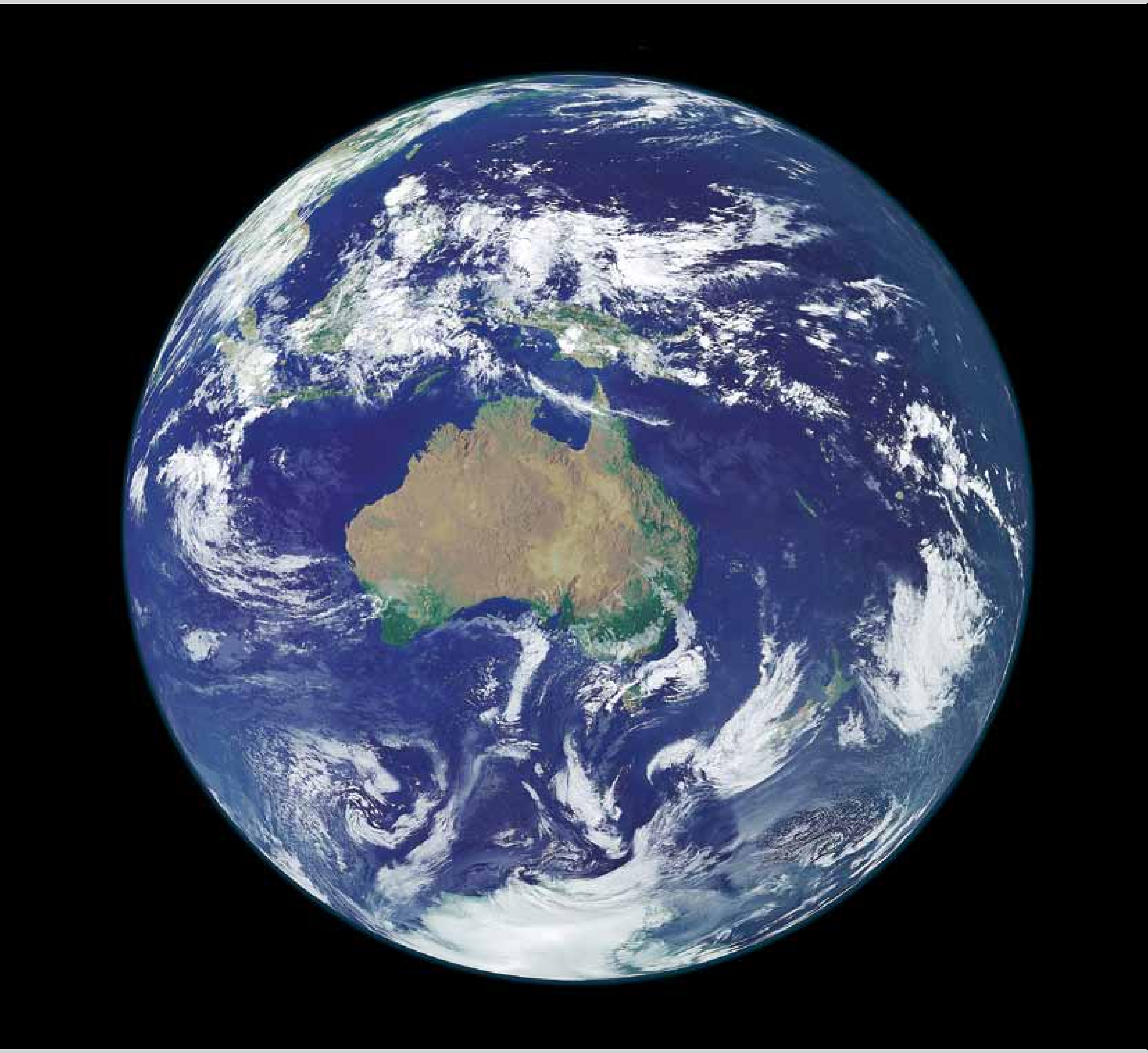

AN AUSTRALIAN STRATEGIC PLAN FOR EARTH OBSERVATIONS FROM SPACE

July 2009

Australian Academy of Science

ATSE
Australian Academy of Technological Sciences and Engineering (ATSE)

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Prepared for the Australian Academy of Science and the Australian Academy of Technological Sciences and Engineering by a working group of Academy Fellows and space science and Earth observation experts.

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FOREWORD

On behalf of the Australian Academy of Science (AAS) and the Australian Academy of Technological Sciences and Engineering (ATSE), we are pleased to present this Australian Strategic Plan for Earth Observations from Space.

Its purpose is to contribute to consensus on, and implementation of, a comprehensive strategy for strengthening Australia's role in space-based observation of the Earth, to meet our rapidly expanding national need for Earth observation data over the next 10 to 15 years.

The plan was prepared by a working group of Academy Fellows and other space science and earth observation experts with strong links to the international satellite community and to a wide cross-section of providers and users of space-based Earth observations in Australia.

The preparation of the plan was supported by the major national Earth observation provider and user agencies, which were represented on a high-level steering committee that provided advice to the working group but which did not determine the content of its report.

The working group was requested to prepare a strategic plan on a tight time-frame, to assist with prompt follow-up to a number of recent space-related initiatives including the November 2008 Senate Economics Committee Report *Lost in Space?*.

The terms of reference for the study and the composition of the working group and steering committee are included in the appendices to this report. The main conclusions of the working group, the essential elements of the proposed strategy and the recommendations for action are summarised in the executive summary.

The working group has concluded that Australia can no longer meet its burgeoning national needs for Earth observations through reliance on the generosity and goodwill of other countries. It believes that we must immediately commit to a much stronger national role in Earth observations from space. It recommends a strategy for ensuring that Australia plays its part in the international Earth observation effort in ways that will optimally meet our national needs over the next 10 to 15 years and beyond.

We place on record the Academies' appreciation to the steering committee and the working group. We endorse the general conclusions of this report and commend its recommendations for urgent follow-up action by all concerned.

Kurt Lambeck AO, Pres AA, FRS
(President, Australian Academy of Science)

Robin Batterham AO, FAA, FTSE, FREng
(President, Australian Academy of Technological Sciences and Engineering)

PREFACE

This report has been prepared by a working group of sixteen Academy Fellows and other space science and Earth observation experts in response to the terms of reference assigned to the working group by the Presidents of the Australian Academy of Science (AAS) and the Australian Academy of Technological Sciences and Engineering (ATSE) on 23 December 2008.

