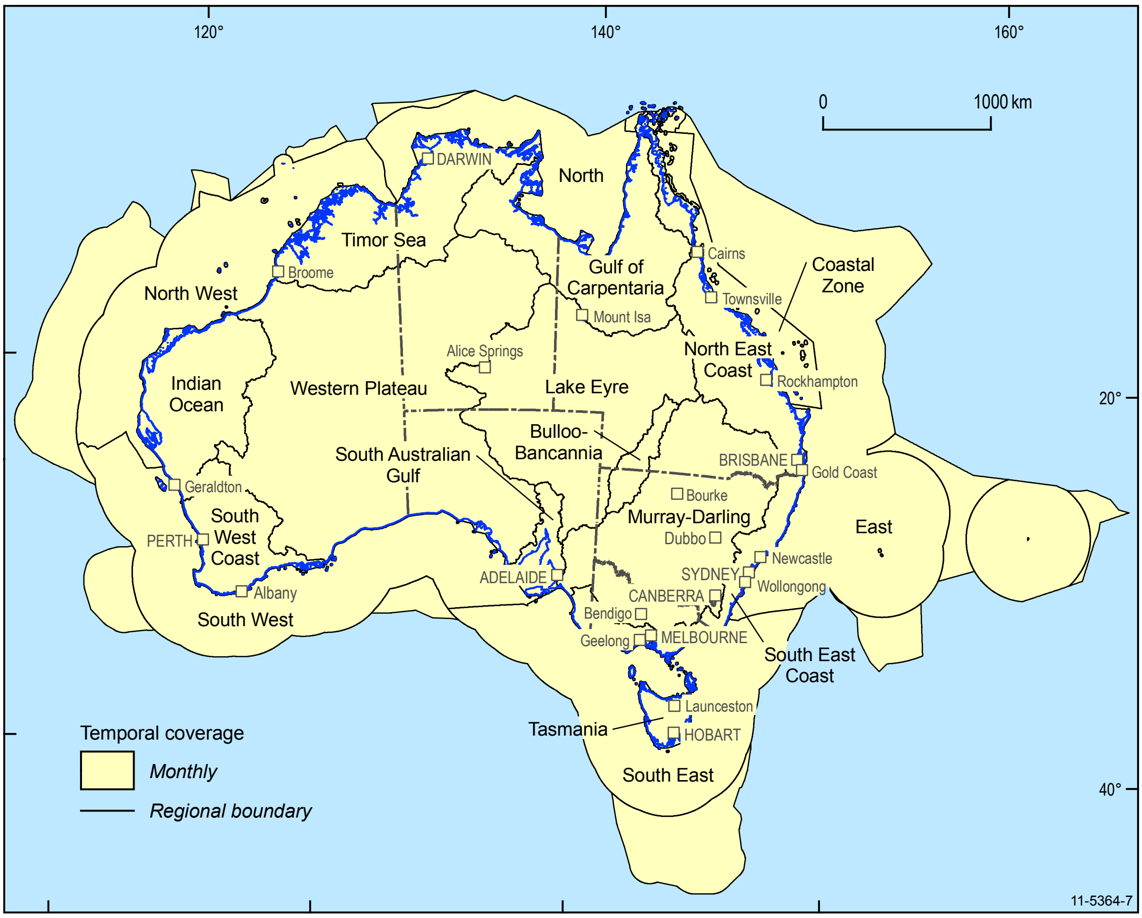
3.3.5 PASSIVE MICROWAVE

Only four Australian government programs currently use passive microwave data and they use this data for:

- Modelling ocean processes and refining geoid models;
- Mapping soil moisture and groundwater hydrology; and
- Monitoring Antarctic sea ice.

Monthly coverage by passive microwave sensors is expected to be required for all areas of Australia in 2015 as illustrated in **Figure 3-5**.

Figure 3-5 Expected Data Requirements in 2015: Passive Microwave



As described in **Section 3.1.2**, and using the coverage derived from **Figure 3-5,** the expected volume of passive microwave data required in 2015 was computed as:

1. The Advanced Microwave Scanning Radiometer for EOS (AMSR-E; which senses brightness temperature for twelve channels (two polarisations at six frequencies) with rectangular pixels sizes of 74×43 km, 51×30 km, 27×16 km, 31×18 km, 14×8 km and 6×4 km)[13] was used as the **typical sensor**;
2. **Using the average pixel size of 973** km², the **data density** for the typical passive microwave sensor = (12 / 973) × 2 / 1000 = 2.47E-5 KB/km²;
3. From **Figure 3-5**, the **temporal area estimate** for monthly passive microwave data = 16,426,326.3 km²;

13 http://www.ghcc.msfc.nasa.gov/AMSR/instrument_descrip.html

4. The **annual area estimate**
   = 16,426,326.3 × 12 =
   = 197,115,915.6 km^2/year;
5. The **annual volume estimate** of data volume to cover the required area
   = 197,115,915.6 × 2.47E-05
   ~ 4.9 MB/year; and
6. The **annual data storage estimate** was determined as 4.9 × 3
   ~ 15 MB/year.

This estimate is considerably lower than those for the other data types due to the significantly larger pixel size involved with passive microwave sensors.

3.3 SUMMARY

The number of operational programs that are currently using each category of EOS data is summarised in **Table 3-1**.

Table 3-1 EOS Data Sensors: Current Australian Usage

Measure of Usage	Sensor Type					TOTAL
	Optical			SAR	Passive Microwave	
	Low spatial resolution (> 80 m)	*Med. spatial resolution (10-80 m)*	*High spatial resolution (< 10 m)*			
Number of Programs	44	72	40	14	6	176
Proportion of Sample	48%	79%	44%	16%	7%	

The spatial coverage of EOS data that will be required by the 91 sample government programs in 2015 is summarised for all CEODA-Ops data categories in **Table 3-2**. Quite simply, full Australian coverage is anticipated to be needed for all five sensor types. Additionally, coverage of Antarctica is required for medium resolution optical data and SAR data, and coverage in three data types (low resolution optical, medium resolution optical and SAR) is also required for Australia's support for countries implementing verifiable forest monitoring systems[14].

Table 3-2 Spatial Requirements for EOS Data

CEODA-Ops Status	Sensor Type				
	Optical			SAR	Passive Microwave
	Low spatial resolution (> 80 m)	*Medium spatial resolution (10-80 m)*	*High spatial resolution (< 10 m)*		
Australia	All regions	All regions	All regions	All regions	All regions
Overseas	Potential IFCI Countries	Potential IFCI Countries and Antarctica	None	Potential IFCI Countries and Antarctica	None

14 Potential IFCI Countries include: Myanmar, Laos, Vietnam, Thailand, Cambodia, Philippines, Brunei, Malaysia, Singapore, Indonesia, Timor Leste, Papua New Guinea, Solomon Islands, Guyana (South America) and Tanzania (Africa).

The projected temporal requirements of the 91 programs in 2015 are tabulated for each CEODA-Ops data category in **Table 3-3**.

Table 3-3 Temporal Requirements for EOS Data

Temporal Requirement	Sensor Type				
	Optical			SAR	Passive Microwave
	Low spatial resolution (> 80 m)	*Medium spatial resolution (10-80 m)*	*High spatial resolution (< 10 m)*		
Hourly	All regions				
Daily		All terrestrial regions, plus Coastal marine region			
Monthly		Other marine regions	Some urban areas	Some urban areas, Tasmania, Timor Sea, Gulf of Carpentaria and Northeast Coast terrestrial regions	All regions
Quarterly			Southwest Coast, South Australian Gulf, Southeast Coast, Murray-Darling and Northeast Coast terrestrial regions		
Annually			Other terrestrial regions, plus Coastal marine region	Other terrestrial regions, plus coastal marine region	
Triennially			Other marine regions	Other marine regions	

For each CEODA-Ops data category, the annual data storage estimates needed to satisfy the expected spatial and temporal requirements for EOS data in 2015 are listed in **Table 3-4**. The total data storage that is expected to be required for the 91 sample programs in 2015 is 1,192 TB (~1.2 PB) per year. Compared to the current annual EOS data storage by GA of 60 TB, this represents nearly a twentyfold increase in data volume over the next five years.

Table 3-4 Estimated EOS Data Requirements in 2015

Estimate	Sensor Type					TOTAL
	Optical			SAR	Passive Microwave	
	Low spatial resolution (> 80 m)	*Med. spatial resolution (10-80 m)*	*High spatial resolution (< 10 m)*			
Data Density (KB/ km^2)	0.47	27	14,127	160	2.5 × 10-5	
Annual Area Estimate (Million km^2/ year)	143,895	2,910	17	16	197	
Annual Data Storage Estimate	202 TB	235 TB	747 TB	8 TB	15 MB	**1,192 TB**

Note: 1TB = 1,000,000 MB

By these projections, in 2015 the annual data storage will be equivalent to 80% of the EOS data storage required to process the entire archive of EOS data that has been collected by GA over the past three decades (namely 1.5 PB). Using another comparison, by 2015, the EOS data acquired in a single year will exceed the volume acquired by GA from the Landsat series of satellites over three decades.

This increase is slightly less than the predicted growth in the volume of global EOS data illustrated in **Figure 1-2**. As detailed in **Section 1.4.4**, the supply chain for EOS data involves many stages (namely acquisition, transmission, storage, processing, re-storage and re-transmission), all of which will need increased capacity to support this increase in data volume.

Note that, as outlined in **Section 3.1**, this estimate of the total annual EOS data storage for 2015 is only based on the projected usage within the 91 sample government programs described in **Appendix E**, for five operational sensor types. As new technologies, such as lidar, radar altimetry and hyperspectral sensors, become more readily available, they will be increasingly utilised by both existing and new EOSdependent programs. As such this estimate should, once again, be viewed as a conservative indication of future, operational EOS data requirements in Australia.

Section 4

EOS Data Availability

4.1 INTRODUCTION

The following sub-sections summarise the Australian availability of data from EOS satellite sensors in each CEODA-Ops data category. The availability of both currently operational sensors, and those planned for use in the near future, is considered. In particular, this analysis highlights those sensors whose data are, or will be, accessible in Australia, namely:

- **Currently operational sensors** whose data Australia is permitted, and able, to utilise, and which are available before May 2011; and
- **Future sensors** for which Australia has attained the authorisation to use data and/or established the infrastructure to receive data. Only sensors whose data are expected to be available before 2021 are included.

Details of most sensors and missions have been derived from the web update[15] of CEOS (2010). Information for some commercial sensors has been extracted from relevant websites.

4.1.1 CEODA-OPS STATUS CATEGORY

In the Tables below, Australia's current usage of operational sensors, or its commitment to forthcoming sensors, is indicated by a status category. This status differentiates four mutually exclusive sensor categories:

Used Currently operational sensor whose data are regularly utilised for active government programs in Australia;

Not Used Currently operational sensor whose data are not actively utilised in Australia, but may be used on an *ad hoc* basis;

Committed Future sensor for which a formal agreement has been ratified with GA/BOM or for which infrastructure has been established for data reception; and

Not Committed Future sensor for which Australia currently has no formal access plans.

In this context, active government programs only include the 91 sample programs defined by GA (2010) and summarised in **Appendix E**.

The relationships between CEODA-Ops status, sensor status and Australian access is summarised in **Table 4-1**.

15 http://www.eohandbook.com/eohb2010//PDFs/EOHB%202010%20key%20tables.pdf
Note that instruments classified as 'TBA', 'Proposed', 'Prototype' or 'No longer operational' have not been considered in the present report. Further, multiple radar modes of any relevant sensors have not been considered as separate sensors.

Table 4-1 CEODA-Ops Status Characteristics

CEODA-Ops Status	Sensor Status	Usage by Government
Used	Currently operational	Regular
Not Used	Currently operational	*Ad hoc* or none
Committed	Planned for future	Feasible
Not Committed	Planned for future	Not Feasible

4.1.2 SOURCE SHIFTS BETWEEN EOS SENSORS

While several different EOS sensors acquire similar measurements, their utility and interchangeability depends on data quality and coverage. When an instrument is carried on multiple satellites in a single mission series, such as the TM sensor currently on-board Landsat 5 and Landsat 7, the acquired data sets can be used interchangeably for most purposes. The majority of EOS sensors, however, even those acquiring similar data measurements, are not designed as substitutes, that is, they do not generate interchangeable data sets.

The quality of data from different EOS sensors depends on the accuracy and precision of the sensor mechanism, consistency and reliability of instrument calibration, and the validation of supplied data for a particular application. The coverage of different sensors can vary both spatially and temporally. This is particularly significant for critical surveillance activities, such as disaster monitoring or border protection, which depend on frequently updated imagery. Accordingly, while many sensors appear to offer similar data sets, which may be sufficiently compatible for *ad hoc* projects, their differences will invariably impact the validation, processing, and continuity of ongoing EOS programs.

Although it is possible to use alternate EOS data for many applications, substitution of input data, also known as source shifting, is a non-trivial task that involves significant time and effort on the part of the data provider and/or user. ACIL Tasman (2010) estimated the economic impact of an unplanned source shift to be in the order of $100 million per year, to cover the costs of lost productivity, replacement data, and/or loss of outcomes or benefits. Additionally, due to differences in EOS data quality and coverage, source shifts may also compromise the reliability and consistency of results from operational programs.

4.1.3 SENSOR STANDARDS

The operational success of an EOS sensor depends on several characteristics of the sensor itself, its mission and its supplier, including:

- Quality of sensor design, construction and operation;
- Quality of data calibration;
- Space system redundancy;
- Data licensing arrangements; and
- International collaboration of supplier.

Highly successful sensors, such as Landsat TM provide a bench-mark for EOS. As listed in **Appendix F**, numerous EOS sensors are now available, but not all sensors deliver the same 'standard' of data in terms of quality, reliability, and value for money.

4.1.4 ALTERNATIVE DATA SOURCES

Some, but not all, types of EOS data can be acquired from alternate sources, such as sensors carried by aerial platforms. When alternative sources of EOS data are available, however, an important consideration for operational programs will be the significantly higher expenditure required to acquire a comparable level of spatial and temporal coverage as is offered by EOS sensors. Other concerns may include the compatibility of alternative data sources with the data processing and validation procedures developed for EOS data sets, especially within operational monitoring programs.

4.2 CEODA-OPS DATA CATEGORY AVAILABILITY

4.2.1 LOW RESOLUTION OPTICAL

As detailed in **Section 2.3.1**, low resolution optical sensors acquire 'regional scale' data (> 80 m pixels). Public good satellites are the primary source for data of this type. Since large swaths of the Earth's surface can only be viewed from space-based platforms, there are no alternative sources of low resolution optical data.

A detailed list of operational and planned low resolution optical sensors is given in **Table F–1** (in **Appendix F**). The projected availability of low resolution optical sensors from 2011 to 2020 is summarised for each CEODA-Ops status category in **Table 4-2**. For example, this year (2011) 38 sources of low resolution optical data are available internationally, only ten of which are readily available to Australian EOS customers. It should be noted, however, that some of the 38 potential low resolution optical sensors may not offer data to the same standard as the currently used sensors.

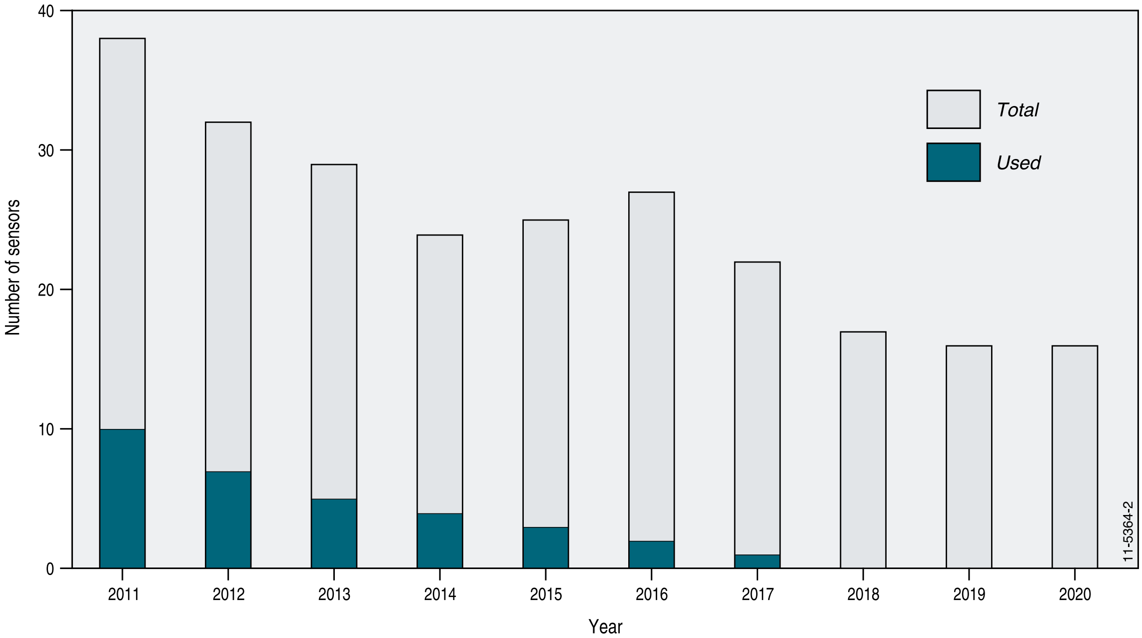
Table 4-2 EOS Sensor Availability: Low Resolution Optical

CEODA-Ops Status[16]	Year									
	2011	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Used	10	7	5	4	3	2	1	0	0	0
Not Used	20	12	8	3	1	1	1	0	0	0
Committed	0	0	0	0	0	0	0	0	0	0
Not Committed	8	13	16	17	21	24	20	17	16	16
TOTAL	**38**	**32**	**29**	**24**	**25**	**27**	**22**	**17**	**16**	**16**

Using these projections, the numbers of accessible and potentially accessible low resolution optical EOS sensors over the next decade is contrasted in **Figure 4-1.** While these projections indicate a reducing number of such satellites being planned over this period, an imminent shortage of low resolution optical EOS data in Australia is not expected.

16 Status categories are described in **Section 4.1.1**.

Figure 4-1 EOS Sensor Accessibility: Low Resolution Optical



Total = Used + Not Used + Committed + Not Committed (see **Section 4.1.1**)
Used = Current sensors whose data are used for operational government programs in Australia

Figure 4-2 details the life expectancies of the low resolution optical data sensors that are currently being used in Australia. As reflected in the lower portion of this figure, Australia has not yet secured access to any future EOS low resolution optical sensors.

Figure 4-2 Used and Committed Sensors: Low Resolution Optical

Low resolution optical data are currently used by 44 of the 91 sample programs, most commonly from the MODIS (Terra/Aqua) and AVHRR (NOAA) sensors. Should EOS data cease to be available from one of these sensors, low resolution optical EOS data would still be available in Australia from an adequate number of alternative sensors.

4.2.2 MEDIUM RESOLUTION OPTICAL

Medium resolution optical sensors, or 'paddock scale' sensors (10–80 m), are operated for both public good and commercial purposes. No alternative data sources exist for medium resolution optical data, as the inherent scale and coverage can only be achieved from space-based platforms. This is the EOS imagery type most commonly used by Australian government agencies.