The report responds seriatim to the working group's terms of reference. It identifies Australia's current activities, needs, capabilities and future opportunities in Earth observations from space (EOS) and sets out an overall strategy for the future. It provides nine specific recommendations for follow-up action but it does not address detailed organisational or budgetary issues, which are the proper business of the various relevant agencies of government.

The working group has consulted as widely as possible, nationally and internationally, in the very tight time-frame available for completion of this report, but it has not been possible to include reference to more than a small part of the total national EOS effort. Hence the working group's conclusions do not purport to represent a complete consensus of the Australian Earth observations and space science communities. We do, however, believe that the essential messages in this report carry broad support from both the EOS provider and user communities and that the implementation of the nine recommendations would go a long way towards maximising Australia's future social, economic and environmental benefits from the acquisition and application of EOS.

We believe also, that the implications of EOS for Australia are so enormous and so widespread that we cannot afford to postpone the actions now urgently needed to deliver the additional multi-billion dollar benefits potentially available from EOS over the next decade, or risk the degradation or loss of widely used community services by assuming long-term sustainability of the EOS status quo. The working group, therefore, commends the strategy set down in this report for endorsement by the Academies and urgent and vigorous follow-up action by governments, industry, the research community, and other stakeholders in the national EOS enterprise.

I am grateful to all members of the working group for the time, expertise and hard work that they put into preparing this report and, especially, for their willingness to focus on serving the long-term national interests ahead of those of their own institutions, disciplines or programs. I also wish to thank the Academies and the Earth observation agencies and steering committee members who assisted with the preparation of the report, especially the project officer, Bruce Neal, who provided the working group with cheery, wise and highly professional support throughout the preparation of this report.

John W Zillman AO, FAA, FTSE
(Chairman of the Working Group)
31 July 2009

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EXECUTIVE SUMMARY

The essential messages

- Earth observations from space (EOS) are the single most important and richest source of environmental information for Australia. 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.

- Australia's needs for EOS data are increasing rapidly. Extensive EOS information is essential for addressing urgent national challenges in climate change, water, natural disaster mitigation, transport, energy, agriculture, forestry, ecosystems, coasts, oceans and national security.

- The satellite-provider nations have many new missions planned for the next 10 to 15 years, providing powerful new EOS capabilities for addressing Australia's needs. We have, however, become fully dependent on foreign-owned satellites and we can no longer significantly influence their capabilities in support of our unique requirements. Time is running out for our historical free-rider status on the international EOS system.

- Australia must immediately embark on a national strategy to secure long-term access to the international EOS system and to better focus its capabilities on Australian-specific needs for EOS information. We must also greatly strengthen our national EOS operational, data acquisition, data processing, research, education and industry infrastructure to take full and timely advantage of existing EOS satellites and the many new opportunities that will become available over the next decade.

- The opportunity costs of living with the national EOS status quo are mounting rapidly. The strategy set down in this plan will ensure that Australia realises the additional multi-billion dollar economic, social and environmental benefits that are potentially available from full participation in the global EOS enterprise, and which are likely to be widespread across the Australian community.

1. Introduction

Everyone needs Earth observations. Accurate and reliable information on the state of the atmosphere, oceans, coasts, rivers, soil, crops, forests, ecosystems, natural resources, ice, snow and built infrastructure, and their change over time, is directly or indirectly necessary for all functions of government, all economic sectors and almost all day-to-day activities of society.

EOS provide an essential means for meeting this need and a primary rationale for the world's trillion dollar annual investment in space science and technology. They promise to transform Australia's capacity to address such critical national challenges as 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.

Australia is already a major user and beneficiary of EOS. Our large land area, low population, long coastline, vast Exclusive Economic Zone and extreme vulnerability to a wide range of natural hazards have made it essential that we take the maximum possible advantage of the unique capabilities of EOS. We have long experience and invaluable pockets of expertise in the use of EOS for natural disaster mitigation, weather forecasting and warning, navigation, mapping and mineral exploration, natural resource management, ocean and coastal monitoring, and for many other public and private purposes.

Australia is, however, fully dependent for these purposes on EOS satellites that are funded and operated by other countries. The vast majority of EOS satellite missions are provided and maintained by foreign governments (and consortia of governments) for their national purposes and as a global public good in support of disaster reduction, public safety, economic development, environmental stewardship and general community wellbeing around the world. While a number of Australian Earth observation agencies have historically contributed in complementary ways to the total Earth observation system, Australia is, and is widely seen to be, a free-rider on the international system of cooperation to which several developing countries are now contributing much more strongly than we are.

Australia's dependence on EOS is growing rapidly. The new generation of global satellite missions progressively coming into operation is strongly directed at the comprehensive measurement from space of the essential climate variables required to support the work of the Intergovernmental Panel on Climate Change (IPCC) and the UN Framework Convention on Climate Change (UNFCCC). We will be reliant on information from these missions to meet Australia's monitoring and reporting obligations under the UNFCCC framework, as well as for addressing our own array of national problems concerning the impacts of climate change.

The recent Commonwealth government establishment of an Australian Space Science Program opens up welcome opportunities for Australia to benefit from the empowering capabilities of the new EOS technologies, but our time is almost up as a free-rider on the EOS programs of the satellite-provider nations. These nations have made it clear that they expect Australia, as a major developed country, to contribute to the internationally coordinated EOS system. We cannot expect to be able to continue to rely on the generosity and goodwill of other countries. We will soon have to make clear our long-term willingness to contribute much more strongly in complementary ways to the total global Earth observation system and begin planning to join other satellite-operating countries as a provider of satellites for our own purposes and as a meaningful Australian contribution to the globally coordinated Earth observation systems.

This report is designed to help Australia begin its urgently needed transformation to an active participant in the global EOS enterprise and to being a much more effective user of EOS information for our own unique national purposes. It briefly reviews Australia's current EOS activities and future national needs, and sets out the essential elements of a national EOS strategy and implementation schedule that will set Australia on a sound course for provision and application of EOS data in support of national needs and priorities over the next decade and beyond.

2. Current activities

EOS data are already the single most important and richest source of environmental information for Australia. They cover the huge gaps in surface-based and airborne remote sensing systems, and provide the comprehensive information needed for environmental stewardship over the Australian continent, its surrounding oceans, and Antarctica. Satellite instruments can capture multispectral images with a spatial resolution of less than 50 metres over this entire area and can measure detailed properties of the atmosphere, land and oceans at one to six hourly intervals, with a spatial resolution of 1 to 50 kilometres. This coverage, density and volume of information cannot be matched by any other observational system.

Many major EOS-related activities throughout Australia now rely critically on the long-term continuity of consistent and accurate information derived from satellite missions operated by the USA, the European Union, Japan, China and Canada. We are also involved with these nations, and others such as India, Indonesia, Russia and South Korea, under our International Science Linkages Program and various bilateral programs for cooperation in science and technology.

Australia is a member of the intergovernmental Group on Earth Observations (GEO), which consists of 79 UN member states, the European Commission, and 56 participating organisations. GEO is implementing a 10-year plan to put in place a Global Earth Observation System of Systems (GEOSS), which is emerging as the overarching global framework for cooperation and coordination in the implementation of Earth observing systems for nine major societal benefit areas. The space-based components of GEOSS embrace the known plans of international satellite missions to the year 2025.

Australia's current international engagement in EOS activities occurs primarily through inter-agency and project-specific links to the national space agencies of other countries, and through GEO and its major component coordinating mechanisms such as the Committee on Earth Observation Satellites (CEOS) and the Coordination Group for Meteorological Satellites (CGMS). Our international engagement is, however, hampered by the fact that we have no clear national focus for EOS activities, no EOS strategic plan and no identified funding source for support of Australian participation in international EOS programs.

Within Australia, there is some current activity in most aspects of EOS except for the provision and operation of spacecraft but, overall, the level of activity is well below capacity and it falls far short of meeting present national needs. There is a large diversity in the use of EOS throughout Australia and, in order to get a full picture, it will be necessary to conduct a more detailed audit of the true national capacity, costs and effectiveness to perform EOS-related services.

There is no doubt, however, that EOS are playing a major role in helping Commonwealth, state and local government agencies to discharge a wide range of responsibilities in such areas as land, coast, ecosystem, agriculture and fisheries management, environmental protection, and provision of emergency services for fires, floods, earthquakes, tsunamis and cyclones. EOS are helping

Commonwealth agencies discharge their specific responsibilities in national security, border protection, weather forecasting, natural disaster mitigation, national mapping, transport, forestry, agriculture, water resources, the Murray-Darling Basin, the national environment, and climate change mitigation.

The major areas of scientific expertise in EOS in Australia are in the development and application of atmospheric, oceanographic, hydrological, cryospheric, ecological, geological, geophysical and geodetic sciences. EOS applications are currently being used to varying degrees for many purposes in Australian society but, in all cases, the utilisation is below potential capacity and falls well short of meeting identified needs. It has been shown that EOS data input essentially doubles the useful range of weather forecasting for Australia but, at present, we are not able to make full use of more than a small part of the data available from foreign satellites.

Australia has, however, established world leadership in the use of EOS for carbon accounting. Other important EOS applications include national security, border protection, natural disaster mitigation, water resources management, agriculture, fisheries and forestry management, geophysical and resources mapping, geodesy, mineral and petroleum exploration, solar and wind energy development, transportation and tourism, Antarctic research, many aspects of the monitoring of Australia's climate, ecosystems, and the marine environment.

Australia's research capabilities in EOS are of high quality and well respected internationally. However, they are mostly small, fragmented and the product of opportunistic involvement of Australian scientists in satellite data studies and as principal investigators in foreign satellite missions, as leaders of local calibration/validation projects and the like. They include both research into fundamental scientific problems (such as climate change and sea-level rise) and a wide range of research groups committed to developing the potential of new EOS missions and instruments for practical application in the Australian context.

There are major weaknesses in national planning, coordination and resourcing arrangements, in data archival and access, and in education, training and capacity-building activities. These weaknesses are limiting Australia's opportunities to fully exploit the potential utility of space-based observations. University groups, Cooperative Research Centres (CRCs) and some government agencies contribute to EOS education, training, capacity building and staff development, but Australia has no coordinated national approach to building and maintaining its pool of EOS expertise. Our national EOS arrangements reflect the historical response of individual agencies and university research groups to needs and opportunities as they emerged at the time, with only very limited overall national planning and coordination. This is also reflected in the current status of EOS satellite downlink ground stations.

Major ground stations for EOS data reception have been designed and are operated primarily to serve the separate purposes of the Bureau of Meteorology (for national weather, climate, water and related services), Geoscience Australia (for national mapping, navigation and other geophysical purposes), the specific and extensive EOS data needs of Western Australia (through the Perth-based WASTAC consortium), and the needs for research and applications over the Southern Ocean and Antarctica (through the Hobart-based TERSS consortium). CSIRO is involved in the two consortia and in data access aspects for all these networks. An Australian company has exclusive reception and distribution rights to the commercial SPOT constellation of satellites and has established a Geospatial Acquisition Centre in Adelaide.

The Australian Earth observation industry comprises about 100 small and medium enterprises engaged in basic data acquisition and sales and the provision of specialised consultative services, mainly with respect to EOS high-resolution spatial information products. The major clients are Commonwealth government organisations (particularly the Department of Defence), state, territory and local government users, and the mining and resources sector. Only in two known instances are locally built and operated imaging technologies used in the procurement of these services.

3. Future needs and opportunities

The global community is addressing future needs for Earth observations via an integrated, coordinated and consultative approach which aims to transfer the global benefits of observational science and technology to the community. Australia needs to align itself with this global approach that has been adopted by almost all other major developed countries. In the first instance, this requires the establishment of a national coordinating mechanism for the strategic planning of EOS activities.

Accurate and timely scientific observations form the basis of almost all scientific research, as well as the development of new systems and services to improve the prosperity and operation of our society. To use EOS to address our critical national challenges, we need to ensure that:

- Australia has continuing access to a timely and consistent stream of EOS data that are calibrated for Australian conditions and that EOS mission-to-mission transition is managed so that there is no disruption to the continuity of national and state-based programs and data sets which are critically dependent on EOS information; and
- Australia's capacity to transform EOS data to essential information is developed from the current relatively few key areas in natural resource management to a broad range of applications.