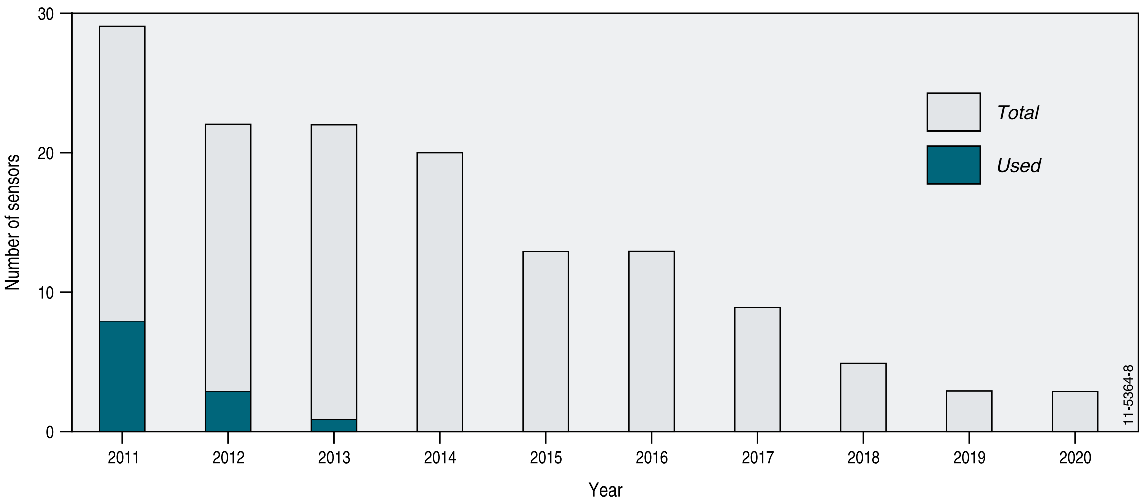
Table F–2 (in **Appendix F**) lists operational and planned medium resolution optical sensors to 2020. **Table 4-3** summarises the expected availability of medium resolution optical sensors from 2011 to 2020. For example, this year (2011) 29 sources of medium resolution optical data are available internationally, only eight of which are readily available to Australian users. It should be noted that some of the 29 potential medium resolution optical sensors may not offer data of a comparable standard to the currently used sensors.

Table 4-3 EOS Sensor Availability: Medium Resolution Optical

CEODA-Ops Status[17]	Year									
	2011	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Used	8	3	1	0	0	0	0	0	0	0
Not Used	16	10	9	6	1	1	1	0	0	0
Committed	0	0	0	0	0	0	0	0	0	0
Not Committed	5	9	12	14	12	12	8	5	3	3
TOTAL	**29**	**22**	**22**	**20**	**13**	**13**	**9**	**5**	**3**	**3**

As illustrated in **Figure 4-3**, there is a dramatic trend of decreasing access to medium resolution optical data in Australia over the next decade, such that, unless existing data acquisition arrangements change in the near future, no medium resolution EOS data will be available in Australia after 2013.

Figure 4-3 EOS Sensor Accessibility: Medium Resolution Optical

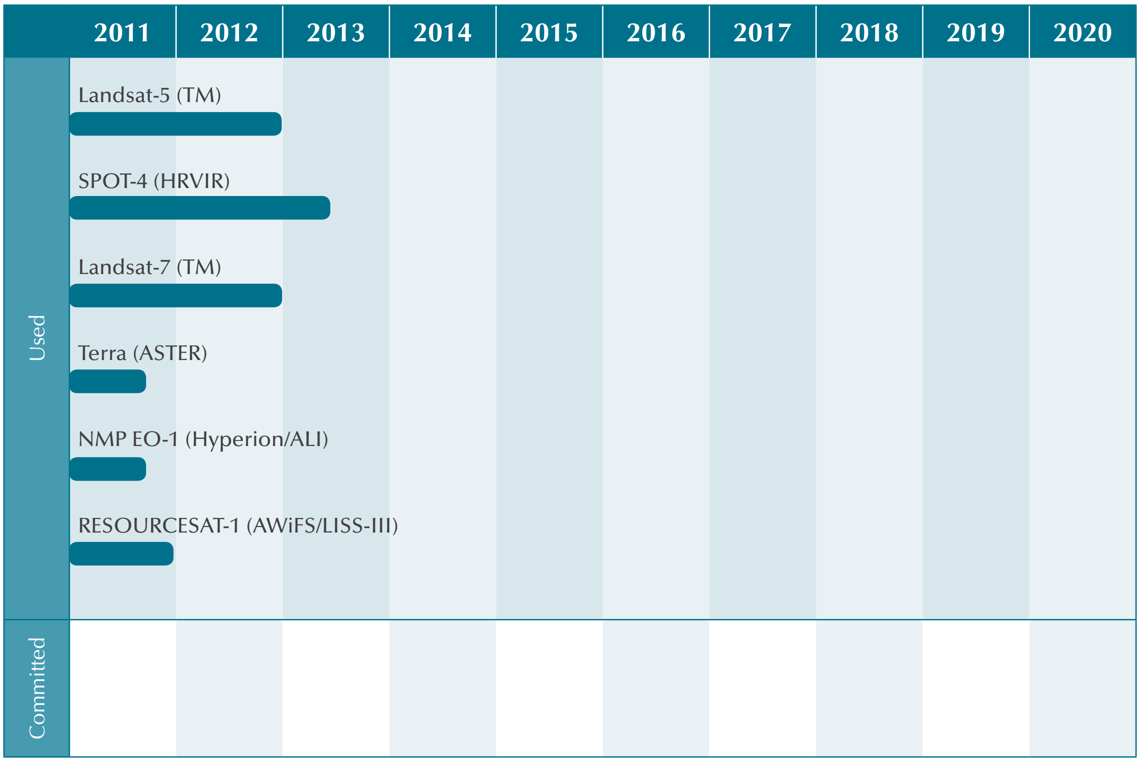


Total = Used + Not Used + Committed + Not Committed (see **Section 4.1.1**)
Used = Current sensors whose data are used for operational government programs in Australia

The life expectancy of medium resolution optical sensors currently available for use in Australia, and those to which a commitment for use has been made, are shown in **Figure 4-4**. As indicated by the lower portion of this figure, Australia does not have any formal arrangements in place to access future space-based medium resolution optical sensors.

17 Status categories are described in **Section 4.1.1**.

Figure 4-4 Used and Committed Sensors: Medium Resolution Optical



The Landsat series of satellites has been extremely popular in Australia for several decades, but the current satellites, Landsat 5 and Landsat 7, are already operating well beyond their design life. The Landsat Data Continuity Mission (LDCM) is being planned but will not be operational before 2013. The most widely used alternative to Landsat TM is SPOT-4 MSS which offers increased spatial resolution, but reduced spatial coverage and fewer spectral channels at a much higher cost, with more restrictive licensing conditions.

Source shifts for Landsat MSS and TM have been investigated for several operational programs, including the National Carbon Accounting System (NCAS) (Wu et al., 2009; Furby and Wu, 2006). Australian experience with some substitute data sets highlighted the importance of data integrity and the paramount importance of the high quality data and reliability of observations available from the Landsat program.

Some operational programs, such as the Statewide Land and Tree Survey (SLATS) conducted annually in Queensland, have adapted their processing procedures to use both SPOT and Landsat imagery. However, in general, operational programs are linked to a specific sensor, and source shifting is expensive and difficult.

An increasing number of new medium resolution optical sensors, especially hyperspectral and multispectral, are being designed to acquire a significantly larger volume of data in the near future. This increased volume is expected to exceed the currently available EOS data storage facilities and will also present challenging data transfer rates for existing communication infrastructure.

Given the widespread usage of medium resolution optical imagery in Australia, the potential loss of access to this data source is of extreme concern to the EOS community.

4.2.3 HIGH RESOLUTION OPTICAL

High resolution optical data (< 10 m pixels), or 'urban scale' imagery, is available from both space-based and airborne platforms. This imagery is offered by an increasing number of commercial outlets both in Australia and internationally. Aerial platforms currently supply over half the high resolution optical imagery being used in Australia and, as such, provide a viable alternative to space-based data sources. In addition to commercial sources, several federal and state government agencies operate their own high resolution airborne sensors.

Table F–3 (in **Appendix F**) lists operational and planned high resolution optical sensors to 2020. **Table 4-4** summarises the expected availability of high resolution optical sensors each year from 2011 to 2020. Of the 30 sources of high resolution optical data that are available internationally in 2011, only 2 sensors have been classified as 'used' in Australia, that is, 'currently operational sensors whose data are regularly utilised for active government programs in Australia' (see **Section 4.1.1**). Also, some of the 30 potential high resolution optical sensors may not provide data to an acceptable operating standard.

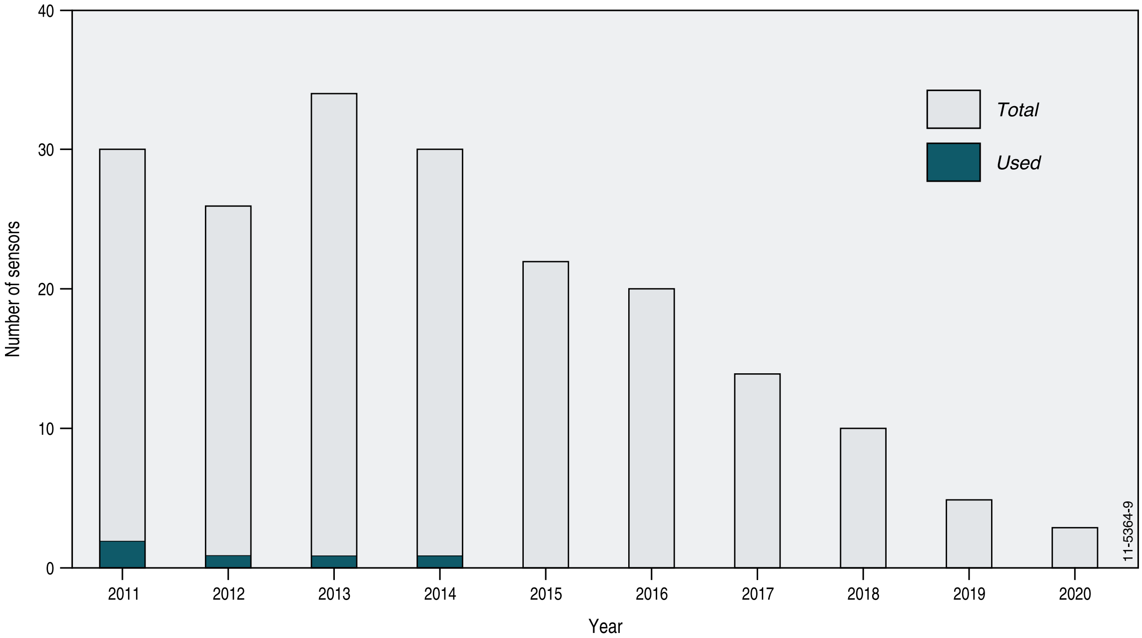
Table 4-4 EOS Sensor Availability: High Resolution Optical

CEODA-Ops Status[18]	Year									
	2011	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Used	2	1	1	1	0	0	0	0	0	0
Not Used	25	17	17	12	6	4	3	2	1	1
Committed	0	0	0	0	0	0	0	0	0	0
Not Committed	3	8	16	17	16	16	11	8	4	2
TOTAL	**30**	**26**	**34**	**30**	**22**	**20**	**14**	**10**	**5**	**3**

The projections in this table show a trend of decreasing access to space-based high resolution optical data in Australia over the next decade, as is also illustrated in **Figure 4-5**.

18 Status categories are described in Section **4.1.1**.

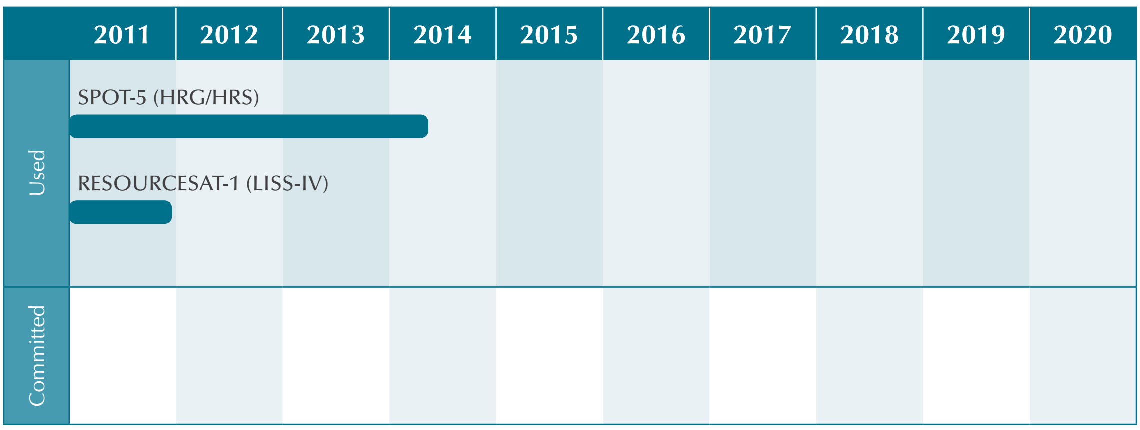
Figure 4-5 EOS Sensor Accessibility: High Resolution Optical



Total = Used + Not Used + Committed + Not Committed (see **Section 4.1.1**)
Used = Current sensors whose data are used for operational government programs in Australia

The expected life spans of the currently available high resolution optical EOS sensors are shown in **Figure 4-6**.

Figure 4-6 Used and Committed Sensors: High Resolution Optical



There is currently no provision for Australia to directly acquire data from future space-based high resolution optical sensors. Given the ready availability of airborne high resolution optical imagery, however, a serious shortage of this data type is not anticipated.

4.2.4 SYNTHETIC APERTURE RADAR

Satellite-based radar technology is relatively new compared with optical systems and usage is expected to increase with data familiarity and availability. While SAR data are available from both space-borne and aerial platforms, only space-based acquisition provides a synoptic view for large area studies. Accordingly, most land-surveying applications involving SAR data now use satellite observation. The rapid revisit time being offered by space-based SAR sensors provides the advantage of frequent data updates for critical applications such as disaster management and surveillance.

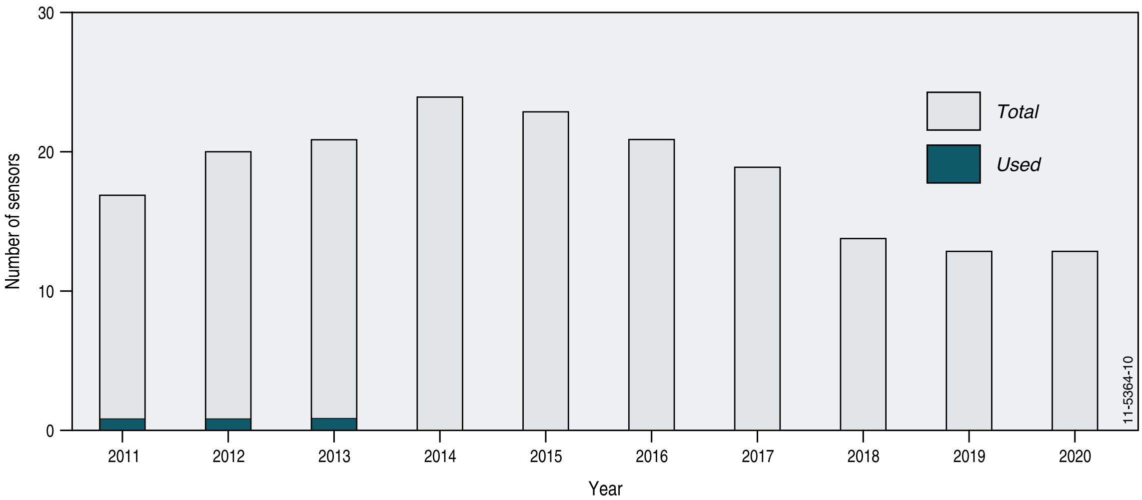
Table F–4 (in **Appendix F**) lists **both** operational and planned SAR sensors (to 2020). **Table 4-5** summarises the expected availability of SAR sensors from 2011 to 2020. While 17 sources of space-based SAR data are now available (in 2011), Australia is currently only acquiring data from one sensor on a routine basis. Some of the 17 potential SAR sensors, however, may not offer an acceptable standard of data for operational purposes.

Table 4-5 EOS Sensor Availability: Synthetic Aperture Radar

CEODA-Ops Status[19]	Year									
	2011	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Used	1	1	1	0	0	0	0	0	0	0
Not Used	13	13	11	10	5	1	1	0	0	0
Committed	0	0	0	0	0	0	0	0	0	0
Not Committed	3	6	9	14	18	20	18	14	13	13
TOTAL	**17**	**20**	**21**	**24**	**23**	**21**	**19**	**14**	**13**	**13**

Figure 4-7 illustrates a trend of decreasing access to SAR data in Australia over the next decade. Australia has no arrangements in place for access to operational, satellite-borne SAR data beyond 2013.

Figure 4-7 EOS Sensor Accessibility: Synthetic Aperture Radar

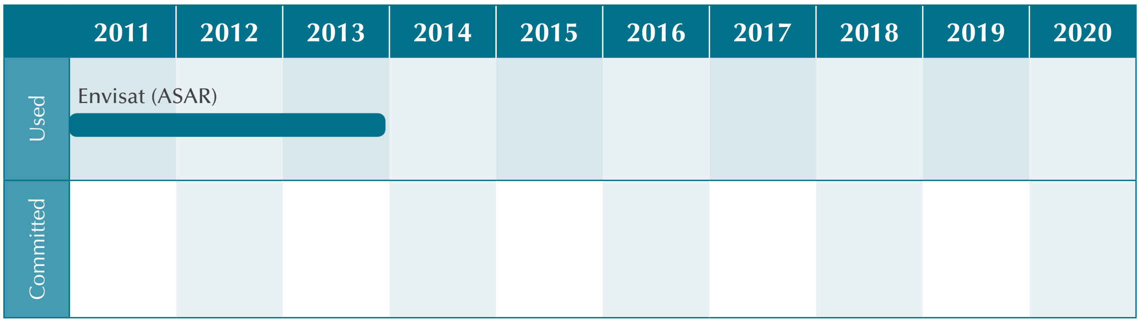


Total = Used + Not Used + Committed + Not Committed (see **Section 4.1.1**)
Used = Current sensors whose data are used for operational government programs in Australia

After the recent demise of ERS-1, the only SAR data being acquired in Australia is from the ASAR sensor, onboard the Envisat satellite. The life expectancy of this satellite is shown in **Figure 4-8**. There are currently no commitments in place to receive EOS SAR data in Australia from any planned sensors.

19 Status categories are described in Section **4.1.1**.

Figure 4-8 Used and Committed Sensors: Synthetic Aperture Radar



Given the potential for SAR data to support a wide range of applications, and the lack of alternative data sources, this projected data gap presents a serious risk for Australian EOS users.

4.2.5 PASSIVE MICROWAVE

Passive microwave data can also be acquired from both space-based and aerial platforms, but only satellite observations provide the synoptic view that enhances the value of this data source for regional and global studies.

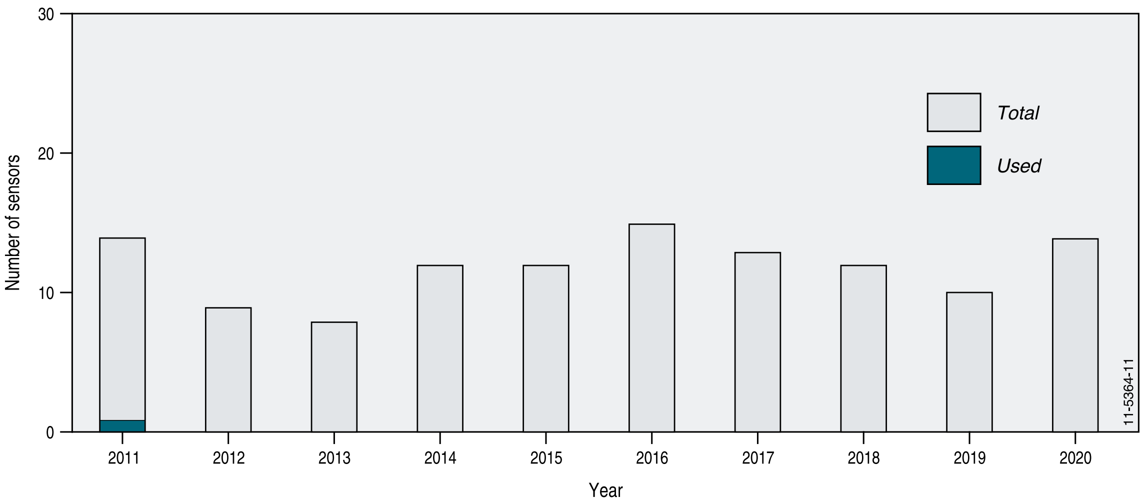
Table F-5 in **Appendix F** summarises the number of operational and planned passive microwave EOS sensors from 2011 to 2020. **Table 4-6** summarises the expected availability of passive microwave sensors from 2011 to 2020. Some of the potential passive microwave sensors, however, may not offer data of an acceptable standard for operational use.

Table 4-6 EOS Sensor Availability: Passive Microwave

CEODA-Ops Status[20]	Year									
	2011	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Used	1	0	0	0	0	0	0	0	0	0
Not Used	12	5	2	0	0	0	0	0	0	0
Committed	0	0	0	0	0	0	0	0	0	0
Not Committed	1	4	6	12	12	15	13	12	10	14
TOTAL	**14**	**9**	**8**	**12**	**12**	**15**	**13**	**12**	**10**	**14**

The projected access to passive microwave sensors over the next decade in Australia is illustrated in **Figure 4-9**.

Figure 4-9 EOS Sensor Accessibility: Passive Microwave

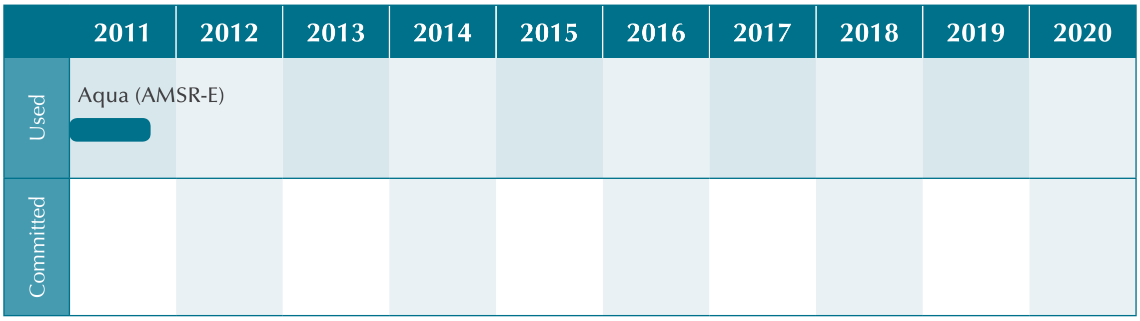


Total = Used + Not Used + Committed + Not Committed (see **Section 4.1.1**)
Used = Current sensors whose data are used for operational government programs in Australia

20 Status categories are described in Section **4.1.1**.

The only satellite-based, passive microwave sensor whose data is currently being acquired in Australia is AMSR-E, which is carried by the Aqua satellite. The life expectancy of AMSR-E is shown in **Figure 4-10**. There are no commitments in place at present for reception of passive microwave data from any of the planned sensors.

Figure 4-10 Used and Committed Sensors: Passive Microwave



Use of passive microwave is actively being researched in Australia for several monitoring applications, including hydrological modelling (Summerill *et al*, 2009). As such, its usage is expected to increase in the future. While the potential loss of access to this data type will currently have limited impact on the Australian EOS community, it warrants consideration in forward planning.

4.3 SUMMARY

The number of sensors in each CEODA-Ops Status category that *could* provide EOS data between 2011 and 2020 is summarised in **Table 4-7**. This summary clearly shows the extent to which Australia is currently using available EOS data. It also highlights the absence of plans and commitments to receive data from forthcoming sensors.

Table 4-7 Summary of CEODA-Ops Status21 (2011–2020)

CEODA-Ops Status[21]	Sensor Type					TOTAL
	Optical			SAR	Passive Microwave	
	Low spatial resolution (> 80 m)	*Med. spatial resolution (10-80 m)*	*High spatial resolution (< 10 m)*			
Used	10	8	2	1	1	22
Not Used	20	17	25	13	12	87
Committed	0	0	0	0	0	0
Not Committed	36	16	18	22	22	114
TOTAL	**66**	**41**	**45**	**36**	**35**	**223**

The annual availability of EOS data is summarised across all five sensor types, for each CEODA-Ops Status category, in **Table 4-8**. This table gives a year-by-year picture of EOS data availability, showing that data could continue to be available in Australia.

Table 4-8 EOS Sensor Availability: All Data Types

CEODA-Ops Status[21]	Year									
	2011	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
Used	22	12	8	5	3	2	1	0	0	0
Not Used	87	58	48	32	14	8	7	2	1	1
Committed	0	0	0	0	0	0	0	0	0	0
Not Committed	19	39	58	73	78	86	69	56	46	48
TOTAL	**128**	**109**	**114**	**110**	**95**	**96**	**77**	**58**	**47**	**49**

The total number of operational sensors (CEODA-Ops Status 'used' and 'not used') in 2011 is: 22 + 87 = 109.

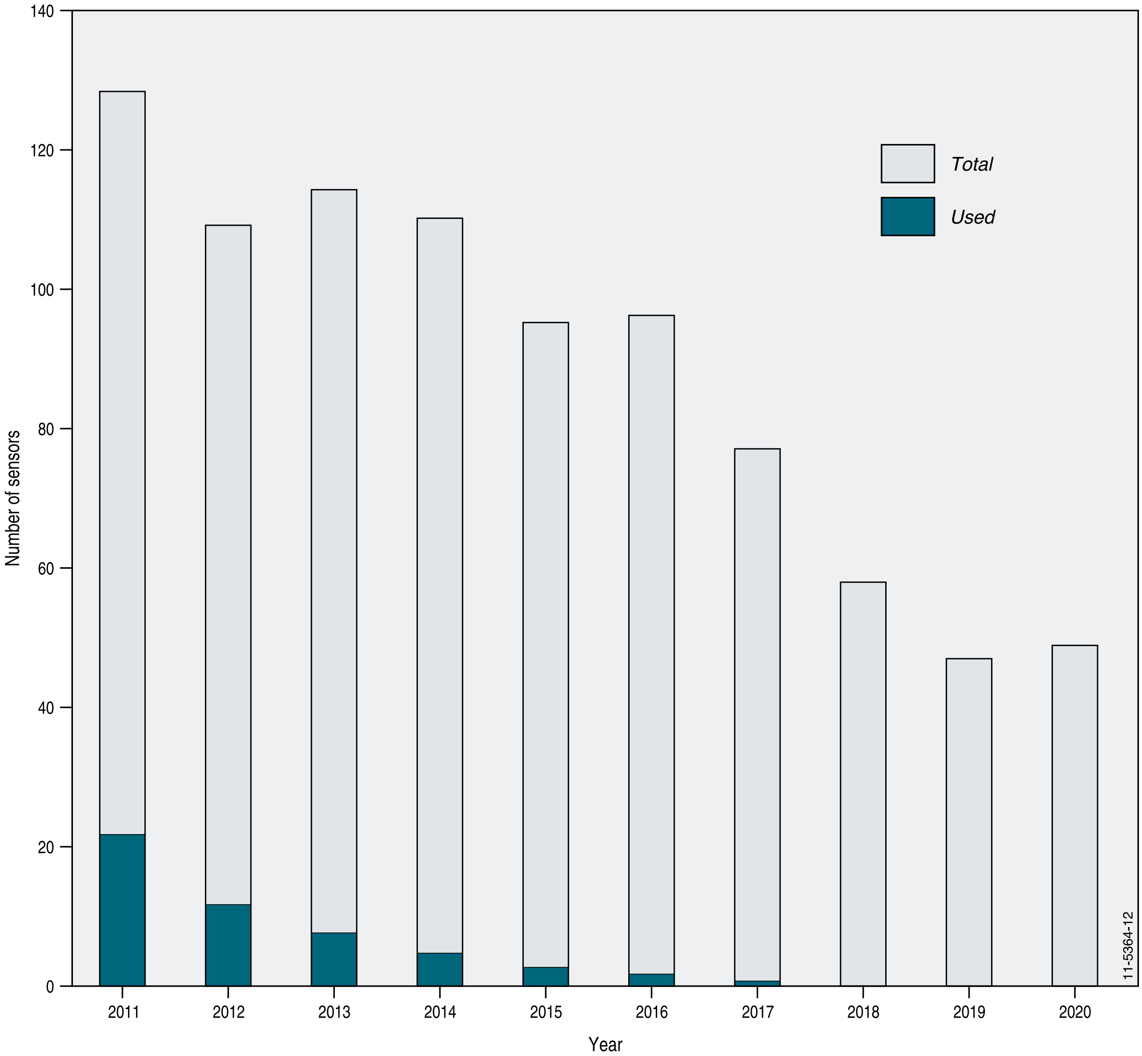
The data presented in **Table 4-8** illustrates that:

- Australia currently uses EOS data from 22 sensors, approximately 20% of the total number available; and
- Acquisition arrangements have *not* been ratified for any future sensors.

This is further illustrated in **Figure 4-11**, which shows the proportion, over time, of current and future sensors that Australia either uses or has plans to use. Note, however, that some of the available sensors may not provide EOS data to an acceptable standard for operational use.

21 Status categories are described in **Section 4.1.1**.

Figure 4-11 EOS Sensor Accessibility: All Data Types



Total = Used + Not Used + Committed + Not Committed (see **Section 4.1.1**)
Used = Current sensors whose data are used for operational government programs in Australia

In **Table 4-9**, for each data type, the number of EOS data sources projected to be available in Australia in 2015 is contrasted with the number available in 2011.

Table 4-9 Current and Projected EOS Sensors Available in Australia

EOS Sensors	Sensor Type					TOTAL
	Optical			SAR	Passive Microwave	
	Low spatial resolution (> 80 m)	*Med. spatial resolution (10-80 m)*	*High spatial resolution (< 10 m)*			
Accessed Operationally in 2011	10	8	2	1	1	**22**
Accessed Operationally in 2015 by Status Quo	3	0	0	0	0	**3**
2011 Sensors Available in 2015	30%	0%	0%	0%	0%	**< 14%**

The data presented in **Table 4-9** indicate that, under the current arrangements, Australian government programs will suffer a dramatic decline in access to operational EOS capabilities between 2011 and 2015. Less than 14% of the EOS data sets that are in use in 2011 will be available in 2015. The consequences of this situation are much more severe for individual data sets. No arrangements are currently in place for access to EOS data from medium and high resolution optical, SAR, or passive microwave sensors in 2015. There will be a 70% decline in data sets available from low resolution optical sensors over the same period.

Since alternative data sources exist for high resolution optical data, the projected shortage of space-based imagery in that data type is less critical to operational programs. The currently low level of usage of passive microwave data also means that a data shortage will impact fewer users and applications. The projected data gaps, however, are critical for medium resolution optical and space-based SAR data. In particular, the widespread usage of medium resolution optical data makes a potential shortage of this data type the most alarming.

Section 5
Discussion

The projected EOS data requirements detailed in **Section 3**, and the likely EOS data availability outlined in **Section 4**, warrant some additional comment. The disparities between requirements and operational availability (based on current plans and commitments), and their ramifications, will be discussed for each data type. Possible pathways are also suggested to avoid or minimise projected EOS data gaps in Australia.

5.1 MEETING PROJECTED REQUIREMENTS

Based on the analyses of data requirements and availability presented in **Sections 3** and **4** respectively, the current usage, expected requirements and projected availability of each CEODA-Ops data category are summarised in **Table 5-1**.

Table 5-1 EOS Data Usage, Requirements and Availability

	Sensor Type				
	Optical			SAR	Passive Microwave
	Low spatial resolution (> 80 m)	*Medium spatial resolution (10-80 m)*	*High spatial resolution (< 10 m)*		
Proportion of Sample Programs using Data Type in 2010	48%	79%	44%	16%	7%
Annual Data Storage Estimate in 2015[22]	202 TB	235 TB	747 TB	8 TB	15 MB
Potential Sensors Available in 20158	25	13	22	23	12
Expected sensors Accessible in Australia in 2015	3	0	0	0	0

5.1.1 DATA USAGE ISSUES

To consider the ramifications of these projections for each data type, three issues will be addressed:

1. What data access policy applies to this data type?
2. What infrastructure is required to acquire this data type?
3. What usage restrictions are imposed on this data type?

22 It should be noted that some potential sensors may not provide data of an acceptable standard for operational use.

5.1.1.1 Access Policies

Data providers, such as NASA, operate satellites for public good and provide data on a subsidised basis. Such data are available at a relatively low cost. Other sensors are operated as commercial enterprises, with costs that may be prohibitive for operational purposes.

5.1.1.2 Infrastructure Requirements

Infrastructure requirements are largely dictated by data volumes. The data rates associated with different data types necessitate the use of different downlink frequencies for data acquisition. When data acquisition involves low data rates, due either to low spatial resolution (large pixels) or low spectral extent (few data channels), the lower frequency microwave bands are sufficient for data capture. When the rate of data transmission necessitates the use of the higher frequency Ka band, however, significantly more expensive infrastructure is required for data acquisition.

5.1.1.3 Usage Restrictions

The final issue relates to the usage restrictions imposed on the data by the provider. Some suppliers impose restrictions on data sharing, which indirectly increase the cost of those data sets to the EOS community. Many forms of EOS data in Australia are now covered by a 'Creative Commons Acquisition Licence' that allows completely unrestricted sharing of the raw data and subsequent products. In an international context, this is referred to as an open data policy.

5.1.2 DATA TYPE ASSESSMENTS

5.1.2.1 Low Resolution Optical

The results presented in **Section 4.2.1** indicate that an Australian data gap in low resolution optical data is not likely before 2015. This is due to several factors:

1. All low resolution optical data are provided by public good sensors, which have an open data policy (such as WMO);
2. The low acquisition rates associated with this data type involve less expensive infrastructure; and
3. Australia's access to low resolution optical data is likely to be secured since most of the sensors are part of global monitoring missions, which are covered by multi-lateral agreements.

Given that the majority of low resolution optical sensors are operated for public good and involve low data acquisition rates, only a modest infrastructure upgrade would be required to ensure access to the expanded range of sensors planned to 2020. It is highly likely that low resolution optical data continuity will be secured through access to the NPP and JPSS missions (see **Section 8**).

5.1.2.2 Medium Resolution Optical

As discussed in **Section 4.2.2**, a significant data continuity problem is forecast for medium resolution optical data before 2015. The projected loss of this very widely used data type is cause for serious concern.

The current medium resolution optical workhorse, Landsat 5, is now over two decades past its design life. If this sensor should fail, the ensuing data gaps and source shifting could cost Australia $100 million per year (ACIL Tasman, 2010). Despite the current dependency on Landsat 5, and its precarious existence, there are no formal arrangements in place to receive medium resolution optical data from any of the planned sensors, including LDCM (Landsat Data Continuity Mission).

If high resolution imagery is used as a substitute for medium resolution data, there will be greatly increased data processing and storage overheads, substantially greater data costs and reduced data coverage (both spatially and temporally), as well as restricted data sharing due to licensing conditions. Should sources of medium resolution optical imagery become available through commercial outlets, such data will invariably be more expensive than that which is currently available from public good satellites. All of these potential costs must be borne by users, both government and private, and will necessarily involve disruptions and delays in current monitoring activities.

The potential impacts of data gaps in medium resolution optical imagery are demonstrated by numerous case studies. Were Landsat TM data to be unavailable during the Queensland floods, for example, EOS coverage would have been both less effective and more expensive. A number of legislative monitoring programs are currently dependent on data from this satellite, including NCAS (National Carbon Accounting System). Implementing an alterative source of imagery for carbon accounting, would involve considerable processing delays and an increased operational budget.

Most sources of medium resolution optical data are covered by an open data policy and are being operated for public good, although there are some commercial data sensors in this category. While access to medium resolution data from the LDCM and the Sentinel missions will largely alleviate the projected data shortage, their sensors can only satisfy some of the anticipated data requirements. To meet the expected requirements in 2015, some medium resolution optical data will also have to be acquired from commercial sensors.

The high data acquisition rates associated with some of the planned medium resolution optical sensors will also necessitate the use of Ka band equipment, with its increased infrastructure costs.

5.1.2.3 High Resolution Optical

The analyses presented in **Section 4.2.3** illustrated that a shortage of space-based, high resolution optical data is likely to develop in Australia before 2015. Since this data type can also be acquired from airborne platforms, and there are already several opportunities to acquire such data in Australia (involving both commercial and government enterprises), data gaps are not expected for high resolution optical data. The advantages of repeated, consistent broad area coverage from satellite sources, and their lower data cost, however, should encourage investigation of Australian access to future high resolution optical sensors.

Most sources of high resolution optical imagery are now acquired from commercial aircraft, with some being provided by commercial spacecraft and a small proportion being acquired from public good satellites. Currently, aerial data are available without licence restrictions, but most satellite sources of high resolution optical data have restrictive licensing. It is hoped that, by 2015, an open data policy will apply to at least some, if only a limited number, of the satellite-based, high resolution optical data sources.

The high data volumes associated with this data type will also necessitate the use of Ka band equipment for data acquisition. Thus, the infrastructure costs associated with this data type will also increase.

5.1.2.4 SAR

The results presented in **Section 4.2.4** and summarised in Table 5-1 indicate that no space-based SAR data will be available in Australia in 2015. While this data type is not currently used as widely as optical data, its advantages of frequent coverage and independence from weather and lighting conditions, will invariably increase its usage in the future. These advantages will be especially valuable for essential services such as disaster mitigation, pollution monitoring, search and rescue, and border protection. Usage will also increase as the analytical skills required to maximise data value are further developed in Australia and adapted to the Australian environment.

SAR data in Australia is currently acquired from both public good and commercial sources. Most public good sources offer an open data policy while most commercial sources of SAR data have highly restrictive licensing agreements. Less restrictive licensing arrangements are expected by 2015, with some sources possibly being unrestricted.

The infrastructure costs involved with acquiring SAR data are also high.

5.1.2.5 Passive Microwave

Passive microwave data from space-based platforms are also expected to be unavailable in Australia in 2015. Although the passive microwave data type is a high priority for the Bureau of Meteorology (as input into the numerical weather prediction system and for sea ice mapping), current usage of this data type for land and other marine applications, is low. Most passive microwave data are supplied by public good satellites, with no data licensing restrictions and low infrastructure costs.

5.1.3 OVERVIEW

The data presented in **Table 5-2** provide an overview of the differences between data types in terms of the risks of data gaps, the cost of infrastructure, and current and expected data licensing arrangements. The 'risk rating' ranks the relative severity of the projected data access situation for each data type, in terms of its impact on the Australian EOS community and the complexity of gaining access to new data in this area.