To meet these requirements, we need to develop a coordinated approach to prepare national and state infrastructure for imminent major changes in the operation of the global EOS system, and to strengthen the links, communications and support between state and Commonwealth EOS-based programs, as well as the activities of universities, CRCs and industry. We must strategically assess the optimal design and maintenance of our national data reception, our computing and communications infrastructure, and our data archive and access systems, in the light of major changes that will be introduced in the next 5 years in the global space-based data collection and distribution system.

Australia is developing Earth system modelling and spatial data analysis capabilities that are essential to assimilate the next generation of EOS data and convert them into products and services, but we are not well prepared to access and assimilate the flood of complex new data streams that will soon become available to improve the capabilities of these models. A greatly strengthened and more focused research effort is needed to develop the EOS applications required to address major national challenges. This must include both user-driven research in the key applications sectors and provider-driven research into the application of new EOS data to Australia's national needs. The first essential step is to develop a national EOS priority-setting mechanism that includes the scientific and applications communities.

In conjunction with the strengthening national EOS research effort, there is a need to make a major investment in EOS training and capacity building in the mission agencies, the university sector and the applications communities. There is a concurrent need to build the capacity of industry and the EOS commercial sector to help support and further exploit emerging opportunities associated with an expected transformation of Australia's role and national policies for the use of space-based technologies.

Australia's new National Framework for Climate Change Science identifies key areas where science must deliver information to inform important decisions for the nation. Much of the required environmental information can only be provided by the space-based observations that will come from the new generation of global EOS missions. Australia must rapidly embrace the opportunity to exploit these new data to the fullest.

The world is entering another period of major change in the science, technology and mode of use of EOS data. Australia has a great opportunity to expand its current access to and use of EOS information in the period 2010–25. The plans and status of all global EOS missions for 2010–25 are already catalogued. The GEOSS 10-Year Implementation Plan provides a broadly-based international framework for integration of space-based and surface-based Earth observation activities.

Opportunities are emerging for Australia to enter into new partnerships to make better use of Earth observations from space, which give reason for industry and commerce to be more optimistic about satisfying some of their future needs. The Department of Defence has already taken such an initiative and Australian society may be able to achieve further benefits from this through future synergies between the civil and defence EOS programs.

Other partnership opportunities are emerging for cooperation in both public good and commercial satellite missions. These range from involvement in missions using constellations of micro-satellites to missions in which Australia might modestly share some of the costs, or provide one or more of the satellite sensors. Argentina, Indonesia, Mexico, Nigeria, South Africa, Thailand and Venezuela have recently announced plans to establish EOS missions. Most of these programs are modest and involve cooperative ventures with other nations.

4. Strategy for the next decade and beyond

The working group proposes a strategy for meeting Australia's future EOS needs based on the following goal, strategic objectives and strategic initiatives:

Strategic goal:

To maximise Australia's social, economic and environmental benefits from the acquisition and application of EOS.

Strategic objectives:

To use the critical value adding input of EOS:

- to monitor, understand and predict climate change and variability, to assess the impacts of climate change, and to develop strategies to mitigate and adapt to climate change on national, regional and global scales;
- to monitor, understand and predict the water balance across Australian catchments in order to optimise the management of water;
- to monitor natural disasters and to develop strategies to manage and mitigate the impacts of natural disasters in the Australian region;
- to monitor and predict weather and other environmental factors in order to ensure the safety and security of Australian transport and navigation systems on land, sea and in the air;

- to assess sites for renewable energy sources and to predict weather and climate conditions relevant to overall load management and to expected energy demand in Australia;
- to monitor, manage and plan agriculture, forestry and natural ecosystems in Australia;
- to monitor, manage and predict the environment of the coasts and oceans around Australia; and,
- to monitor Australian borders and to assure national security.

Strategic initiatives:

- develop and implement a new overarching national EOS policy framework;
- develop a mechanism to assess and review national EOS priorities;
- develop a national approach to optimising Australia's EOS infrastructure;
- establish a critical mass of strategic EOS research and education capability;
- enhance EOS industry capability to support an increased Australian global role in EOS;
- safeguard essential EOS use of the radio spectrum; and
- establish international partnerships in EOS provision.

In the short to medium term, the proposed strategy involves the consolidation and strengthening of our established EOS capacities and the gradual building of our competence and credentials for playing a much larger role than we have in the past in the collaborative global arrangements. By 2025, we should become an established provider, as well as a user, of EOS capabilities in ways which enable us to better serve our national needs while also benefiting to the full from becoming part of the coordinated global system for meeting the EOS needs of all countries.

The key enabling strategic initiative is the development and implementation of a new overarching EOS policy framework. Policy development should build on recent initiatives to establish the Australian Space Science Program and to invest heavily in space-based technology for strategic defence purposes. The overarching policy framework should define:

- national policies for Australia's strategic engagement with the international community;
- national policies for the acquisition and use of EOS to support the national challenges;
- the role of science, technology, innovation and industry in addressing these challenges;
- national contributions to global EOS activities, including our contribution to GEOSS;
- guidelines for managing Commonwealth-state interests in EOS exploitation; and
- synergies for defence and civil use of EOS information.

5. Implementation of the strategy

The established Commonwealth, state and academic institutions currently involved in various aspects of EOS data utilisation, research and management are major strengths for Australia. Within the limits of available resources, these institutions prioritise their use of EOS to help deliver their various mission outputs. Major weaknesses lie in EOS-specific arrangements for national coordination and national strategic planning, and the lack of a clearly recognised national focus for dealing with EOS matters internationally.

The working group supports the approach recommended by the November 2008 Senate Economics Committee report of a gradual change in institutional arrangements commensurate with those needed to accompany the evolution of Australia's proposed national and international roles. Three specific institutional initiatives are proposed in support of the implementation of the strategy:

- Establishment of a broadly-based EOS advisory council to guide the integrated strategic development of the application of EOS in Australia and to advise the Commonwealth government on strategic needs. Its first tasks should be to establish an ongoing national EOS priority-setting mechanism, including the full involvement of EOS provider institutions, the learned academies and the broader user community, and to assess priorities for the uptake of opportunities for Australian partnerships in international EOS missions and for enhanced global and regional cooperation.
- Establishment of a small national EOS office to support the EOS advisory council, to enhance the national EOS profile within Australia's new Space Science Program, and to drive and coordinate the implementation of the proposed strategy. It would be logical to establish this office as a component of the new Space Policy Unit in the Department of Innovation, Industry, Science and Research (DIISR).
- Reaffirmation and strengthening of the main Commonwealth EOS mission agencies in their role as essential elements of the core national infrastructure for EOS data acquisition, processing, applications and research.