Table 5-2 Expected Data Risks, Infrastructure and Licensing

	Sensor Type				
	Optical			SAR	Passive Microwave
	Low spatial resolution (> 80 m)	*Medium spatial resolution (10-80 m)*	*High spatial resolution (< 10 m)*		
Data Gap Expected Before 2015[23]?	No	Yes	No	Yes	No
Data Source	Public Good	1. Public Good 2. Commercial	1. Airborne 2. Commercial 3. Public Good	Public Good/ Commercial	Public Good
Relative Infrastructure Costs	Low	High	High	High	Low
Data Licensing in 2011	Unrestricted	PG: Unrestricted *Comm*: Most restricted	*Airborne*: Unrestricted *Satellite*: Most restricted	PG: Unrestricted *Comm*: Highly restricted	Unrestricted
Expected Data Licensing in 2015	Unrestricted	Mostly unrestricted	Some unrestricted	Maybe some unrestricted	Unrestricted
Risk Rating[24]	Low	Very High	Medium	High	Low

5.2 POSSIBLE SCENARIOS

There are several scenarios that may be enacted in the near future with respect to Australian access to EOS data. Three possible scenarios are addressed briefly below:

- **No action**—the current access arrangements do not change;
- **Partial action**—some changes are made to the current arrangements to allow access to a minimum number of future sensors in the most critical data types (medium resolution optical and SAR); or
- **Full action**—arrangements are made to allow future access to all data types.

Future access to satellite data sources depends on the existence of both appropriate infrastructure to receive the relevant data format and volume, and ratified agreements with the data supplier to acquire the data. Both of these requirements involve significant lead times and must be planned accordingly.

23 Based on the current situation as assessed in this report.

24 Ratings are based on the relative severity of the projected data access situation, with respect to its impact on the 91 sample programs within state and federal agencies, and the complexity of gaining access to new data of this type.

5.2.1 NO ACTION

If the current arrangements governing access to EOS data in Australia do not change in the near future, projections indicate that in 2015:

- Limited *low resolution optical data will be available*: This outcome will have the greatest impact on Australia's capacity to monitor disasters and oceans.
- *No medium resolution optical data will be available*: This loss of access will either lead to an expensive source shifting exercise (as discussed in **Section 5.1.2.2**), or cessation of current programs such as the National Carbon Accounting System (NCAS) and the International Forest Carbon Initiative (IFCI) in addition to ceasing state monitoring activities required under EPA legislation. Staple inputs to disaster monitoring activities will also be significantly reduced.
- *No high resolution optical data will be available*: This is considered to be the least serious outcome from the current projections as airborne platforms can also acquire high resolution optical imagery. Although high resolution data will be available from airborne sources, acquisition of rural and regional areas in particular would be substantially more expensive and more variable in quality due to the inevitable *ad hoc* acquisition process.
- *No Synthetic Aperture Radar (SAR) data will be available*: This potential shortage will have greatest impact on Defence and civil surveillance activities. Some commercial sources of SAR data could fill this gap but generally these are not economically viable for the majority of applications. Given the increasing usage of SAR data, however, a reduction in access will further reduce the Australian skills base pertaining to this data type and hamper realisation of the potential benefits of SAR analyses.
- *No passive microwave data will be available*: Passive microwave data from aerial platforms will continue to be available for research activities, but the growing dependence on space-based passive microwave data for hydrological modelling cannot be supported from aerial data sources, due to both reduced coverage and greater costs.

The 'No Action' scenario will jeopardise the current $3.3 billion per annum GDP contribution derived from EO and disable the projected growth to $4 billion per annum GDP contribution by 2015. Inaction will also cost Australian agencies dearly in terms of reduced monitoring and surveillance capacity, lack of continuity for operational monitoring programs, greater data and processing budgets, loss of current expertise, and potential non-compliance with several international agreements and treaties.

5.2.2 PARTIAL ACTION

The most serious consequences of 'No Action', outlined in **Section 5.2.1,** can be avoided by securing access to at least two space-based categories of data: medium resolution optical and SAR. This partial action would limit the projected damage to:

- A reduced capacity in low resolution optical imagery; and
- Use of aerial data sets for high resolution optical and passive microwave data.

The 'Partial Action' scenario may protect the $3.3 billion per annum GDP contribution currently derived from EO but will risk realisation of the projected growth to $4 billion per annum GDP contribution by 2015. While this outcome is not ideal, it would significantly reduce the severity of the projected data gaps.

5.2.3 FULL ACTION

Through treatment of the risks currently existing within the EOS sector, Australia would have guaranteed access to at least three future EOS sensors in each data type, as well as access to a greater number of sensors for low resolution optical imagery. This level of access would offer some redundancy to cater for unplanned interruptions to EOS data delivery. It would also provide greater frequency of coverage, which is particularly valuable for emergency and surveillance activities, and increase the likelihood of favourable atmospheric conditions for image acquisition.

An added benefit of this situation would be the expansion and consolidation of the EOS skills base in Australia, allowing its prominence in the international EOS community to be strengthened. A stronger skills base would further benefit the many application areas now relying on EOS data by tailoring methodologies to specific requirements and improving the efficiency of data usage and management.

The 'Full Action' scenario will safeguard the $3.3 billion per annum GDP contribution currently derived from EO and maximise the likelihood of achieving the projected growth to $4 billion per annum GDP contribution by 2015. It should be remembered that Australia's EOS activities are currently providing a return on investment of more than 30 to one.

5.3 PRIORITIES FOR ACTION

As discussed in **Section 3.3**, it has been projected that, by 2015, 1.2 PB of EOS data per year will be required to support the 91 sample programs. This represents a twentyfold increase on the volume of data currently acquired by GA, and will impact all stages of the EOS supply chain described in **Section 1.4.4**.

The collective opinion of GA, CSIRO, BOM and DIGO (Australian Government, 2011) is that the EOS supply chain can be characterised by five space investment areas:

- Coordination and cooperation;
- Securing future Earth observations;
- Investment in ground infrastructure and communications;
- Extracting value; and
- Sustained capability to deliver.

5.3.1 COORDINATION AND COOPERATION

Implementation of this investment area would involve governance structures to coordinate the EOS-related activities within and between relevant agencies and jurisdictions, and a facility to coordinate satellite imagery. The national or virtual facility would assist planning and preparedness for disaster risk reduction and provide rapid access to information from satellites in emergency response situations.

The benefits of governance structures would include reduced duplication, shared expertise and greater unity of effort between agencies. National co-ordination of imagery would allow improved responsiveness to emergency situations through rapid access to satellite information and reduced duplication across all levels of government.

5.3.2 SECURING FUTURE EARTH OBSERVATIONS

Securing future Earth observations as efficiently as possible could be achieved by ensuring access to international public good observation sources and ensuring appropriate and efficient use of commercial capabilities. Investment in these areas would maintain the continuity of data records, provide cost-effective EOS data to government, industry, research and the community, and allow access to capabilities above and beyond those available from public good data.

This investment area would also involve securing Australian engagement and/or partnership in ongoing and new EOS missions, through co-investment where necessary. This would provide access to, and the knowledge to apply, new sources of scientific data for greater understanding of Earth and environmental resources and processes, as well as build capability within the Australian research and industry sectors.

5.3.3 INVESTMENT IN GROUND INFRASTRUCTURE AND COMMUNICATIONS

Investment in ground infrastructure and communications would include a strategically planned and geographically distributed national antenna network to ensure that Australia is able to receive (both directly from space and via international telecommunications networks) and distribute the required data. It would also involve high speed communications, linking ground stations with operating agencies to enable timely analysis and release of information, and assured access to radiofrequency spectrum. The latter facility is required both to downlink public good satellite data and also to protect sensitive passive atmospheric sounding bands (or 'fingerprints of nature').

Benefits from these investments include more efficient and expanded national ground capability, greater access to data from international EOS missions, more timely access to satellite data, and increased interoperability between agencies.

5.3.4 EXTRACTING VALUE

This investment area would establish systems for data processing, scientific analysis and information delivery, which have high volume storage and intensive computational capacities, to ensure that raw EOS data can be rapidly processed to meet user needs. Calibration, data quality and certification activities will also ensure that the value derived from EOS data will be maximised. Innovative research outcomes should be encouraged across all sectors that utilise and benefit from EOS. These investments would improve services from operational agencies and offer increased return on investment from EOS.

5.3.5 SUSTAINED CAPABILITY TO DELIVER

This capability relies on investment in Australian EOS skills. Australian scientists need to have the knowledge and opportunity to be fully engaged in future specialist science missions. Continuous development is also required to ensure that both the scientific capability to process, calibrate, interpret and ensure uptake of new EOS data streams, and the capabilities required to support and sustain the technical and physical infrastructure for EOS data generation, acquisition and handling are readily available in Australia. These capabilities would enable sustained operation of the EOS supply chain and ensure delivery of timely and appropriate EOS products to inform national priorities.

5.4 LINKING PRIORITIES TO APPLICATIONS

The driving force for all EOS data usage, and ultimately space policy, is the application of Earth observations to real world problems. In **Section 1.2.1**, Australia's expertise in EOS was summarised in terms of ten application areas. These application areas both feed into and benefit from the five EOS data types that have been considered in this report.

The interrelationships between space investment areas, data types and EOS applications are presented in Table 5-3.

Table 5-3 Linkages between Investment Areas and Applications

Investment Areas	Sensor Type					Applications
	Optical			SAR	Passive M/wave	
	Low (> 80 m)	*Medium (10-80 m)*	*High (< 10 m)*			
Coordination and Cooperation	✔	✔	✔	✔		
Securing Future Earth Observations	✔	✔		✔		
Investment in Ground Infrastructure and Communications		✔		✔		
Extracting Value		✔		✔	✔	
Sustained Capability to Deliver			✔	✔	✔	
	✔	✔		✔	✔	Weather forecasting
		✔		✔	✔	Climate change/ atmosphere
		✔		✔	✔	Natural disaster mitigation
			✔	✔	✔	Cartography, positioning and navigation
		✔	✔	✔	✔	Mineral and resources exploration
			✔			Infrastructure planning and reporting
	✔	✔				Natural resource management
	✔	✔		✔	✔	Water availability and usage monitoring
	✔	✔		✔	✔	Ocean surveillance and monitoring
		✔	✔			Bathymetry and water quality in coastal areas

Securing future access to medium resolution optical data, the highest priority for action, would involve four of the five investment areas described above, with ensuing benefits to eight of the ten application areas. To secure future access to the second highest priority data type, SAR, would require investment in all five areas, with direct benefits to seven of the ten application areas. Securing access to the other data types would require investment in fewer areas and deliver benefits to fewer applications.

Section 6

Conclusion

Australia currently has at least 91 clearly identifiable programs being conducted by federal and state agencies that depend on EOS data (see **Section 2** and **Appendix E**). These ongoing, operational programs encompass a broad range of application areas, some of which involve monitoring in order to meet international reporting commitments or legislated mapping requirements. In the future, this reliance on EOS data will inevitably increase and expand to include an ever-widening range of land, water and other management applications.

The current (2010[25]) and projected (2015) EOS data requirements of these 91 programs were considered in **Section 3** in terms of five data categories: low, medium and high resolution optical, SAR, and passive microwave. Over three quarters of the 91 operational programs referred to above currently use medium resolution optical data, and nearly half use low resolution optical data. While some EOS data types can be acquired from airborne sensors, the synoptic scale of low and medium resolution optical data is only available from space-based platforms.

The projected data requirements for 2015 (presented in **Section 3**) indicate a substantial increase in required data volumes for all data categories compared with the current usage levels. The total data storage required in 2015 was estimated at 1.2 PB per year, a twentyfold increase on the data storage currently required. This increase will significantly impact the entire EOS supply chain and necessitate infrastructure upgrades for most data types.

Since Australia does not have its own EOS satellite, all EOS data are acquired from satellites that are operated under foreign ownership. Australia's current access to these data depends on ratified agreements with the satellite operators, and establishment and maintenance of appropriate local infrastructure. As detailed in **Section 4**, in 2011, of the 109 internationally available, space-based sensors relevant to the five data types, only 22 are accessible in Australia.

The projected Australian availability of EOS data in 2015 indicates a much more restrictive situation. Australia currently does not have any arrangements to access the additional 114 new sensors that will become operational in the next decade. As the current range of sensors cease operation (and many are already long past their design life), fewer sources of EOS data will be accessible in Australia.

The data availability projections presented in **Section 4** forecast that, under the current arrangements, there will be no access to some EOS data types before 2015. Of the 25 low resolution optical sensors that will be available in 2015, only three will be accessible in Australia. While many sensors will be available internationally in 2015 to acquire medium and high resolution optical, and SAR and passive microwave data (namely 13, 24, 23 and 12 sensors respectively), under the current arrangements none of them will be accessible in Australia[26].

The potential loss of access to these data sets would cut supply of EOS data to 47 of the 91 programs and severely restrict EOS data input to the remainder. The most critical of the potentially affected application areas involve emergency management and/or international agreements on environmental monitoring (such as IFCI), both of which have become critically reliant on EOS data sets.

25 Based on Geoscience Australia (2010)

26 Please note that some of these potential sensors may not provide data of an acceptable standard for operational use.

The most serious of these potential EOS data gaps involve medium resolution optical data, which are currently being used by 72 of the 91 operational programs that form the information basis for this report. Medium resolution optical imagery is already used as the basis for monitoring programs that are necessary to meet legislative or international obligations, for example the National Carbon Accounting System (NCAS). It should be noted that this scale of data is only acquired from space-borne sensors, hence there are no alternative data sources.

The ramifications of these projected data gaps would impact the Australian environment, population and economy, as well as Australia's international credibility. The GDP contribution of the Australian EOS sector has been valued at $3.3 billion per annum (ACIL Tasman, 2010), with significant increases expected in future years. In light of the current government expenditure on remote sensing of approximately $100 million per annum (Geoscience Australia, 2010), this equates to a return on investment of more than 30 to one. The potential data gaps would jeopardise both current and future economic benefits derived from EOS in Australia.

Sensors detecting microwave wavelengths, such as SAR and passive microwave, offer particular flexibility in terms of their independence from weather and illumination conditions. The unique synoptic view that is offered by space-borne, microwave sensors cannot be rendered by airborne sensors. The forecast lack of access to spacwe-based SAR data, a relatively new and growing area of EOS in Australia, is of great concern. Even though passive microwave data are only used by a small number of programs at present, its future access in Australia should also be secured.

While a shortage of low resolution optical imagery is not envisaged in the near future, for a relatively small investment Australia could upgrade infrastructure to receive a greater volume of this data type. More frequent coverage of low resolution optical data would have a direct and immediate benefit for disaster and surveillance monitoring.

Although alternative data sources are available for high resolution imagery, the contiguous, repeated coverage offered by satellite sensors should also encourage investigation of ongoing Australian access to this data type.

Only EOS data used for terrestrial, coastal and ocean monitoring have been considered in this report. By focusing on the projected data requirements of the 91 sample programs, the estimates for these application areas are necessarily conservative. A significant volume of EOS data is also used to support operational meteorological programs in Australia. Furthermore, an active Australian research and development sector is investigating a wide range of EOS data types for a diversity of applications, but this usage has not be considered in the CEODA-Ops projections.

It should also be emphasised that this report has been restricted to analysis of five types of EOS data that are currently being used in Australia. Newer space-based sensors such as lidar and hyperspectral, which offer higher radiometric and spectral fidelity, are poised to become more operationally available in the near future. It is expected that a growing proportion of current government programs will also utilise these newer data sources over the next decade. Additionally, new EOS-dependent programs are envisaged, such as regular surface emissivity mapping for climate modelling or high definition mineral mapping, which can only be realistically supported by these new technologies. These new sources of EOS data will increase both the complexity of observational requirements and the volume of data being acquired and archived.

There are currently no plans for an EOS satellite program in Australia. As Australia's dependence on EOS increases, the risks involved with reliance on foreign satellite data also increase. Australia's involvement in future satellite constellations should also be investigated to allow input into sensor design and coverage. This option would also provide greater data security for the Australian EOS community.

Given the current reliance on foreign satellites for the supply of EOS data in Australia, strategic planning with consideration to the five space investment areas is urgently needed to guarantee future data availability.

As a matter of priority Australia needs to formalise agreements with several upcoming EOS missions, and formulate a decadal infrastructure plan to safeguard the supply of EOS data.

The highest priorities for Australian access to future EOS missions are the Landsat Data Continuity Mission (LDCM), which will replace the Landsat 5 and Landsat 7 satellites in December 2012, and the Sentinel missions, planned for 2013+.

Considering the significant time frames required to ratify formal agreements with data suppliers, and establish appropriate infrastructure for reception and distribution of EOS data, there is limited time available to act on these recommendations.

Section 7
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Section 8
Glossary

AAD	Australian Antarctic Division
AATSR	Advanced Along-Track Scanning Radiometer
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
AFMA	Australian Fisheries Management Authority
AGD	Attorney-General's Department
AGRIC	WA Department of Agriculture and Food (Australia)
AIMS	Australian Institute for Marine Science
ALI	Advanced Land Imager
ALISEO	Aerospace Leap-frog Imaging Stationary interferometer for Earth Observation
ALOS	Advanced Land Observing Satellite (JAXA, Japan)
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
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-2	Along Track Scanning Radiometer-2
ATSR/M	Along Track Scanning Radiometer/Microwave
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)
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)
C-Band SAR	C-Band Synthetic Aperture Radar
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CalVal	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
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.
CHRIS	Compact High Resolution Imaging Spectrometer
CNES	Centre National d'Etudes Spatiales (France)

COCTS	China Ocean Colour & 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)
COSMO	COnstellation of small Satellites for the Mediterranean basin Observation
COSMO-SkyMed	COSMO satellite series
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 Science 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 US satellite system operator and digital image product provider (formerly EarthWatch, and WorldView Imaging Corporation)
DIGO	Defence Imagery and Geospatial Organisation (Australia)
DIISR	Department of Innovation, Industry, Science and Research (Australia)
DIPE	NT Department of Infrastructure, Planning and Environment (Australia)
DLR	Deutsche Zentrum für Luft- und Raumfahrt (Germany)
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)
DRET	Department of Resources, Energy and Tourism (Australia)
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
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)
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
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 Observation: Intergovernmental body established in 2002 that encourages members to coordinate projects, strategies and investments for Earth Observation.
GeoEye	Private US company providing satellite and aerial imagery and services
GEOSS	Group on 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
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)
GMES	Global Monitoring for Environment and Security (ESA)
GOCI	Geostationary Ocean Colour Imager
GOES-R	Geostationary Operational Environmental Satellite R-Series (NOAA)
GOES-S	Geostationary Operational Environmental Satellite S-Series (NOAA)
GRDC	Grain Research and Development Corporation (Australia)
GSQ	Geological Survey of Queensland (Australia)
GSWA	Geological Survey of WA (Australia)
HHI	Hyperion Hyperspectral Imager
HiRI	High Resolution Imager
HJ	Huan Jing (environment) satellite series (China)
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
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
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 Camera
IRS	Infrared Sounding instrument
IRS-P6	Indian Remote Sensing satellite, also known as RESOURCESAT-1
ISA	International Space Agency
ISRO	Indian Space Research Organisation
JAXA	Japan Aerospace Exploration Agency
JMA	Japan Meteorological Agency
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
KB	Kilobyte (210 bytes)
KMSS	ROSHYDROMET MultiSpectral Imager (VIS)
KOMPSAT	KOrea Multi-Purpose SATellite
LAI	Leaf Area Index
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 (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)
LPMA	NSW Land and Property Management Authority (Australia)
MB	Megabyte (103 KB)
MBEI	Multi-Band Earth Imager
MCSI	Multiple Channel Scanning Imager
MDA	MacDonald Dettwiler and Associates (Canada)
MDBA	Murray-Darling Basin Authority (Australia)
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)
MIRAS	Microwave Imaging Radiometer using Aperture Synthesis
MIREI	Middle Infra-Red Earth Imager
MMRS	Multispectral Medium Resolution Scanner
MODIS	MODerate-Resolution Imaging Spectroradiometer (NASA)
Monitor-E	Monitor Experimental (Russia)
MS	MultiSpectral (Camera or Imager)
MSC	Multi-Spectral Camera
MSI	Multi Spectral Imager
MSMR	Multifrequency Scanning Microwave Radiometer
MSS	Multispectral Scanner
MSU-MR	Multispectral Scanning Imager–Radiometer (vis/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)
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)
NFI	National Forest Inventory (Australia)
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 Millenium Program Earth Observing mission 1
NOAA	National Oceanic and Atmospheric Administration (USA)
NPOESS	National Polar-orbiting Operational Environmental Satellite System (USA)
NPP	NPOESS Preparatory Project (USA)
NRSCC	National Remote Sensing Center of China
NRSTRG	National Remote Sensing Technical Reference Group (Australia) (see **Appendix A**)
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)
NTLIS	NT Land Information System (Australia)
NVIS	National Vegetation Information System (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
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)
RADAR	RAdio Detection And Ranging
RADARSAT	RADAR SATellite (Canada)
RADARSAT C	RADAR SATellite Constellation (Canada)
RapidEye	German geospatial information provider
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)
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
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)
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)
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
SZS	Shore Zone Scanner
TanDEM-X	TerraSAR-X add-on for Digital Elevation Measurement (Germany)
TB	Terabyte (109 KB)
TERN	Terrestrial Ecosystem Research Network (Australia)
Terra	From the latin word for "earth", a multi-national NASA scientific research satellite
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 Infra-red Radiometer
TIRS	Thermal Infra-Red Sensor
TM	Thematic Mapper
TMI	TRMM Microwave Imager
TopSat	Tactical Optical Satellite (UK)
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)
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	US Geological Survey (USA)
UWA	University of WA (Australia)
VENμS	Vegitation 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 (panchromaic imager only)
X-Band SAR	X-Band Synthetic Aperture Radar

Appendices

Appendix A—Terms of Reference for NRSTRG

The terms of reference for the National Remote Sensing Technical Reference Group (NRSTRG) are to provide:

- Input to and advise on technical and delivery issues associated with reception and use of public good satellite imagery in Australia; and
- Input and advice on strategic issues concerning access to, and future requirements for, remotely sensed imagery, such as future applications and upcoming earth observation missions.

The group provides:

- Advice on technical and strategic remote sensing issues in a national and international context; and
- Input into the development of GA strategic and contingency plans through a forum for consultation and liaison on remote sensing issues on a technical level and identification of related policy implications.

Appendix B—CEODA-Ops Contributors

Australian Government

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Appendix C—CEODA-Ops Data Coverage

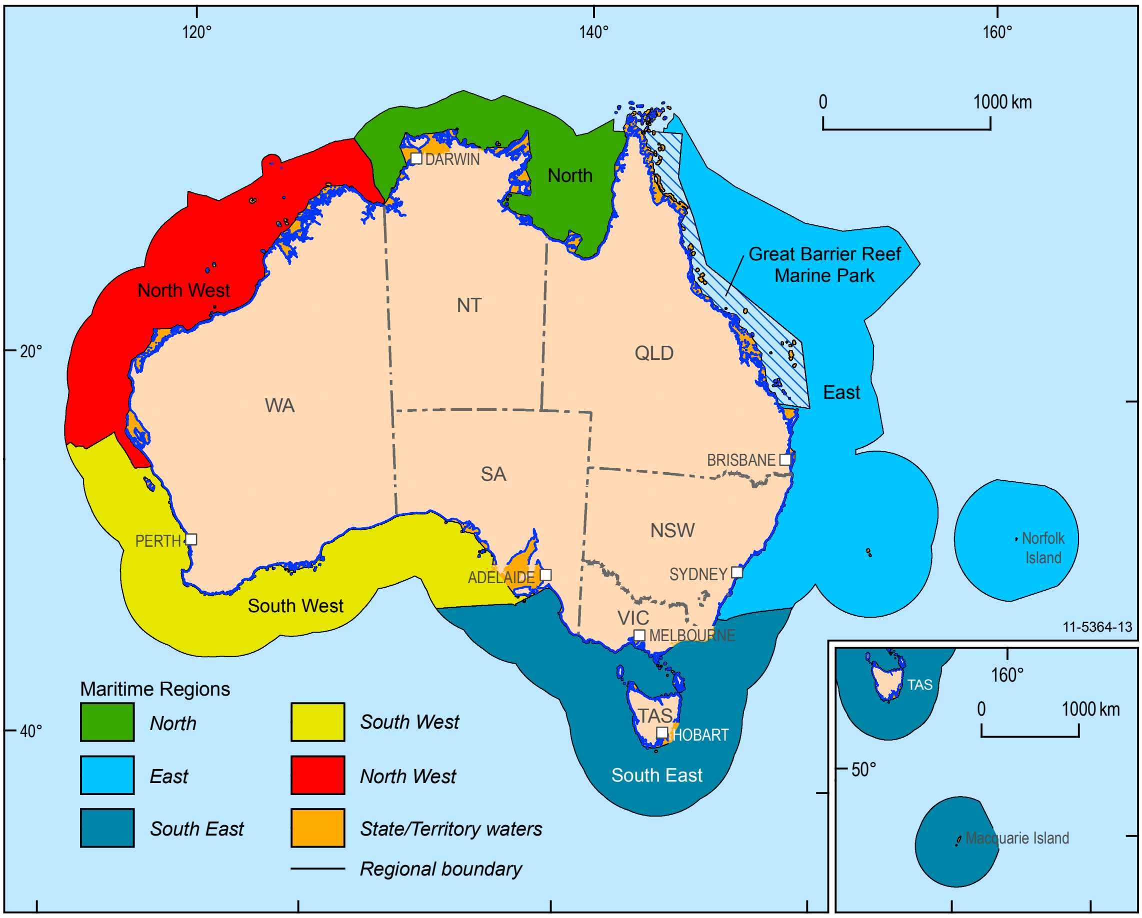
C.1 SPATIAL COVERAGE

For the purpose of this report, spatial coverage of EOS data for Australia is considered in terms of:

- even marine zones;
- Twelve terrestrial regions; and
- All urban locations, defined as cities and towns with at least 2,000 inhabitants.

Six of the marine regions (see **Figure C-1**) are based on the Integrated Marine and Coastal Regionalisation of Australia (IMCRA) v4.0, which identifies a total of 41 on-shelf and off-shelf provincial bioregions[27]. These exclude waters adjacent to the Territory of Heard Island and McDonald Islands, and waters adjacent to the Australian Antarctic Territory.

Figure C-1 CEODA-Ops Maritime Regions



The six IMCRA marine regions are:

- Coastal (including Great Barrier Reef) ;
- East (including Norfolk Island);
- South-east (including Macquarie Island);
- South-west;
- North-west; and
- North.

27 http://www.environment.gov.au/coasts/mbp/publications/imcra/pubs/imcra4.pdf

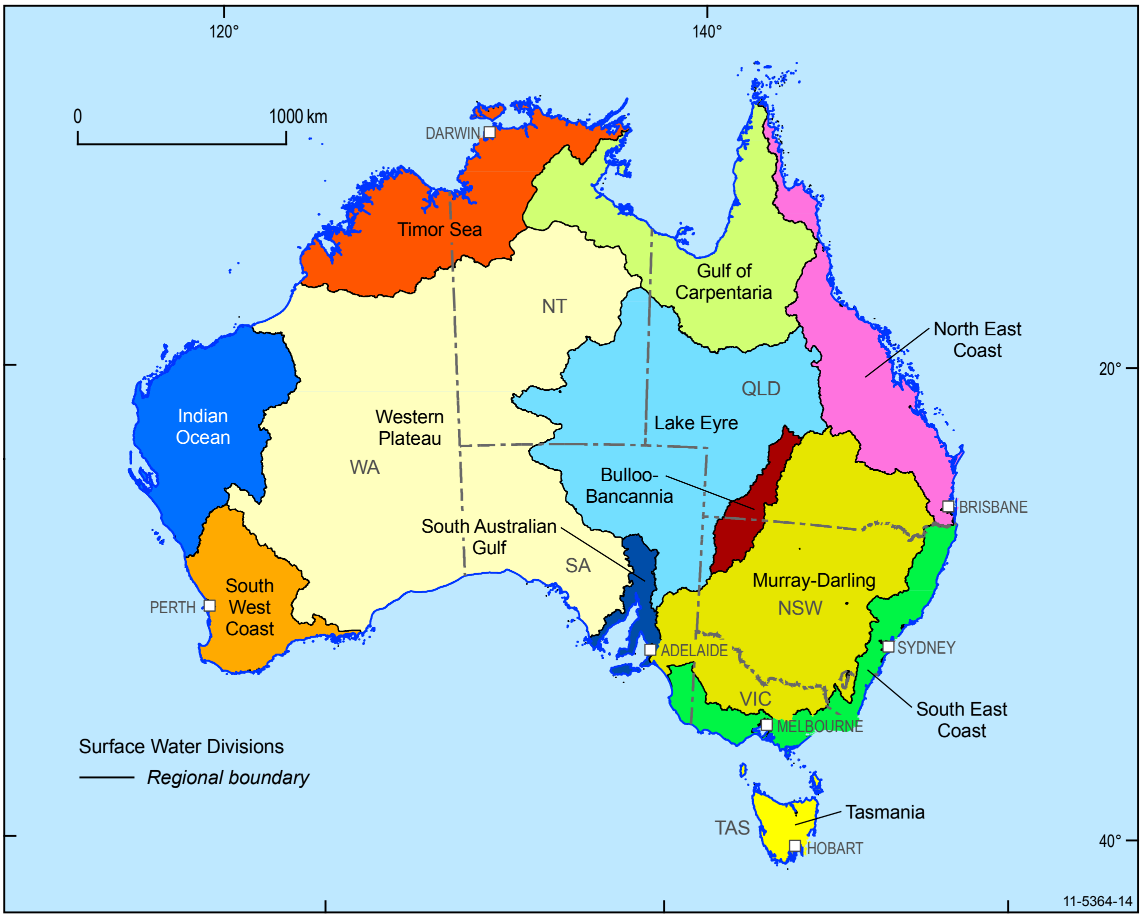
The seventh marine zone covers Australia's extended continental shelf entitlement declared by UNCLOS (United Nations Convention on the Law of the Sea) in 2008[28].

The 12 terrestrial regions illustrated in **Figure C-2** are based on Surface Water Divisions from the Australian Natural Resources Atlas[29]. These regions are:

- Tasmania;
- South-east Coast;
- South Australian Gulf;
- South-west Coast;
- Indian Ocean;
- Western Plateau;
- Timor Sea;
- Gulf of Carpentaria;
- North-east Coast;
- Murray-Darling;
- Bulloo-Bancannia; and
- Lake Eyre.

28 http://www.ga.gov.au/ausgeonews/ausgeonews200903/limits.jsp
29 http://www.anra.gov.au/topics/water/overview/index.html#basin

Figure C-2 CEODA-Ops Terrestrial Regions



The combined coverage of current Australian remote sensing projects requires EOS data in all these regions of interest. Some projects also require coverage of the Australian Antarctic Region.

Due to increasing engagement in regional affairs, there is also a growing need for EOS data, especially low and medium resolution optical, and SAR, that cover territories outside of Australian jurisdiction. Further and ongoing requirements have arisen due to international agreements, such as the International Forest Carbon Initiative[30] (IFCI).

30 http://www.climatechange.gov.au/en/government/initiatives/international-forest-carbon-initiative.aspx

C.2 TEMPORAL COVERAGE

Most monitoring programs rely on imagery being available at regular intervals, on an ongoing basis. The continuity, or temporal coverage, of a particular satellite sensor data set depends on the launch date and life expectancy of the host satellite(s), as well as the performance and reliability of the sensor(s). For some commercial satellites, such as SPOT, where the data are acquired on demand, temporal coverage may be further limited by acquisition timetables.

Temporal requirements for different applications vary widely from hourly to biennially, while some programs only need imagery on an *ad hoc* basis. To allow for data loss due to cloud cover, reception problems or other issues, however, imagery may need to be archived more frequently than the temporal requirement of an application. Some periodic mapping projects also require additional imagery from multiple sensors to produce 'minimum-cloud' composite images. Accordingly, the temporal requirements listed in **Section 3** show the frequency of data actually required in order to service existing remote sensing programs rather than the frequency of the program's product.

In this report, temporal requirements are considered in terms of six categories:

- Hourly: new imagery every hour;
- Daily: new imagery every day;
- Monthly: new imagery every month;
- Quarterly: new imagery every three months;
- Annually: new imagery every year; and
- Triennially: new imagery every three years.

Appendix D—CEOS Instrument Categories

The data categories being considered herein are a subset of those defined by the Committee on Earth Observation Satellites (CEOS; CEOS, 2010).

International EOS capabilities and plans are documented comprehensively in *The Earth Observation Handbook* (CEOS, 2010). Details of sensors and satellites cited in the present report have been derived from the 2010 web update[31] and relevant websites for commercial sensors.

The CEOS Handbook identifies 14 instrument categories:

a. Atmospheric chemistry instruments;

b. Atmospheric temperature and humidity sounders;

c. Cloud profile and rain radars;

d. Earth radiation budget radiometers;

e. High resolution optical sensors;

f. Imaging multi-spectral radiometers (vis/IR);

g. Imaging multi-spectral radiometers (passive microwave);

h. Imaging microwave radars;

i. Lidars;

j. Multiple direction/polarisation instruments;

k. Ocean colour instruments;

l. Radar altimeters;

m. Scatterometers; and

n. Gravity, magnetic field and geodynamic instruments.

For the purposes of this report, only those CEOS instrument types that are currently being used in the 91 Australian EOS programs (defined in Geoscience Australia (2010)) have been included. These are:

o. High resolution optical sensors;

p. Imaging multi-spectral radiometers (vis/IR);

q. Imaging multi-spectral radiometers (passive microwave);

r. Imaging microwave radars;

s. Radar altimeters; and

t. Ocean colour instruments.

31 http://www.eohandbook.com/eohb2010//PDFs/EOHB%202010%20key%20tables.pdf
Note that instruments classified as 'TBA', 'Proposed', 'Prototype' or 'No longer operational' have not been considered in the present report. Further, multiple radar modes of any relevant sensors have not been considered as separate sensors.

Appendix E—EOS Data Dependencies

The following table details the 91 current EOS data programs being undertaken by federal and state agencies in Australia, which were discussed in terms of data requirements in **Section 3**. This information is derived from the set of 92 programs documented by Geoscience Australia (2010)[32].

Nine Societal Benefit Areas (SBA) of global significance have been defined by the Global Earth Observation System of Systems (GEOSS; CEOS, 2010). As detailed in **Section 1.3.3**, these nine areas are:

- Disasters;
- Health;
- Energy;
- Climate;
- Agriculture;
- Ecosystems;
- Biodiversity;
- Water; and
- Weather.

To emphasise common objectives and outcomes, each of the 91 Australian EOS programs in **Table E-1** has been associated with one or more of the GEOSS SBA.

32 The original numbering of programs (from 1 to 92) that was used in Geoscience Australia (2010) has been retained in **Table E-1**, although program 26 is not included due to insufficient EOS usage. Accordingly, the total number of sample programs being considered was reduced to 91.

Table E-1 Australian Programs Dependent on EOS Data

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
1	AGD	EMA	Emergency Management Australia	***Emergency Management Australia* gives the Commonwealth the means to assist the States and Territories in major disasters particularly once the Commonwealth Disaster Plan is activated (COMDISPLAN).** EMA has access to a range of resources used to detect, track, and mitigate emergencies, including data, images, satellite imagery, infrared monitoring, and mapping tools. EMA encourages an 'all agencies' and 'all hazards' approach to emergency management. The Australian Government is committed to supporting States and Territories in developing their capacity for dealing with emergencies and disasters, and providing physical assistance to States or Territories during an emergency.	✔	✔	✔	✔	✔	Disasters
2	DAFF	BRS, DAFF, CLWRA, MDBA, DCCEE, DEWHA, NT DIPE, QLD DNRM, SA DWLBC, VIC DPI, TAS DPIWE	Australian Collaborative Land Use Mapping Program (ACLUMP)	***ACLUMP* promotes the development of nationally consistent land-use through land use** mapping coverage for Australia at both continental and catchment scale, and by developing a national information system for land management practices. ACLUMP also facilitates national technical standards, including the Australian Land Use and Management (ALUM) Classification; a national land use data directory and the maintenance of land use datasets on Australian and State government data repositories; and regional and national reporting of land use and land management practices.	✔	✔		✔		Agriculture, Ecosystems, Biodiversity

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
3	DAFF	DAFF	Caring For Our Country	***Caring for our Country* is a $2.25 billion program of the Australian Government** involving high frequency large scale ground-cover monitoring. Caring for our Country includes six national priority areas: the National Reserve System; biodiversity and natural icons; coastal environments and critical aquatic habitats; sustainable farm practices; natural resource management in northern and remote Australia; community skills, knowledge and engagement, delivered in partnership with regional natural resources management groups, local, state and territory governments, Indigenous groups, industry bodies, land managers, farmers, Landcare groups and communities.	✔	✔				Agriculture, Ecosystems, Biodiversity
4	DAFF	DAFF, AFMA	National Fisheries Production Database, Australian Fish Distributions and Fishing Areas	**Spatial data is the key to modern fisheries management.** It provides understanding where fishing takes place, how much is caught, where differing fishing methods are used, and defining and using areas of water for fisheries, closures, and marine protected areas.	✔					Ecosystems, Water

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
5	DAFF	DAFF	National Forest Inventory	**The National Forest Inventory.** The NFI is a partnership between the Commonwealth and all State and Territory governments, and combines on-the-ground measurement with aerial and satellite technologies. It aims to provide a single authoritative source of forestry data at the national level; ensure the development of sound forest policies; ensure the viability of Australia's forest industries; and to ensure the development of effective forest conservation strategies.		✔				Climate, Ecosystems, Biodiversity
6	DAFF	DAFF	National Land and Water Resources Audit	**The NLWRA assessed changes in natural resources over time.** The program finished in 2008. Objectives were to develop the assessment of change in natural resources as a result of government programs, using mapping technologies, Digital Elevation Model (DEM) and satellite imagery.	✔	✔				Climate, Agriculture, Ecosystems, Biodiversity
7	DCCEE	DFAT, DCCEE, CSIRO, AusAID, GA	International Forest Carbon Initiative (IFCI)	**The International Forest Carbon Initiative is a key Australian contribution to global action on REDD.** Integration of optical and radar satellite observations will provide the necessary time-series as input to carbon accounting models and ultimately biomass estimation. L-band RADAR satellites can provide consistent observations of the tropical zone. Through the IFCI, Australia is working to help build capacity and provide momentum to support inclusion of REDD in a post-2012 global climate change agreement. A central element of the Initiative is taking practical action on REDD through collaborative Forest Carbon Partnerships with Indonesia and Papua New Guinea.	✔	✔	✔	✔		Energy, Agriculture, Ecosystems