6. Recommendations

The working group offers nine recommendations for implementation of the proposed strategy, as follows:

1. **National EOS policy.** Australian government policy on space science and industry development should include an explicit national policy on EOS, based on strengthening, broadening and coordinating existing EOS activities and a strategic commitment to full Australian participation in the international EOS system by 2025.

2. **EOS priority setting.** A high level, cross-portfolio EOS advisory council should be established with the active involvement of the national EOS provider agencies, the learned academies and the EOS user community to advise on national priorities for EOS operations, research, education and applications across all sectors and all levels of government.

3. **National EOS infrastructure.** The main operational EOS agencies and ground station consortia should jointly establish a coordinated approach to strengthening and optimising the national investment in the EOS data acquisition, processing, archival, distribution and applications infrastructure that will be needed to handle the massive increase in EOS availability and user needs over the next decade.

4. **EOS research and education.** A national plan and funding framework should be developed to establish and maintain a critical mass of strategic research and education expertise in Australian universities to underpin the operational EOS systems, services and applications in industry and government agencies.

5. **EOS industry capability.** In order to support a strengthened Australian role in the global Earth observation satellite community, the Space Science and Innovation Project Grants scheme should be enhanced within the framework of the national EOS policy to promote local industry capabilities in EOS systems development and applications.

6. **Radio spectrum for EOS.** Given the enormous social, economic and environmental benefits to Australia from the use of EOS data, those parts of the radio spectrum that are uniquely required for satellite remote sensing of atmospheric and Earth characteristics should be permanently protected from interference, in the public interest. Means should also be found for meeting the costs of commercial sharing of those parts of the radio spectrum that are used for public-good transmission of EOS data from satellites.

7. **International engagement in EOS.** Australia should strengthen its role and influence in international EOS through development of bilateral and multilateral (including regional) partnerships in EOS provision, greater involvement in the Committee on Earth Observation Satellites (CEOS), and enhanced contribution to the implementation of the Global Earth Observation System of Systems (GEOSS).

8. **EOS national office.** An EOS national office should be established as part of the Australian Space Science Program, to support the EOS advisory council, to maintain links with the operational EOS agencies, and to serve as the national focal point for Australian EOS activities.

9. **EOS mission agencies.** The EOS operational and research mandates of the Bureau of Meteorology, Geoscience Australia and CSIRO should be reaffirmed and strengthened, and they should collaborate with the Department of Defence, other Commonwealth and state EOS agencies and universities in the progressive development of a more integrated national EOS service and research framework for Australia.

CHAPTER 1: **INTRODUCTION**

Australia faces many formidable national challenges whose solution will require comprehensive environmental information and the best possible scientific skills over the coming decades. The need for accurate and reliable information is widespread across society. Sustained long-term observations of the state of the atmosphere, cryosphere, oceans, coasts, lakes, rivers, soil, crops, forests, ecosystems, Earth resources and built infrastructure are needed by all levels of government, all economic sectors and virtually every member of the community. Comprehensive Earth observation is a national imperative for the decades ahead.

While many of our specific information requirements are unique to Australia, the overall needs for long-term Earth observations are global, and finding the most effective ways of meeting them is a common challenge for the Earth science and Earth system science communities in all countries (Box 1). The provision of Earth observations from space (EOS) is an essential and powerful tool for meeting many of these needs and a primary rationale for the world's trillion dollar annual investment in space science and technology (Box 2).

Box 1: Earth science and Earth system science

Earth science is the study of the planet Earth as a whole, based on the traditional disciplines of geology, geophysics, geochemistry, meteorology, oceanography, hydrology and palaeontology, and embracing also a range of recent environmental disciplines. It has become useful to distinguish between 'Earth science' in the restricted sense of the solid Earth sciences, and 'Earth system science'. Earth system science is a rapidly evolving interdisciplinary field focused on observing, understanding, reconstructing and predicting global environmental changes involving interactions between land, atmosphere, water, ice, biosphere, societies, technologies and economies.

There are many international intergovernmental and non-governmental scientific programs for the study of the Earth system, including the intergovernmental programs of UNESCO and the World Meteorological Organization (WMO), various discipline-based Earth science programs of the non-governmental International Council for Science (ICSU), and ICSU's interdisciplinary International Geosphere-Biosphere Programme (IGBP).

In Australia, there are numerous Commonwealth and state government organisations with broad responsibilities for various aspects of Earth science and Earth system science including, especially at the national level, the Bureau of Meteorology (BoM), Geoscience Australia (GA) and CSIRO. Most Australian universities include Earth science or other environmental science departments or institutes.

The primary mechanism for non-governmental scientific coordination at the national level, and for provision of the Australian links to the relevant international scientific programs, is provided by the Australian Academy of Science through its National Committee for Earth Sciences (NCES) and its National Committee for Earth System Science (NCESS). The primary link to the relevant international intergovernmental programs is provided by Australian representatives to UNESCO, WMO, the Food and Agricultural Organization (FAO) and the United Nations Environment Programme (UNEP).

Box 2: Space science and technology

Space science embraces the study of the sun and the solar system as a whole, the study of the planets and their climates, and the techniques for studying them. It includes both the *science of space* and the *science that can be done from space*. The former encompasses the study of everything from Earth's middle atmosphere to the centre of the sun and the boundaries of the solar system. The latter includes the study from space of the atmosphere, land and oceans, and the Earth's interior. It involves both operational and research satellites used for meteorological, environmental, navigation and Earth resources studies.

The sun and its radiation, activity and variability strongly affect the properties and habitability of the Earth as well as human technology and society. Space weather processes, such as changes in the interplanetary magnetic field, coronal mass ejections from the sun, and disturbances in Earth's ionosphere and magnetic field, can affect the near Earth environment. The effects of 'space weather' can range from damage to satellites to disruption of GPS services and power grids on Earth. In Australia, the Ionospheric Prediction Service (IPS) issues warnings of dangerous space weather events.