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
8	DCCEE	DCCEE, CSIRO	National Carbon Accounting System (NCAS)	**The National Carbon Accounting System** provides accounts for the emission and removal of greenhouse gases from land-based activities. This requires knowledge of the dynamics of carbon (for carbon dioxide and methane emissions) and nitrogen (for nitrous oxide emissions) in the landscape. The NCAS estimates emissions through a system that combines thousands of satellite images to monitor land use and land use change since 1972, updated annually; monthly maps of climate information; maps of soil type and soil carbon; databases containing information on plant species, land management, and changes in land management over time; and ecosystem modelling - the Full Carbon Accounting Model (FullCAM).		✔	✔			Energy, Climate, Ecosystems
9	DEWHA	DEWHA	Approvals and Wildlife	**Remote sensing is critical for day-to-day compliance monitoring.** It is cost effective when compared to field inspection, and provides the ability to compile time series.		✔				Ecosystems, Biodiversity
10	DEWHA	DEWHA (Australian Antarctic Division)	Australian Antarctic Division, Australian Antarctic Data Centre	**AADC is a national facility managing scientific data resulting from Australia's Antarctic scientific research program**, including information about remote areas, especially Antarctica and Heard Island. It is important for core functions such as research, logistical management and keeping people safe. Key areas using remote sensing are glaciology, topographic data mapping, and the sea ice atlas.	✔	✔	✔	✔	✔	Climate, Ecosystems, Biodiversity, Water

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
11	DEWHA	MDBA	Murray Darling Basin Plan	**The Basin Plan relies on comprehensive on-ground, aerial and satellite monitoring** to ensure that the requirements of the Water Act 2007 are met, namely, that MDBA measure, monitor and record the quantity of Basin water resources and the condition of their associated water dependent ecosystems, and to disseminate information about them.	✔	✔	✔	✔		Climate, Agriculture, Water
12	DEWHA	DEWHA, DAFF	National Vegetation Information System (NVIS)	**The Native Vegetation Information System provides information on vegetation types** in the Australian landscape. The NVIS provides land managers with up-to-date and reliable information about the extent and distribution of vegetation types, to aid in the development of long-term solutions for the Australian environment.		✔				Agriculture, Ecosystems, Biodiversity
13	DEWHA	DEWHA, BoM	National Weather and Climate	**The Bureau of Meteorology is concerned with all aspects of climate and weather.** It provides information for primary producers and natural resource managers, marine and aviation services, a tsunami warning system, and specialised research activities. The BoM identifies remote sensing as the most important of all inputs into weather modelling and prediction.	✔				4	Disasters, Climate, Weather
14	DEWHA	DEWHA	Parks Australia	**Remote sensing is increasingly used for park management**, for example whole of park imagery twice or three times per year.			✔			Ecosystems, Biodiversity, Water

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
15	DEWHA	GBRMPA	Predictive Ocean Atmosphere Model for Australia (POAMA), ReefTEMP	**Remote sensing is gaining increasing usage in reef management**, for disaster impacts, reef structure, geomorphology, ecosystem functions, water quality assessments, boundary assessments, impacts of coastal infrastructure developments on coastal ecosystems	✔	✔	✔			Ecosystems, Biodiversity, Water
16	DEWHA	AAD, GA, DCCEE, BoM	Satellite Altimetry	**Satellite altimetry provides accurate measurements of altitude and heights**, ocean heights, observation of sea-level rise, Antarctic topography, and tsunami warnings in real time.	✔					Disasters, Water, Weather
17	DEWHA	DEWHA, States	State of Environment (SOE)	**National Environmental Information and Accounting** *State of the Environment* reports provide information about environmental and heritage conditions, trends and pressures for the Australian continent, surrounding seas and Australia's external territories. The main purpose of the Reports is to provide relevant and useful information on environmental issues to the public and decision-makers, in order to raise awareness and support more informed environmental management decisions, leading to more sustainable use and effective conservation of environmental assets.	✔	✔	✔			Ecosystems, Biodiversity, Water
18	DEWHA	DEWHA	Supervising Scientist Division	**Remote sensing provides contextual data** for scientific analysis, vegetation mapping, environmental change analysis.		✔	✔	✔		Climate, Ecosystems, Biodiversity

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
19	DEWHA	DEWHA (ERIN)	Sustainable Environment and Water Use	**Environmental Resources Information Network (ERIN) aims to improve environmental outcomes** by developing and managing a comprehensive, accurate and accessible information base for environmental decisions. Information is drawn from many sources and includes maps, species distributions, documents and satellite imagery, and covers environmental themes ranging from endangered species to drought and pollution.	✔	✔	✔			Health, Biodiversity, Water
20	DEWHA	CSIRO, BoM	Water Information Research and Development Alliance (WIRADA)	**Evapotranspiration monitoring for regional and national scale water budgets.** The science is now sufficient to allow operational monitoring of ET on a daily basis from satellites.	✔	✔		✔	✔	Climate, Agriculture, Water
21	DIAC	ACBPS	Border Protection	**The Australian Customs and Border Protection Service** employs satellite technology for communications, surveillance and marine rescue. Where client agencies do not have their own satellite technology capabilities, transmission of data and pictures from surveillance aircraft can be facilitated via the Customs National Surveillance Centre in Canberra.				✔		Disasters

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
22	DIISR	CSIRO, TERN, DEWHA	AusCover TERN	**The Terrestrial Ecosystems Research Network (TERN) will provide a network for terrestrial ecosystem research** to coordinate national observational information and encourage research collaboration and cooperation nationally, to facilitate improved access, including by electronic means, for researchers to quality assured observational data; and to identify future needs for research and strengthen the capability of the terrestrial ecosystem community across Australia.	✔	✔		✔		Energy, Climate, Ecosystems, Biodiversity, Water
23	DIISR	CSIRO, GRDC	Biomass Monitoring	**Measurement of biomass can be made over a range of scales from point source to regional level.** Satellite platforms are effective for large–scale appraisal of landscape systems, and assessment of spatial and temporal variation of vegetation across a broad area. Satellite–derived information for estimating crop production has been well established. Sensors on Landsat and SPOT provide higher resolution information making them well suited to assessing the impact of human activity on agricultural production from paddock to regional scale. Remote sensing can detect where agricultural activity is causing a shift in production potential due to changing soil quality.	✔	✔				Agriculture
24	DIISR	CSIRO, BoM, DEWHA, DIISR	Centre for Weather and Climate Research (CAWCR)	**CAWCR is a partnership between CSIRO and the Bureau of Meteorology.** It is responsible for the Australian Community Climate and Earth System Simulator (ACCESS), and a number of atmosphere, weather and climate science programs.	✔			✔	✔	Climate, Weather

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
25	DIISR	CSIRO, State geological surveys, GA	International Hyperspectral Imaging Satellite Programs	**Covered under international agreements such as those with ERSDAC (Japan) and GFZ (Germany)**, CSIRO and collaborating Australian/State government departments are using Australia for (1) establishing southern hemisphere vicarious calibration capability; (2) public geoscience information products and related (inter)national standards. > 90% of current funding is provided by international partners (e.g. ERSDAC).		✔	✔			Ecosystems, Water, Weather
27	DIISR	CSIRO, IMOS, AIMS, DEWHA	Ocean Colour Monitoring	**Large area monitoring of marine resources** through ocean colour and temperature can be an effective way of defining zones of ocean and coastal regions, and taking measures relating to habitat status and changes over time. The technology may also be used for coral bleaching prediction and monitoring.	✔	✔				Ecosystems, Biodiversity, Water
28	DIISR	CSIRO, Landgate (WA). AGRIC (WA)	Pastures from Space	**'Pastures from Space' is a farm management tool.** Satellites orbit the earth twice a day collecting the infrared response of pastures. The data is then used to estimate the rate of pasture growth during the growing season. Farmers can navigate and zoom-in to their paddocks by using map layers such as road and town names. Weekly data is also downloadable for use in estimating pasture growth rates of paddocks, which can help calculate feed and livestock quantities to keep on the farm.	✔					Agriculture

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
29	DIISR	CSIRO, GSWA, GSQ, Ausscope, UWA, Curtin University, Industry, GA	WA Centre of Excellence (CoE) for 3D Mineral Mapping (C3DMM)	**Led by CSIRO, the five year C3DMM CoE is supported by the WA government** (provides $1 for every $3 contributed by others to the CoE), UWA, government departments, industry and CSIRO. The main aim of C3DMM is to build capabilities that deliver publicly accessible 3D mineral mapping products from a new generation of remote sensing and drill core logging hyperspectral technologies of value to the Australian Resources sector. C3DMM is working with Australian/State geo-surveys to generate new public-accessible precompetitive geoscience products of the Australian continent from a new generation of remote sensing systems (e.g. HyMap and ASTER).		✔	✔			Energy
30	DRET	GA, CSIRO	Coastal Monitoring	**The Coastal Research and Management project provides information and advice** to support effective management of Australian estuaries and coastal waterways. In particular, new environmental data are acquired and compiled to establish a national overview of coastal water quality and develop agreed methods and indicators for the assessment of water quality and ecosystem integrity.		✔	✔			Ecosystems, Biodiversity, Water

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type: Optical			Sensor Data Type: SAR	Sensor Data Type: Passive M/wave	GEO Societal Benefits Area
					Low	*Medium*	*High*			
31	DRET	GA, DFAT	LoSaMBA	**The LoSaMBA project defines Australia's national maritime boundaries**, advises on the definition of administrative boundaries, and advises on geo-scientific aspects of the Law of the Sea. The project also involves administration and enhancement of web-based information systems, in particular the Australian Marine Spatial Information System (AMSIS); provision of specific ad-hoc advice including provision of maps, written boundary descriptions and digital data to assist Government Agencies with regulatory authority in the Australian maritime jurisdiction; support to the Office of Transport Security on the definition of Security Regulated Ports; advice to Pacific Island Countries through SOPAC on maritime boundary related issues.		✔	✔			Disasters, Water
32	DRET	GA, BRS	National Land Cover Mapping	**Land-cover mapping at Geoscience Australia provides a national dynamic mapping system** placing current land cover status and changes in a historical context at a national, regional and local scale, and to support and facilitate a national standard baseline for change detection and environmental reporting, emergency management and aid in Natural Resource Management decisions.	✔	✔				Disasters, Agriculture, Ecosystems, Biodiversity
33	DRET	GA, States	National Topographic Mapping	**National broad-scale operational mapping based on satellite images,** captured at least annually over large areas (continental scale). Imagery is used to detect change in topographic features, and to create up to date topographic maps.		✔	✔			Disasters, Water

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
34	DRET	GA	Petroleum Acreage and Release	**Development of tools and techniques for the detection of natural hydrocarbon seepage**, ranging from the assessment of remote sensing applications to the geochemical analysis of sea bed samples.	✔	✔	✔	✔		Energy, Water
35	DRET	GA, CSIRO	Pre-competitive Mineral Prospecting Research	**Geoscientific surveys of Australia's mineral provinces** to identify areas of new mineral potential that may be of exploration interest. Geoscience Australia markets these opportunities domestically and internationally.		✔	✔			Energy
36	DRET	GA	Sentinel Hotspots	**Sentinel is a national bushfire monitoring system**, which allows users to identify fire locations where there is a potential risk to communities and property. Sentinel obtains data from satellites that orbit the Earth collecting data in a path 2330 km wide, at least once a day. Data are received by Geoscience Australia's Data Acquisition Facility, located at Alice Springs. Locations of high temperature are identified and extracted to a small text file and transmitted from Alice Springs to Canberra where they are fed into a spatial database. From there, the data can be queried and added to dynamically-created maps using a web-based mapping system.	✔					Disasters, Weather

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type: Optical					GEO Societal Benefits Area
					Low	*Medium*	*High*	SAR	Passive M/wave	
37	PM&C	AEC	Electoral Mapping	**Satellite imagery provides essential data to the Australian Electoral Commission** for establishing and monitoring electoral boundaries to household level.			✔			Health
38	ACT	ACTPLA	ACT Planning and Land Authority	**Satellite imagery used for land use monitoring**, mapping, catchment management, bushfire detection and management.		✔				Disaster, Ecosystems, Biodiversity
39	ANZLIC	ANZLIC	DEM and Surface Modelling	**The National Elevation Data Framework (NEDF)** is a collaborative framework that can be used to increase the quality of elevation data and derived products such as digital elevation models (DEMs) describing Australia's landform and seabed. The aim is to optimise investment in existing and future data collections and provide access to a wide range of digital elevation data and derived products to those who need them.			✔			Disasters, Energy, Ecosystems, Water
40	NSW	DECCW	DustWatch	The **DustWatch Program monitors aerosols**, focusing on dust, across southern Australia using field monitoring stations, and MODIS derived groundcover, fire and dust.	✔					Disasters, Health, Agriculture, Weather
41	NSW	Department of Planning & Local Government & Shires Associations	Electronic Housing Code Pilot (EHC)	**e-Planning.** The EHC is focussed on developing and demonstrating a shared, integrated platform for the online and end-to-end processing of residential housing development applications under the NSW Housing Code. Funded under the Commonwealth Housing Affordability Fund.		✔				Health

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type: Optical			Sensor Data Type: SAR	Sensor Data Type: Passive M/wave	GEO Societal Benefits Area
					Low	*Medium*	*High*			
42	NSW	DECCW	Elevation and vegetation structural mapping	**Wetland and water resource management** are programs that make use of ground surface elevation. Vegetation structure derived (from Lidar) is increasingly used as in a variety of programs including vegetation mapping & fire modelling.		✔				Disasters, Ecosystems, Water
43	NSW	DECCW	Groundwater Dependent Ecosystems (GDE) Water Balance	**Groundwater dependant ecosystem location mapping** and hydraulic modelling (eg evapotranspiration levels) undertaken by the NSW Office of Water.	✔					Agriculture, Ecosystems, Water
44	NSW	DECCW	Groundwater Quality and Coastal GDE Mapping	**Mapping of coastal groundwater dependant ecosystems** (GDE) as inputs to catchment hydraulic & water balance modelling.		✔				Health, Ecosystems, Water
45	NSW	DECCW	Inland wetland inventory and monitoring	**The Inland Wetland Inventory is a storehouse of standardised information** on wetlands in a management area. Inventory data may be generated from available data sources (tenure, climate, population, land use etc) or collected through surveys (flora, fauna, water quality etc) involving the use of field observation and satellite imagery.	✔	✔	✔			Ecosystems, Biodiversity, Water
46	NSW	DECCW	Mapping Wetland Inundation Histories for Iconic NSW Wetlands	**Mapping wetland inundation histories** for adaptive management of environmental water.		✔				Ecosystems, Biodiversity, Water

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
47	NSW	DECCW	Marine Monitoring Reporting and Evaluation	**Chlorophyll estimates are required** to support reporting against NSW natural resources management marine targets.	✔					Ecosystems, Biodiversity, Water
48	NSW	OOW	Monitoring: State of the Catchments	**The NSW Office of Water is responsible for measuring and reporting on progress** towards state-wide targets for rivers and groundwater. These targets are: by 2015 there is an improvement in the condition of riverine ecosystems; by 2015 there is an improvement in the ability of groundwater systems to support groundwater dependent ecosystems and designated beneficial uses. Catchment and riverine vegetation monitoring by satellite imagery are extensively used.		✔				Health, Ecosystems, Biodiversity, Water
49	NSW	DECCW	NSW High-Resolution Vegetation Monitoring Program	**The High-Resolution Program complements the SLATS (Landsat) Program** and enables monitoring and reporting of vegetation extent change to about 5% crown cover using scientifically developed and tested methods. These combine field verification and computer processing using state-of-the-art remote sensing and Geographic Information System (GIS) technologies. This imagery is also used for state wide native vegetation mapping. Short-term mapping priorities include the Hunter and the Central Western regions of NSW.		✔	✔			Disasters, Agriculture, Ecosystems, Biodiversity

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
50	NSW	DECCW	NSW Woody Vegetation Monitoring Program (NSW SLATS)	**SLATS (Moderate resolution eg Landsat) is a major vegetation monitoring initiative to investigate the overall cover of woody vegetation**, and to report on the previously unquantified extent of land clearing in NSW using scientifically developed and tested methods. This program uses similar approaches to the NSW High-Resolution Vegetation Monitoring Program.		✔				Climate, Agriculture, Ecosystems
51	NSW	DECCW	Rural Floodplain Management	**Remote sensing is an essential component of rural floodplain management.** Data is used to determine flood-ways and flooding, map vegetation communities and delineate floodplain habitats.	✔	✔	✔			Disasters, Agriculture, Water
52	NSW	DECCW /Industry	Sea Surface Temperature and Height Anomaly	**Manly Hydraulics Laboratory provides access to sea surface temperature products**, and a range of other satellite derived ocean products from CSIRO that receives data from a number of environmental satellite instruments including MODIS, AVHRR and SeaWifs.	✔			✔		Disasters, Climate, Water, Weather
53	NSW	LPMA	Topographic Mapping Program	**Mapping topographic features** to meet the requirements of the State of NSW for this type of Spatial Data Infrastructure (SDI). This program utilises satellite imagery for the Western Division of NSW and airborne imagery for the Central and Eastern Divisions of NSW.		✔	✔			Agriculture, Water

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
54	NSW	LPMA	Valuation for Taxation Purposes	**Using imagery for taxation valuation purposes.** This program utilises satellite imagery for the Western Division of NSW and airborne imagery for the Central and Eastern Divisions of NSW.		✔				Agriculture
55	NSW	DECCW	Vegetation Monitoring – Grassland	**A range of satellite-derived vegetation indices have been widely used to classify land cover**, estimate crop acreage, and detect plant stress. The National Oceanic and Atmospheric Administration (NOAA) produces global estimates based on the reduced resolution Global Area Coverage (GAC) data from the NOAA orbiting satellites.	✔	✔	✔			Agriculture, Ecosystems
56	NSW	LPMA	Western Lands Monitoring and Compliance	**Managing the Crown Estate** in Western Division for Leasehold Tenure land managers.		✔				Agriculture
57	NSW / VIC	BF CRC	Grasslands curing assessment	**Satellite derived vegetation indices may be used to quantify vegetation condition.** These indices use a combination of wavelength bands to highlight specific features of the vegetation. The most common of these is the Normalised Difference Vegetation Index (NDVI) that is sensitive to vegetation chlorophyll content and cover: The NDVI has been used to map various characteristics of vegetation such as biomass, vegetation health and phenological stage. It is this latter application that makes the index of particular interest in the area of grassland curing.	✔					Disasters, Climate, Agriculture

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
58	NSW, Vic, Qld, SA	CRCSI / LPMA / UNSW	Radar Watch	**Radar Watch is a research demonstration program to promote radar EO** in partnership with agencies from Europe (including ESA, e-GEOS and Infoterra), Japan and China. Radar Watch includes a range of targeted application modules such as Mine Watch for mapping mine subsidence, City Watch for monitoring urban subsidence due to groundwater extraction and underground construction, Earthquake Watch for detecting co-seismic ground deformation, Bushfire Watch for supplementing optical and infrared EO, and Flood Watch for all-weather as well as day and night observations.		✔		✔		Disasters, Water
59	NT	NTLIS, NREA	Rangeland monitoring	**Remote sensing is the primary means of monitoring** natural resource management in the Northern Territory.		✔				Agriculture, Ecosystems, Biodiversity
60	NT	Bushfires NT	Fire mapping: National Parks and Arnhem Land Fire Management Area	**Satellite imagery plays a vital role in bushfire containment and management**, particularly in the very large areas of the Gulf Country and inland areas of the Territory. One example of this is the Indji Watch hotspot system.	✔	✔				Disasters
61	QLD	DERM	Biomass monitoring	**It is now practical to measure above-ground biomass** of woody vegetation from certain RADAR satellites.				✔		Disasters, Agriculture, Ecosystems
62	QLD	DERM	Groundcover monitoring	**Land managers, pastoralists, policy and planning staff can make important management decisions** based on satellite derived information on groundcover.		✔				Agriculture

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
63	QLD	DERM	QLUMP land-use program	**Queensland Land Use Monitoring Program (QLUMP) mapping** is performed according to the Australian Land Use and Management Classification (ALUM). The methodology is fast, reliable and accurate, and makes the best use of available databases, satellite images, and aerial photos.		✔				Agriculture, Ecosystems, Biodiversity
64	QLD	DERM	Queensland Wetland mapping and Classification	**The Queensland Wetland Mapping and Classification project provides a comprehensive coverage of wetlands**, mapped at a scale and level of detail that can guide the implementation of management actions and support management decision-making. It is also part of a larger project involving the development of a wetlands inventory database. The water body mapping for Queensland been completed using satellite imagery, combined with other data sources to form the water body layer of the final wetlands mapping product.		✔				Ecosystems, Biodiversity, Water
65	QLD	DERM	Reef Catchment Monitoring (RCM)	**Reef Catchment Monitoring to characterise land use, gully erosion and the extent of riparian vegetation.** The baseline data is to be updated in five years or earlier.		✔				Ecosystems, Biodiversity, Water
66	QLD	DERM	Regional ecosystem mapping	**Regional ecosystem maps describe the extent and conservation status of remnant vegetation** as regional ecosystems. They provide information crucial to the preparation of an application to clear vegetation, particularly for developing a property vegetation management plan.		✔				Agriculture, Ecosystems, Biodiversity

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
67	QLD	DERM	Soil exposure assessment	**Land degradation problems persist in large areas of rural and regional Australia.** Generally, these problems have resulted from a trial and error approach to land management, and the imposition on the Australian environment of agricultural systems that have significantly altered hydrology and soil properties, and have caused a loss of biodiversity. Satellite imagery and remote sensing are important to monitor and remediate these areas.		✔				Agriculture, Biodiversity, Water
68	QLD	DERM	Statewide Landcover and Tree Study (SLATS)	**SLATS is a major vegetation monitoring initiative** to investigate the overall cover of woody vegetation, and to report on the previously unquantified extent of land clearing in Queensland using scientifically developed and tested methods. These methods combine field verification and computer processing using state-of-the-art remote sensing and Geographic Information System (GIS) technologies.		✔				Agriculture, Ecosystems, Biodiversity
69	SA	DWLBC	Imagery Baseline Data Project	**The Imagery Baseline Data Project used aerial photography and satellite imagery of high priority areas across SA** with a 600km DEM of the entire SA section of the River Murray, invaluable for integrated water security and environmental management in SA.		✔	✔			Agriculture, Biodiversity, Water

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type: Optical			Sensor Data Type: SAR	Sensor Data Type: Passive M/wave	GEO Societal Benefits Area
					Low	*Medium*	*High*			
70	SA	DWLBC	Statewide Native Vegetation Detection	**The Statewide Native Vegetation Detection project created a classification of land cover** from 2004 Landsat imagery into seven classes which included one class to represent woody native vegetation. The project verified DEH's existing woody native vegetation mapping data in the agricultural regions for the years 1990, 1995 and 2004. Verification work identified where woody vegetation mapping was incorrect based on clearance.		✔	✔			Agriculture, Ecosystems, Biodiversity
71	TAS	DPIW	TASVEG	**TASVEG was produced by the Tasmanian Vegetation Mapping and Monitoring Program (TVMMP).** Aerial photographic interpretation (PI) is the primary data collection method with field verification of representative polygons accounting for approximately one quarter to one fifth of vegetation mapping time. The most recent photographs are used where possible. High resolution satellite imagery may be used, where available, for capture and interpretation of features.			✔			Agriculture, Ecosystems, Biodiversity
72	VIC	DSE	Bushfire areas and tree cover	**Remote sensing is the most practical method for mapping** and quantifying fire impacts at landscape scales. Sensors on board earth observation satellites or other platforms measure the radiation emitted and reflected from the earth surface at distinct wave-length.	✔	✔	✔			Disaster, Ecosystems, Biodiversity

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
73	VIC	DPI	Evapo-transpiration modelling	**Evapotranspiration of irrigated pastures** remotely sensed vegetation index and thermal data are combined at the individual paddock scale to model the ET of irrigated pastures.		✔				Agriculture, Water
74	VIC	DPI, DSE	Land use	**Victorian land-use has been monitored from regional to paddock scale.** Agricultural land uses were determined through an automated process to spatially allocate the agricultural census data using satellite imagery, using a method described as SPREAD (Walker & Mallawaarachi 1998).	✔	✔	✔			Agriculture, Ecosystems
75	VIC	DSE	Native vegetation extent and condition	**Remote sensing is an essential component of native vegetation monitoring.** The health and revegetation of native vegetation is vital to the natural processes that we rely on for clean air and water, for natural heritage.	✔	✔				Ecosystems, Biodiversity
76	WA	Landgate	Agimage - SW of WA	**Agimage provides land management professionals access to satellite maps** and an extensive archive of biomass images since 1993 covering Western Australia's Southwest, used at paddock level to determine variations in crop growth. Farmers and land management professionals can use this information at large paddock scale to estimate crop yield and pasture growth rates, and to forecast potential crop yield.		✔				Agriculture, Water

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
77	WA	Landgate	Carbon Watch	**Landgate is developing a suite of online carbon accounting tools**, designed specifically for forest carbon sink projects. CarbonWatch is aimed at making it easier for project owners to plan, monitor, quantify and report on carbon sequestration projects.	✔	✔	✔			Energy, Climate
78	WA	Landgate, FESA	Emergency management	**Operational staff use the Shared Land Information Platform Emergency Management (SLIP-EM) services** to assist decision making during incidents. The WA emergency management community in collaboration with strategic information providers (i.e. Bureau of Meteorology, Landgate and others) collaborated in the development of SLIP-EM to ensure each agency is able to effectively share authoritative and current spatial information.	✔	✔	✔			Disasters, Ecosystems, Weather
79	WA	DEC	Fire Mapping and Modelling	**The mapping and locations of fire patterns within the DEC Estate.** Information on precise fire boundaries, burn intensities and occurrences are vital for fire management and understanding.	✔	✔				Disasters, Weather
80	WA	Landgate	FireWatch Program	**Satellite imagery is an important component of fire management.** The FireWatch map service provides emergency services personnel with an online map application to help in the management of bush fires over Australia. Datasets include fire hotspots, burnt area maps since 1997, greenness images updated daily and weekly, lightning data and other useful map layers.	✔	✔	✔			Disasters, Climate, Ecosystems, Weather

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
81	WA	Landgate	FloodMap Program	**FloodMap provides emergency services personnel with datasets and an online map** to help in the management and mitigation of floods over Australia. Datasets include current surface water derived from MODIS, historical flooding, flood risk products, soil moisture from AMSRE, soil moisture saturation index and profile available water from MTSAT.	✔	✔	✔			Disasters, Water
82	WA	DEC	Land Audit and Compliance	**Audit and compliance of native vegetation.** Appropriate image sets are sighted to checked native vegetation compliance with appropriate applications. Major focus has been within the SW but development occurring to the rest of the State.		✔	✔			Agriculture, Ecosystems
83	WA	Landgate, CSIRO, DEC, DAFWA, DoW, DPI	Land Monitor Project - SW of WA	**Land Monitor is a coordinated initiative originally under the National Dryland Salinity Program.** The project originally aimed to systematically monitor salt-affected land and remnant vegetation change over the agricultural area of south west of Western Australia. Land Monitor phase III is aimed at vegetation monitoring on an annual bases across the SW of WA.	✔	✔	✔			Agriculture, Water

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type: Optical Low	Optical Medium	Optical High	SAR	Passive M/wave	GEO Societal Benefits Area
84	WA	DEC	Marine Mapping and Monitoring	**Monitoring, with evaluation and reporting, is the key feedback mechanism** in a 'best practice' natural resource adaptive management approach. Hence, it is primarily the responsibility of management agencies. Monitoring, for measuring success of management actions towards objectives (of Marine Protected Areas management plans and marine fauna conservation programs) and for applying active adaptive management principles to marine conservation, will be a priority for WA's marine science program.		✔				Climate, Ecosystems, Water
85	WA	DOW	Monitoring Groundwater Decline	**The Land Monitor Project produces maps based on Landsat data** of the extent and recent (~10 year) change in areas of salt-affected/persistent low productivity land. Spatial resolution is 25 m by 25 m. The project covers the entire SW agricultural area (24 million hectares). Accuracy assessments of salinity mapping are carried out and published for sample areas within each region.		✔	✔			Agriculture, Water
86	WA	Landgate	OceanWatch Program	**OceanWatch provides access to sea surface temperature, optical attenuation, and chlorophyll products** and in the future, a range of other satellite derived ocean products.	✔	✔	✔			Ecosystems, Water
87	WA	Water Corporation	Urban Monitor	**The Perth Water Corporation is a partner agency in collecting high resolution multi-spectral imagery** over greater Perth metro area for range of analyses options.			✔			Water

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
88	WA	Water Corporation	Vegetation Monitoring	**Land Monitor products are used to gain understanding on vegetation dynamics** and its effect on water yield in Perth dam catchments.		✔				Ecosystems, Biodiversity, Water
89	WA	Water Corporation	Vegetation Monitoring and cover estimates	**High resolution airborne multi-spectral imagery are used to evaluate change in forest cover** and effectiveness of forest management to increase water yield from Wungong Catchment.		✔				Disasters, Ecosystems, Biodiversity, Water
90	WA	DEC	Vegetation Monitoring.	**Key DEC responsibilities include broad roles in conserving biodiversity and protecting, managing, regulating and assessing many aspects of the use of the State's natural resources.** Many operational tasks require ongoing accepted monitoring procedures that use consistent, repeatable imagery.		✔	✔			Ecosystems, Biodiversity
91	WA	Landgate	Vegetation Watch Program	**VegetationWatch produces greenness image maps over Australia.** MODIS and NOAA satellite images are processed to provide greenness images at 250m and 1km resolution. Greenness images from MODIS are available within 3 hours of the overpass and a fortnightly composite over Australia is available weekly.	✔	✔	✔			Disasters, Ecosystems, Biodiversity

Table E-1 (continued)

Prog ID	Jurisdiction	Lead Portfolio	Program/ Product Name	Description	Sensor Data Type					GEO Societal Benefits Area
					Optical			SAR	Passive M/wave	
					Low	*Medium*	*High*			
92	WA	Landgate	WALIS	**WALIS is a partnership of government agencies working with business, education and the general community** to manage and promote the State's geographic information. Data captured through the State Land Information Capture Program (SLICP) can range from aerial photography, topographic data, satellite imagery, bathymetry, LIDAR, infrastructure, to 3D surveys, soils, ortho-imagery and any other type of spatial data required. The data requested through SLICP provides an opportunity to drive decision making on important issues such as climate change, planning, mining and health. Landgate has both simplified the SLICP process and is seeking to expand the capabilities and funding of SLICP to address the future needs of the state's land and spatial information.	✔	✔	✔			Health, Climate, Ecosystems, Biodiversity

Appendix F—Available EOS Data Sensors

Most sensor and mission characteristics in the **Tables F-1** to **F-5** have been derived from CEOS (2010; see **Appendix D**). Details for some commercial sensors were extracted from relevant web sites.

In the tables below, the 'CEODA-Ops Status' column indicates either Australia's current usage of operational sensors (available before May 2011) or its commitment to forthcoming sensors (expected to be available before the end of 2020):

Used current operational sensor whose data is regularly utilised for active government programs;

Not Used currently available sensor whose data is not actively utilised by operational programs;

Committed future sensor for which a formal agreement has been ratified or infrastructure has been established for data reception; and

Not Committed future sensor for which Australia currently has no formal access plans.

Note that where the 'Expected End of Life' is not specified for a sensor, a lifespan of five years has been assumed.

Please refer to the **Glossary** (**Section 8**) for expansions of instrument and agency acronyms and abbreviations. Also note that some of the sensors listed in the tables below may not provide data of an acceptable standard for operational use.

Table F-1 Low Resolution Optical Sensors

Agency	Mission	Instrument	CEODA-Ops Status	Launch Date	Expected End of Life
BNSC	Envisat	AATSR	Not Used	1-Mar-02	31-Dec-13
CAST	HJ-1A	HIS	Not Used	6-Sep-08	1-Sep-11
CAST	HJ-1B	IR	Not Used	6-Sep-08	1-Sep-11
CAST	HY-1C	COCTS	Not Committed	1-Jun-11	1-Jan-13
CAST	HY-1C	CZI	Not Committed	1-Jun-11	1-Jan-13
CAST	HY-1D	COCTS	Not Used	1-Dec-10	1-Jan-13
CAST	HY-1D	CZI	Not Used	1-Dec-10	1-Jan-13
CONAE	SAC-C	HSTC	Not Used	21-Nov-00	1-Jan-12
CONAE	SAC-C	MMRS	Not Used	21-Nov-00	1-Jan-12
CONAE	SAC-D/Aquarius	HSC	Not Committed	1-Apr-11	1-Apr-17
CONAE (CSA)	SAC-D/Aquarius	NIRST	Not Committed	1-Apr-11	1-Apr-17
ESA	EarthCARE	MSI (EarthCARE)	Not Committed	25-Oct-13	25-Oct-16
ESA	Envisat	MERIS	Used	1-Mar-02	31-Dec-13
EUMETSAT (ESA)	MTG-I1 (imaging)	FCI	Not Committed	15-Dec-16	15-Jun-25
INPE	AMAZÔNIA-1	AWFI	Not Committed	30-Jun-13	30-Jun-17
INPE/CRESDA	CBERS 3	WFI-2	Not Committed	Jan-11	Jan-16
INPE/CRESDA	CBERS 4	WFI-2	Not Committed	Jan-13	Jan-18
ISRO	INSAT-2E	CCD camera	Not Used	3-Apr-99	31-Dec-11
ISRO	INSAT-2E	VHRR	Not Used	3-Apr-99	31-Dec-11
ISRO	INSAT-3A	CCD camera	Not Used	4-Apr-03	10-Apr-13
ISRO	INSAT-3A	VHRR	Not Used	4-Apr-03	10-Apr-13
ISRO	INSAT-3D	Imager	Not Committed	1-Aug-11	1-Aug-18
ISRO	KALPANA-1	VHRR	Not Used	12-Sep-02	9-Dec-12
ISRO	OCEANSAT-1	OCM	Not Used	26-May-99	31-Dec-11
ISRO	OCEANSAT-2	OCM	Not Used	24-Sep-09	24-Sep-14
ISRO	OCEANSAT-3	TIR	Not Committed	1-Jan-14	1-Jan-19
JAXA	GCOM-C1	SGLI	Not Committed	1-Feb-14	1-Feb-19
JAXA	GCOM-C2	SGLI	Not Committed	1-Feb-18	1-Feb-23
JMA	MTSAT-2	IMAGER	Used	18-Feb-06	1-Jan-17
KARI	COMS	GOCI	Not Used	26-Jun-10	1-Dec-17
NASA	Aqua	MODIS	Used	4-May-02	30-Sep-11
NASA	CALIPSO	WFC	Not Used	28-Apr-06	30-Sep-11
NASA	Terra	MODIS	Used	18-Dec-99	30-Sep-11
NASA (USGS)	LDCM	TIRS	Not Committed	19-Dec-12	19-Dec-17
NOAA	GOES-R	ABI	Not Committed	1-Oct-15	1-Mar-25
NOAA	GOES-S	ABI	Not Committed	1-Feb-17	1-Oct-28

Table F-1 (continued)

Agency	Mission	Instrument	CEODA-Ops Status	Launch Date	Expected End of Life
NOAA	Metop-A	AVHRR/3	Used	19-Oct-06	30-Apr-12
NOAA	Metop-B	AVHRR/3	Not Committed	2-Apr-12	1-May-17
NOAA	Metop-C	AVHRR/3	Not Committed	2-Apr-16	1-Dec-21
NOAA	NOAA-15	AVHRR/3	Used	1-May-98	30-Jun-11
NOAA	NOAA-16	AVHRR/3	Used	21-Sep-00	31-Dec-12
NOAA	NOAA-17	AVHRR/3	Used	24-Jun-02	31-Dec-14
NOAA	NOAA-18	AVHRR/3	Used	20-May-05	31-Dec-15
NOAA	NOAA-19	AVHRR/3	Used	4-Feb-09	1-Mar-16
NOAA (NASA)	JPSS-1	VIIRS	Not Committed	1-Jan-15	1-Jun-23
NOAA (NASA)	JPSS-2	VIIRS	Not Committed	1-Jan-18	1-Oct-26
NOAA (NASA)	NPP	VIIRS	Not Committed	23-Sep-11	23-Sep-16
NRSCC (CAST)	FY-1D	MVISR	Not Committed	15-May-02	31-Dec-10
NRSCC (CAST)	FY-3A	VIRR	Not Used	27-May-08	31-May-11
NRSCC (CAST)	FY-3B	VIRR	Not Used	31-Dec-10	31-Dec-12
NRSCC (CAST)	FY-3C	VIRR	Not Committed	31-Dec-12	31-Dec-16
NRSCC (CAST)	FY-3D	VIRR	Not Committed	31-Dec-14	31-Dec-18
NRSCC (CAST)	FY-3E	VIRR	Not Committed	31-Dec-16	31-Dec-20
NRSCC (CAST)	FY-3F	MVIRS	Not Committed	31-Dec-18	31-Dec-22
NRSCC (CAST)	FY-3F	VIRR	Not Committed	31-Dec-18	31-Dec-22
NRSCC (CAST)	FY-3G	MVIRS	Not Committed	31-Dec-20	31-Dec-24
NRSCC (CAST)	FY-3G	VIRR	Not Committed	31-Dec-20	31-Dec-24
NRSCC (CAST)	FY-4 O/A	MCSI	Not Committed	31-Dec-12	31-Dec-17
NRSCC (CAST)	FY-4 O/B	MCSI	Not Committed	31-Dec-15	31-Dec-20
NRSCC (CAST)	FY-4 O/C	MCSI	Not Committed	31-Dec-15	31-Dec-20
NRSCC (CAST)	FY-4 O/D	MCSI	Not Committed	31-Dec-19	31-Dec-24
NRSCC (CAST)	FY-4 O/E	MCSI	Not Committed	31-Dec-19	31-Dec-24
Orbimage	ORBVIEW 2	SeaWIFS	Not Used	Aug-97	Dec-11
ROSHYDROMET (ROSKOSMOS)	Meteor-M N1	MSU-MR	Not Used	18-Sep-09	18-Sep-14
ROSHYDROMET (ROSKOSMOS)	Meteor-M N2	MSU-MR	Not Committed	1-Jul-11	1-Jul-16
ROSHYDROMET (ROSKOSMOS)	Meteor-M N3	OCS	Not Committed	31-Dec-12	31-Dec-17