Australia has had significant influence on international space policy via the UN Committee on the Peaceful Uses of Outer Space (COPUOS) and has contributed expertise on a range of international expert bodies. Within Australia, the primary government coordination mechanism for space science is the Australian Government Space Forum (AGSF) hosted by the Department of Innovation, Industry, Science and Research. Non-governmental coordination is provided by the Australian Academy of Science through its National Committee for Space Science (NCSS).

Australia provides crucial spacecraft tracking and data download infrastructure for US, European, Chinese and other space programs. Australia has substantial ground segment augmentation facilities for satellite-based navigation and timing systems, enabling explosive growth in the use of GPS receivers throughout the nation.

Communications satellites, Global Navigation Satellite Systems (GNSS), and Earth observation satellites are used every day, often unknowingly, by people everywhere, and represent the three major global applications of space technology. Communications and GNSS satellites also play additional important roles in supporting and complementing the role of the EOS satellites for Earth observation.

In situ measurements and observations remain essential for many purposes, but only space-based observations are capable of providing the spatial and temporal detail and coverage that is now required for most important purposes in most countries. Though taken for granted nowadays, the provision of EOS information (Box 3) in support of societal needs is a large, complex and expensive international scientific undertaking. Ensuring the future availability of EOS presents formidable scientific, technological and policy challenges which need urgent attention by governments in all countries, especially in Australia.

Australia is a major user and an enormous beneficiary of EOS. Our large land area, low population, long coastline, vast Exclusive Economic Zone (EEZ) and extreme vulnerability to a wide range of natural hazards make it essential that we use the capabilities of EOS to the full. We have long experience and pockets of great scientific and practical skill in the use of EOS for natural disaster mitigation, weather forecasting and warning, climate research, national mapping, mineral exploration, natural resource management, ocean monitoring, and for many other public and private purposes. We are, however, fully dependent, for these purposes, on Earth observation satellites that are funded and operated by other countries.

While some Earth observation satellites are operated by governments and corporations for national security and exclusive commercial purposes, the vast majority of EOS satellites are provided and maintained by foreign governments and consortia of governments for national public purposes and as a global public good in support of disaster reduction, public safety, economic development, environmental stewardship and general community wellbeing around the world. Although some

Box 3: Earth observations from space

EOS are provided by the globally coordinated satellite missions of some 28 countries. These countries fund and operate their space programs primarily in support of their own national priorities, but almost all have agreed to make their EOS information available for use by the global community. Most of these countries invest between 0.02% and 0.06% of their GDP on space activities. The USA, Russia, France and India spend more. Australia does not operate a national space program, but participates in a range of international EOS activities under various multilateral and bilateral arrangements.

Earth-orbiting satellites observe the Earth from outside the atmosphere and ionosphere of the planet. Currently there are more than 70 Earth observation satellites operating primarily for public-good applications. The satellite-operating countries are planning some 240 new Earth observation missions within the next 15 years. Observations are made from three common satellite orbit types:

- **Low Earth orbiting (LEO) satellites**, typically at altitudes of 450-1000 kilometres, observing successive relatively narrow swathes of the Earth as the planet revolves beneath them. Highly elliptical orbits enable the satellites to survey particular parts of the Earth for extended periods. Near-polar and near-circular orbits enable the satellites to revisit the same Earth location at approximately the same time each day.
- **Medium Earth orbiting (MEO) satellites**, typically at altitudes of about 20,000 kilometres. Constellations of satellites at this altitude, distributed over several elliptical orbit planes, form the basis of Global Navigation Satellite Systems (GNSS), which provide users with the capacity to accurately determine their position on the Earth.
- **Geostationary Earth orbiting (GEO) satellites**, at altitudes of 35,800 kilometres over the equator, moving at the same speed of rotation as the planet and remaining over the same location on the equator. These satellites are capable of continuously observing the same very large areas of the globe and are especially useful for meteorological purposes.

LEO satellites have the highest spatial resolution capability. Temporal resolution can be improved by operating clusters or constellations of LEO satellites with different times of passage. GEO satellites have lower spatial resolution but much higher temporal resolution. Apart from their navigation and timing capabilities, MEO satellites enable the derivation of vertical profiles of the structure of the atmosphere using radio occultation techniques.

Satellite instruments include passive sensors which measure electromagnetic radiation emitted or reflected from the Earth, as well as active sensors such as GPS instruments and synthetic aperture radars which transmit signals towards the Earth and determine Earth system characteristics from the nature of the transmitted or returned signal. Before the raw data can be useful, the remote sensing instruments must be calibrated against observations taken within the Earth system, and each piece of data must be geospatially navigated. All of this involves highly specialised, complex scientific techniques.

For some satellites, some or all of the data collected can be downloaded immediately to ground stations within the field of view. For others the data are downloaded (with various degrees of delay) only to the host country. The data can be made freely available, or can be encrypted for national security or commercial reasons. Data volumes are very large.

Australian agencies have historically leveraged goodwill and special EOS access arrangements through other forms of contribution to the total Earth observation system, Australia is, and is widely seen to be, a free-rider on the international EOS system to which several developing countries are now contributing much more strongly than we are.

Australia's dependence on EOS is growing rapidly and we face two major challenges over the next 10 to 15 years. The first will be to maintain and strengthen the national Earth observation infrastructure and the research and applications skills that will be needed to deliver the potential benefits from the many new satellite missions that are planned and funded for launch over the next decade. The second will be to put in place robust policies and strategies that will enable Australia to exert a greater influence on future EOS missions and to help ensure the long-term sustainability of the system of international cooperation in Earth observations, on which we now so heavily depend.

Australia cannot expect to be able to continue to rely on the generosity and goodwill of the traditional satellite-provider nations. We would be unlikely to be able to afford the cost of procuring all the observations needed if the present international system of cooperation were to break down as a result of the unwillingness of countries to carry a fair share of the cost of this essential global public good. There is an urgent need to make clear our willingness to begin to contribute more strongly to the total global Earth observation system, and to signal our specific intention to join other satellite-operating countries as a provider of space hardware (remote sensing instrumentation and/or spacecraft) as part of a greatly strengthened Australian commitment to both Earth observation and space science.