Table F-2 Medium Resolution Optical Sensors

Agency	Mission	Instrument	CEODA-Ops Status	Launch Date	Expected End of Life
ASI	PRISMA	HYC	Not Committed	1-Jan-12	1-Jan-17
BNSC	UK-DMC	SLIM-6	Not Used	27-Sep-03	31-Dec-11
BNSC	UK-DMC2	SLIM-6-22	Not Used	29-Jul-09	29-Jul-14
CAST	HJ-1A	CCD camera	Not Used	6-Sep-08	1-Sep-11
CAST	HJ-1B	CCD camera	Not Used	6-Sep-08	1-Sep-11
CNES/Astrium	SPOT-4	HRVIR	Used	24-Mar-98	1-Jun-13
CONAE	SAC-C	HRTC	Not Used	21-Nov-00	1-Jan-12
DLR	EnMAP	HSI	Not Committed	9-May-14	9-May-19
DMCii	Beijing-1	MSS	Not Used	Oct-05	Oct-13
DMCii	DMC Deimos-1	SSTL MSS - 3 band	Not Used	Jul-09	Jul-14
ESA (BNSC)	PROBA	CHRIS	Not Committed	22-Oct-01	31-Dec-12
ESA (EC)	Sentinel-2 A	MSI	Not Committed	1-May-13	1-Aug-20
ESA (EC)	Sentinel-2 B	MSI	Not Committed	31-Dec-14	31-Mar-22
ESA (EC)	Sentinel-2 C	MSI	Not Committed	1-Jan-20	1-Apr-27
GISTDA	THEOS	MS	Not Used	1-Oct-08	1-Oct-13
INPE/CRESDA	CBERS 3	IRS	Not Committed	Jan-11	Jan-16
INPE/CRESDA	CBERS 3	MUX	Not Committed	Jan-11	Jan-16
INPE/CRESDA	CBERS 4	IRS	Not Committed	Jan-13	Jan-18
INPE/CRESDA	CBERS 4	MUX	Not Committed	Jan-13	Jan-18
ISRO	AWiFSSAT	AWiFS	Not Committed	1-Jan-12	1-Jan-16
ISRO	IMS-1	MxT	Not Used	28-Apr-08	28-Jun-11
ISRO	RESOURCESAT-1	AWiFS	Used	17-Oct-03	10-Dec-11
ISRO	RESOURCESAT-1	LISS-III	Used	17-Oct-03	10-Dec-11
ISRO	RESOURCESAT-2	AWiFS	Not Used	12-Dec-10	12-Dec-14
ISRO	RESOURCESAT-2	LISS-III	Not Used	12-Dec-10	12-Dec-14
ISRO	TES-HYS	HySI	Not Committed	1-Jan-13	1-Jan-14
METI (NASA)	Terra	ASTER	Used	18-Dec-99	30-Sep-11
NASA	NMP EO-1	ALI	Used	21-Nov-00	30-Sep-11
NASA	NMP EO-1	Hyperion	Used	21-Nov-00	30-Sep-11
NASA (USGS)	LDCM	OLI	Not Committed	19-Dec-12	19-Dec-17
NASRDA	NigeriaSat-1	NigeriaSat Med Res	Not Used	27-Sep-03	31-Dec-11
NASRDA	NigeriaSat-X	NigeriaSat Med Res	Not Used	29-Oct-10	29-Oct-17
NRSCC (CAST)	BJ-1	MSI	Not Used	27-Oct-05	27-Oct-10
NSAU	Sich-2	MIREI	Not Used	1-Oct-10	1-Apr-14

Table F-2 (continued)

Agency	Mission	Instrument	CEODA-Ops Status	Launch Date	Expected End of Life
ROSHYDROMET (ROSKOSMOS)	Meteor-M N1	KMSS	Not Committed	18-Sep-09	18-Sep-14
ROSHYDROMET (ROSKOSMOS)	Meteor-M N2	KMSS	Not Committed	1-Jul-11	1-Jul-16
ROSHYDROMET (ROSKOSMOS)	Meteor-M N3	SZS	Not Committed	31-Dec-12	31-Dec-17
ROSKOSMOS	Monitor-E	RDSA	Not Used	26-Aug-05	31-Dec-11
TUBITAK	RASAT	RASAT VIS	Not Used	30-Oct-10	15-Oct-13
USGS (NASA)	Landsat-5	TM	Used	1-Mar-84	31-Dec-12
USGS (NASA)	Landsat-7	ETM+	Used	15-Apr-99	31-Dec-12

Table F-3 High Resolution Optical Sensors

Agency	Mission	Instrument	CEODA-Ops Status	Launch Date	Expected End of Life
ASI	MIOSAT	ALISEO SAGNAC	Not Committed	01-Jan-13	01-Jan-16
ASI	MIOSAT	PAN CAM	Not Committed	01-Jan-13	01-Jan-16
ASI	PRISMA	PAN CAMERA	Not Committed	01-Jan-12	01-Jan-17
Astrium	SPOT 6	MSS/Pan	Not Committed	01-Jan-12	31-Dec-22
Astrium	SPOT 7	MSS/Pan	Not Committed	01-Jan-16	31-Dec-24
BNSC	TopSat	TOPSAT Telescope	Not Used	27-Oct-05	31-Dec-11
CDTI (ESA)	Ingenio	PAN+MS	Not Committed	31-Dec-12	31-Dec-19
CNES/Astrium	Pleïades-HR 1	HiRI	Not Used	31-Mar-11	31-Mar-16
CNES/Astrium	Pleïades-HR 2	HiRI	Not Committed	31-Mar-12	31-Mar-17
CNES (ISA)	VENUS	VSC	Not Committed	31-Jan-13	31-Jan-16
CNES/Astrium	SPOT-5	HRG/HRS	Used	04-May-02	01-Jun-14
Digital Globe	QUICKBIRD 2	Quickbird 2	Not Used	01-Oct-01	01-Jan-14
Digital Globe	WORLDVIEW-1	WV60	Not Used	01-Sep-07	31-Dec-18
Digital Globe	WORLDVIEW-2	WY110	Not Used	01-Oct-09	31-Oct-09
Digital Globe	WORLDVIEW-3	Multispectral	Not Committed	01-Oct-14	01-Oct-19
DLR	RapidEye	MSI	Not Used	29-Aug-08	30-Aug-15
DMCii	Beijing-1	PAN	Not Used	01-Oct-05	01-Jan-13
EIAST	DubaiSat 1	DMAC	Not Used	01-Jul-09	31-Dec-14
EIAST	DubaiSat 2	EOS-D	Not Committed	01-Jan-12	31-Dec-14
GeoEye	GeoEye-1	GIS	Not Used	01-Sep-08	31-Dec-13
GeoEye	GeoEye-2	GeoEye-2	Not Committed	01-Jan-13	01-Jan-18
GeoEye	IKONOS 2	IKONOS 2	Not Used	01-Sep-99	01-Jan-14
GISTDA	THEOS	PAN	Not Used	01-Oct-08	01-Oct-13
INPE/CRESDA	CBERS 3	PAN	Not Committed	01-Jan-11	01-Jan-16
INPE/CRESDA	CBERS 4	PAN	Not Committed	01-Jan-13	01-Jan-18
ISRO	CARTOSAT-1	PAN	Not Used	05-May-05	31-Dec-11
ISRO	CARTOSAT-2	PAN	Not Used	10-Jan-07	01-Jan-11
ISRO	CARTOSAT-2B	PAN	Not Used	12-Jul-10	01-Jul-15
ISRO	CARTOSAT-3	ULTRAPAN	Not Committed	01-Jan-13	01-Jan-17
ISRO	RESOURCESAT-1	LISS-IV	Used	17-Oct-03	10-Dec-11
ISRO	RESOURCESAT-2	LISS-IV	Not Used	12-Dec-10	12-Dec-14
ISRO	TES	TES PAN	Not Used	22-Oct-01	31-Dec-11
KARI	KOMPSAT-2	MSC	Not Used	27-Jul-06	27-Jun-11
KARI	KOMPSAT-3	AEISS	Not Committed	15-Dec-11	15-Dec-15
NASRDA	NigeriaSat-2	NigeriaSat	Not Used	29-Oct-10	29-Oct-17
NRSCC (CAST)	BJ-1	PAN	Not Used	27-Oct-05	27-Oct-11

Table F-3 (continued)

Agency	Mission	Instrument	CEODA-Ops Status	Launch Date	Expected End of Life
NSAU	Sich-2	MBEI	Not Used	01-Oct-10	01-Apr-14
NSPO	FORMOSAT 5	RSI	Not Committed	01-Jan-13	31-Dec-18
NSPO/Astrium	FORMOSAT 2	RSI	Not Used	20-May-04	01-Jan-13
ROSKOSMOS	Monitor-E	PSA	Not Used	26-Aug-05	31-Dec-11
ROSKOSMOS (ROSHYDROMET)	Resurs DK 1	Geoton-L1	Not Used	15-Jun-06	30-Jun-11
ROSKOSMOS (ROSHYDROMET)	Resurs P N1	Geoton-L1	Not Committed	31-Dec-11	31-Dec-16
ROSKOSMOS (ROSHYDROMET)	Resurs P N2	Geoton-L1	Not Committed	31-Dec-13	31-Dec-18
SANSA (Uni of Stellenbosh)	SumbandilaSat	SumbandilaSat Imager	Not Used	18-Sep-09	18-Sep-14
TUBITAK	RASAT	RASAT VIS Panchromatic	Not Used	30-Oct-10	15-Oct-13

Table F-4 SAR Sensors

Agency	Mission	Instrument	CEODA-Ops Status	Launch Date	Expected End of Life
ASI (MiD (Italy))	COSMO-SkyMed 1	SAR 2000	Not Used	08-Jun-07	08-Jun-14
ASI (MiD (Italy))	COSMO-SkyMed 2	SAR 2000	Not Used	09-Dec-07	09-Dec-14
ASI (MiD (Italy))	COSMO-SkyMed 3	SAR 2000	Not Used	27-Oct-08	27-Oct-15
ASI (MiD (Italy))	COSMO-SkyMed 4	SAR 2000	Not Used	30-Oct-10	15-Oct-17
ASI (MiD (Italy))	CSG-1	SAR-2000 S.G.	Not Committed	30-Apr-14	30-Oct-21
ASI (MiD (Italy))	CSG-2	SAR-2000 S.G.	Not Committed	30-Apr-15	30-Oct-22
CAST	HJ-1C	S-Band SAR	Not Committed	31-Dec-11	31-Dec-14
CDTI	PAZ	Paz SAR-X	Not Committed	31-Dec-11	31-Dec-16
CONAE	SAOCOM 1A	SAR-L	Not Committed	01-Dec-12	01-Dec-17
CONAE	SAOCOM 1B	SAR-L	Not Committed	01-Jun-13	01-Jun-18
CONAE	SAOCOM-2A	SAR-L	Not Committed	01-Jan-15	01-Jan-20
CONAE	SAOCOM-2B	SAR-L	Not Committed	01-Jan-16	01-Jan-21
CSA	RADARSAT-1	SAR C band	Not Used	04-Nov-95	31-Mar-12
CSA	RADARSAT-2	SAR C band	Not Used	14-Dec-07	17-Apr-15
CSA	RADARSAT C-1	SAR (RCM) C band	Not Committed	01-Aug-14	01-Aug-21
CSA	RADARSAT C-2	SAR (RCM) C band	Not Committed	01-Apr-15	01-Apr-22
CSA	RADARSAT C-3	SAR (RCM) C band	Not Committed	01-Jun-15	01-Jun-22
DLR/Astrium	TanDEM-X	TSX-SAR	Not Used	21-Jun-10	31-Dec-15
DLR/Astrium	TerraSAR-X	TSX-SAR	Not Used	15-Jun-07	31-Dec-12
DLR	TerraSAR-X2	X-Band SAR	Not Committed	01-Jan-13	01-Jan-18
ESA	Envisat	ASAR	Used	01-Mar-02	31-Dec-13
ESA	Sentinel-1 A	C-Band SAR	Not Committed	15-Dec-12	15-Mar-20
ESA	Sentinel-1 B	C-Band SAR	Not Committed	15-Dec-14	15-Mar-22
ESA	Sentinel-1 C	C-Band SAR	Not Committed	31-Mar-19	30-Jun-26
ISRO	RISAT-1	SAR	Not Used	25-Mar-11	25-Mar-15
ISRO	RISAT-2	SAR-X	Not Used	20-Apr-09	20-Apr-13
ISRO	RISAT-2F	SAR-X	Not Committed	01-Jan-13	01-Jan-17
KARI	KOMPSAT-5	COSI	Not Used	15-Dec-10	31-Dec-14
MDA	Radarsat Constellation 1	SAR	Not Committed	01-Jan-14	31-Dec-21
MDA	Radarsat Constellation 2	SAR	Not Committed	01-Jan-15	31-Dec-22
MDA	Radarsat Constellation 3	SAR	Not Committed	01-Jan-16	31-Dec-23
NASA	SMAP	L-Band Radar	Not Committed	01-Jan-14	31-Dec-17
ROSHYDROMET	Meteor-M N1	Severjanin X-band	Not Used	18-Sep-09	18-Sep-14
ROSHYDROMET (ROSKOSMOS)	Meteor-M N1	BRLK	Not Used	18-Sep-09	18-Sep-14

Table F-4 (continued)

Agency	Mission	Instrument	CEODA-Ops Status	Launch Date	Expected End of Life
ROSHYDROMET (ROSKOSMOS)	Meteor-M N2	BRLK	Not Committed	01-Jul-11	01-Jul-16
ROSHYDROMET (ROSKOSMOS)	Meteor-M N3	SAR X band	Not Committed	31-Dec-12	31-Dec-17

Table F-5 Passive Microwave Sensors

Agency	Mission	Instrument	CEODA-Ops Status	Launch Date	Expected End of Life
CNES	ERS-2	ATSR/M	Not Used	21-Apr-95	30-Jun-11
ESA	Envisat	MWR	Not Used	1-Mar-02	31-Dec-13
ESA	ERS-2	MWR Microwave	Not Used	21-Apr-95	30-Jun-11
ESA	SMOS	MIRAS	Not Used	2-Nov-09	2-Nov-12
ESA (EC)	Sentinel-3 A	OLCI	Not Committed	15-Apr-13	15-Aug-20
ESA (EC)	Sentinel-3 A	SLSTR	Not Committed	15-Apr-13	15-Aug-20
ESA (EC)	Sentinel-3 B	OLCI	Not Committed	31-Dec-14	30-Apr-22
ESA (EC)	Sentinel-3 B	SLSTR	Not Committed	31-Dec-14	30-Apr-22
ESA (EC)	Sentinel-3 C	OLCI	Not Committed	1-Jan-20	1-May-27
ESA (EC)	Sentinel-3 C	SLSTR	Not Committed	1-Jan-20	1-May-27
ISRO	OCEANSAT-1	MSMR	Not Used	26-May-99	31-Dec-11
ISRO	OCEANSAT-3	PMR	Not Committed	1-Jan-14	1-Jan-19
JAXA	GCOM-W1	AMSR-2	Not Committed	1-Feb-12	1-Feb-17
JAXA	GCOM-W2	AMSR-2	Not Committed	1-Feb-16	1-Feb-21
JAXA	GCOM-W3	AMSR-2	Not Committed	1-Feb-20	1-Feb-25
JAXA (NASA)	Aqua	AMSR-E	Used	4-May-02	30-Sep-11
NASA	TRMM	TMI	Not Used	27-Nov-97	30-Sep-11
NASA	SMAP	L-Band Radiometer	Not Committed	1-Jan-14	1-Jan-19
NASA (CONAE)	SAC-D/Aquarius	Aquarius L-Band radiometer	Not Committed	1-Apr-11	1-Apr-17
NOAA (DoD (USA))	DMSP F-14	SSM/I	Not Used	4-Apr-97	1-Oct-11
NOAA (DoD (USA))	DMSP F-15	SSM/I	Not Used	12-Dec-99	1-May-13
NRSCC (CAST)	FY-3A	MERSI	Not Used	27-May-08	31-May-11
NRSCC (CAST)	FY-3A	MWRI	Not Used	27-May-08	31-May-11
NRSCC (CAST)	FY-3B	MERSI	Not Used	31-Dec-10	31-Dec-12
NRSCC (CAST)	FY-3B	MWRI	Not Used	31-Dec-10	31-Dec-12
NRSCC (CAST)	FY-3C	MERSI	Not Committed	31-Dec-12	31-Dec-16
NRSCC (CAST)	FY-3C	MWRI	Not Committed	31-Dec-12	31-Dec-16
NRSCC (CAST)	FY-3D	MERSI	Not Committed	31-Dec-14	31-Dec-18
NRSCC (CAST)	FY-3D	MWRI	Not Committed	31-Dec-14	31-Dec-18
NRSCC (CAST)	FY-3E	MERSI	Not Committed	31-Dec-16	31-Dec-20
NRSCC (CAST)	FY-3E	MWRI	Not Committed	31-Dec-16	31-Dec-20
NRSCC (CAST)	FY-3F	MERSI	Not Committed	31-Dec-18	31-Dec-22
NRSCC (CAST)	FY-3F	MWRI	Not Committed	31-Dec-18	31-Dec-22
NRSCC (CAST)	FY-3G	MERSI	Not Committed	31-Dec-20	31-Dec-24
NRSCC (CAST)	FY-3G	MWRI	Not Committed	31-Dec-20	31-Dec-24

Appendix G—Essential Climate Variables

The Essential Climate Variables (ECV) defined by the Global Climate Observing System (GCOS) are listed in **Table G-1** **(GCOS, 2010)**. Measurement of over half of the recognised ECVs is largely or exclusively dependent on satellite data. These ECVs are underlined in **Table G-1**.

Table G-1 GCOS Essential Climate Variables

(Measurement of underlined ECVs is dependent on EOS)

Domain	Type of Measurement	Essential Climate Variables
Atmospheric	**Surface** (includes measurements at standardized, but globally varying, heights in close proximity to the surface)	Air temperature <u>Wind speed and direction</u> Water vapour Pressure <u>Precipitation</u> Surface radiation budget
	Upper-air (up to the stratopause)	<u>Temperature</u> <u>Wind speed and direction</u> <u>Water vapour</u> <u>Cloud properties</u> <u>Earth radiation budget</u> (including solar irradiance)
	Composition	<u>Carbon dioxide</u> <u>Methane and other long-lived greenhouse gases</u> (including nitrous oxide (N_2O), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6), and perfluorocarbons (PFCs) <u>Ozone and Aerosol properties</u>, supported by their precursors (in particular nitrogen dioxide (NO_2), sulphur dioxide (SO_2), formaldehyde (HCHO) and carbon monoxide (CO))
Oceanic	**Surface** (includes measurements within the surface mixed layer, usually within the upper 15m)	<u>Sea-surface temperature</u> <u>Sea-surface salinity</u> <u>Sea level</u> <u>Sea state</u> <u>Sea ice</u> Surface current Ocean colour Carbon dioxide partial pressure Ocean acidity Phytoplankton
	Sub-surface	Temperature Salinity Current Nutrients Carbon dioxide partial pressure Ocean acidity Oxygen Tracers

Table G-1 (continued)

Domain	Type of Measurement	Essential Climate Variables
Terrestrial		River discharge Water use Groundwater Lakes Snow cover Glaciers and ice caps Ice sheets Permafrost Albedo Land cover (including vegetation type) Fraction of absorbed photosynthetically active radiation (FAPAR) Leaf area index (LAI) Above-ground biomass Soil carbon Fire disturbance Soil moisture