Box 4: Australia's historical engagement in Earth observations from space

The Bureau of Meteorology (BoM), Geoscience Australia (GA) and CSIRO have been deeply involved in EOS since the 1960s and 1970s. In the early 1980s the Western Australian Satellite Applications Consortium (WASTAC), which now comprises Curtin University of Technology, Murdoch University, the WA Land Information Authority, BoM, GA, and CSIRO Space Science and Technology (CSST), established ground station and data sharing arrangements in Perth. In the early 1990s, a consortium now comprising the University of Tasmania, the Australian Antarctic Division, the CSIRO Division of Marine Research, GA, BoM, and CSST established the Tasmanian Earth Resources Satellite Station (TERSS) in Hobart. The former Australian Space Office was a foundation member.

Over the past few decades there have been several initiatives for a more strategic framework for EOS in Australia, including:

- the 1985 Madigan Committee Report from the then Australian Academy of Technological Sciences (ATS), which set out a space policy for Australia for the following decade, with Earth observations as a major component;
- the 1993 establishment of a joint working group for the Global Climate Observing System (GCOS), and Global Ocean Observing System (GOOS) to coordinate Australian participation in the internationally co-sponsored GCOS and GOOS, both of which include major space-based as well as in situ components;
- the Australian Space Council and the Australian Space Office, which operated through the early 1990s, and focused on space-based Earth observation technologies and programs as one of four major areas of planning and development;
- the CSIRO Office of Space Science and Applications (COSSA), the predecessor of CSST, which helped to develop the Australian capability in Earth observation and served as the Australian link to some of the international Earth observation coordination mechanisms such as the Committee for Earth Observation Satellites (CEOS).

More recently, Australian space scientists have contributed to several significant international Earth observation missions including the Advanced Along-Track Scanning Radiometer on the European Space Agency's Envisat mission (launched in 2002), as well as the Australian FedSat mission (launched in 2003).

Australia is recognised internationally for its scientific application of EOS data in many areas of expertise. Australian meteorologists pioneered the application of satellite imagery for synoptic weather analysis over the data-sparse southern hemisphere oceans. Over the past decade, Australia has set the benchmark for international methods of carbon accounting in forests, and is playing a lead role in promoting these methods.

There have been many national conferences and activities on space issues; various state-based operational and research consortia have emerged, and a wide range of Australian space science, technology and industry groups have been initiated. Since the closing of the Australian Space Office in 1996 and the establishment of the Cooperative Research Centre for Satellite Systems (CRCSS), Australian space activities (including their Earth observation component) have, for the most part, been viewed by the Commonwealth government as an industry development issue with information exchange and loose national coordination handled mainly through the industry portfolio.

1.1 Australia's role in Earth observations from space

Several Commonwealth government agencies and Commonwealth-state-university consortia have been actively involved in various aspects of observation from space for many decades (Box 4)[1] and EOS information is now used extensively by many Commonwealth, state and local government departments and agencies including environmental, land use, natural resources, water management and climate change agencies in all states. EOS data provide the basis for a wide range of important research programs in many universities.

Many important government programs rely heavily on consistent and accurate information from EOS missions operated by other countries. The EOS input to all of these programs requires substantial scientific preparatory work in data calibration, validation and 'ground truthing' of the satellite observations, in order to provide reliable information for operational, management and other purposes. These programs also require long-term continuity of EOS data and substantial efforts to ensure the smooth transition of the data flow as individual missions come to an end and new missions are launched. Australian scientists and resource managers have expressed major concerns about the future planning, coordination and resourcing of this critical activity and the need to ensure continued access to vital sources of observations.

The global space community is addressing contingency measures to ensure continuity of various critical missions, but Australia's capacity to influence the outcome has been limited. The Australian Space Science Program, which was established through the 2009–10 Commonwealth Budget to support space research, innovation and skills development, may, however, provide some new opportunities over the next few years to begin to leverage on international developments, in support of Australia's special needs.

1.2 Key challenges for Australia

In addition to the ongoing use of EOS for well-established purposes such as weather forecasting, national mapping and mineral exploration, the joint Academies working group has identified eight key national challenges requiring extensive use of EOS if Australia is to take advantage of the new observational capabilities which will become available from the next generation of global environmental satellite missions over the next 5 to 10 years. The role of EOS in addressing these challenges is a central theme in all chapters of this report.

1.2.1 Climate change

The mitigation of climate change is ultimately a global issue, but adaptation to climate change and variability is a particular local challenge for Australia. Detailed information on carbon sources, sinks and storage, temperature, rainfall and other climate trends throughout Australia will be essential for sound management of the climate issue. The monitoring of global and regional climate is heavily dependent on EOS, and about 80 new international satellite missions over the next 15 years will be dedicated to research into, and operational monitoring of, climate variability and change.

1.2.2 Water availability

The availability of fresh water for agriculture and urban use has become a critical issue in Australia. Major coastal cities are either operating or establishing desalination plants to ensure a secure water supply for urban areas, while decadal-scale changes in regional climate are exacerbating droughts and the issues associated with historically excessive water allocations for agriculture. Satellite-based data are essential for national monitoring of surface-water availability. New satellite systems are now providing an improved capability for measuring rainfall, evaporation and soil moisture, and for monitoring groundwater, which is being heavily drawn down in some basins.

1.2.3 Natural disaster mitigation

Major benefits accrue from the impact of EOS information on the monitoring and mitigation of natural disasters in Australia (bushfires, droughts, earthquakes, floods, severe thunderstorms, tropical cyclones, tsunamis). This information is used in all major phases of disaster mitigation activities (planning, preparedness, response and recovery). The contribution of EOS to this area can take the form of specific satellite-derived products such as tropical cyclone track imagery and maps of bushfire location and intensity. Increasingly, EOS data are becoming an integral component of warning and decision systems specifically tailored to the needs of emergency services agencies.

1.2.4 Safe and secure transport

The economic and social wellbeing of the Australian community is very dependent upon a safe and well-functioning road, rail, air, and sea transport system. All these modes of transport are susceptible to variations in the weather and other environmental influences, and utilise both EOS information and Global Navigation Satellite Systems (GNSS) extensively in their operations. Environmental models make substantial use of EOS to analyse the current state of the atmosphere and to predict future weather, ocean and land-surface conditions. Information from EOS is also used directly by the transport industry to monitor the state of its infrastructure and to optimise routing decisions.

1.2.5 Energy and resources security

Australia has strong energy and resources sectors in which exploration and industry development often take place in remote areas where the use of EOS is essential. Australia's dependence on coal for energy and the international uncertainties associated with greenhouse-gas mitigation policies mean that energy security remains a major national challenge and that there is an increasing emphasis on the development of renewable energy sources. The location and operation of renewable energy sources are greatly influenced by meteorological conditions and solar exposure, which depend on EOS for monitoring and prediction. Mineral and petroleum exploration and the exploration of the geological structure of the Earth, (relevant for identifying regions suitable for geothermal energy), are all making increasing use of EOS.

1.2.6 Agriculture, forestry and ecosystems

Large benefits are being realised through the use of EOS in a range of land-use applications, including forestry, agricultural planning, vegetation and crop mapping for regional areas and individual properties, habitat mapping, peri-urban (urban fringe) development, and the monitoring of erosion. EOS data applications are also valuable in an equally large range of aquatic and marine applications, including impacts on fisheries and the monitoring of riverine ecosystems. The integration of EOS, aircraft and surface-based meteorological, hydrological and other information into thematic mapping of the ongoing changes in all these aspects is an essential resource for use by all three tiers of government and by individual land-holders (Figure 1.1).

1.2.7 Coasts and oceans

The Australian coastline extends for more than 36,000 kilometres. Our maritime jurisdiction extends 370 kilometres offshore and encompasses remote island territories and our claimed Antarctic coastline. Most Australians live within 100 kilometres of the coast. Our coastal waters support a

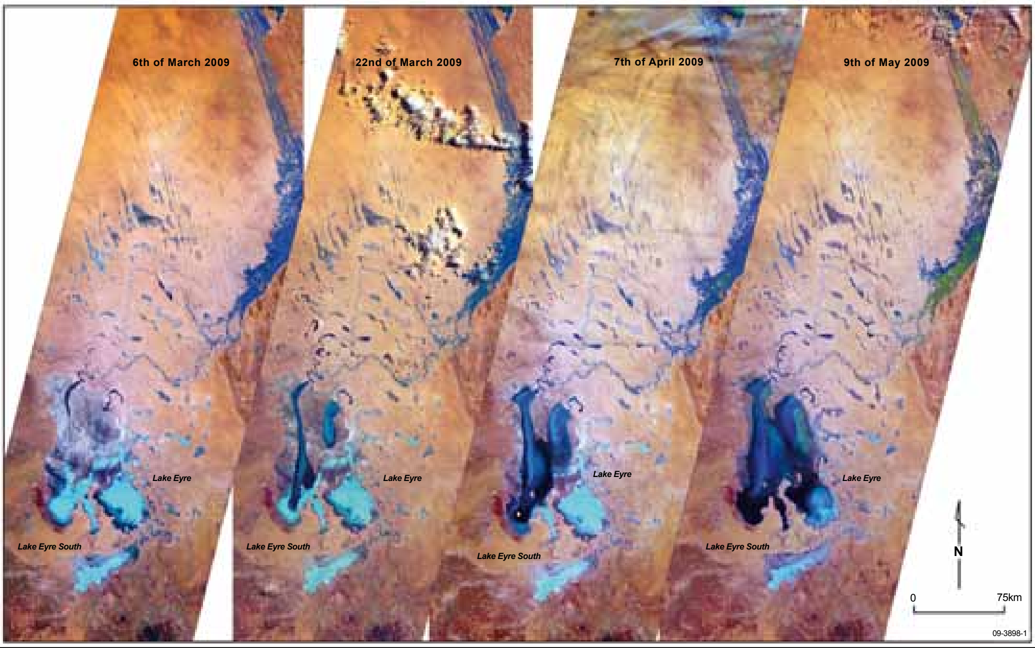

Figure 1.1: The 2009 filling of Lake Eyre, as captured by Landsat. These images show the movement of monsoonal flood waters from the Georgina and Diamantina Rivers in Queensland, southward through the Simpson Desert (Eyre Creek) into South Australia and the Goyder Lagoon. From there flow is south-westerly along Warburton Creek into Lake Eyre. In the desert, the dune structures break the flow into numerous channels spread over more than ten kilometres. Although the rains fell in January and February, Lake Eyre was still rising in early May. By that time (the last image) a flush of green vegetation can be seen in the wetlands and the Simpson Desert. Lake Eyre itself filled simultaneously from two separate points some 30km apart, the Warburton Groove and Kalaweerina Creek, with the waters joining in April. Each image is 550 km from north to south. (Images courtesy of Geoscience Australia)

vast range of commercial and recreational activities. These waters need to be monitored to ensure their environmental health and to ensure the safety of those who use them. EOS data are used for marine weather-forecasting and warning systems, and the monitoring of oil spills and other forms of pollution. The continuing increase in EOS information has provided the foundation for a new capability to routinely predict the daily, seasonal and longer term behaviour of the global oceans. EOS information is helping to improve the assessments of sea state and ocean currents in the Australian region, and providing comprehensive monitoring of sea ice, icebergs and glacial flows in Antarctica used to predict changes in sea level.

1.2.8 National security

Australia's national security activities rely heavily on EOS information to enhance situational awareness and surveillance in the combat operations of the Australian Defence Force, and to assist the activities of the Border Protection Command to safeguard Australia's national interests against security threats such as those associated with illegal exploitation of natural resources, illegal activity in protected areas, marine pollution, compromises to biosecurity, and unauthorised maritime arrivals. The government has made a major strategic investment in upgrading the space-based capabilities of the Department of Defence and recently announced that Australia will acquire a satellite with a remote-sensing capability. This upgrade will improve Australia's intelligence collection capabilities and help meet future needs for very high-quality spatial information for national security purposes.

1.3 The importance of Earth observations for Australia

EOS are the single most important and richest source of environmental information for Australia. Satellite instruments can capture multispectral images with a spatial resolution less than 50 metres over the entire area of the globe shown in Figure 1.2, and can measure the scientific properties of the atmosphere, land, and oceans at one to six hourly intervals with a spatial resolution of 1–50 kilometres. This coverage, density and volume of information cannot be matched by any other observational system.

Figure 1.2: This satellite view of the globe is dominated by the Australian land mass and a vast expanse of oceans. Australia needs to monitor all this area (and more) in order to understand and predict weather and climate, and we need to map, monitor and manage the 25 million square kilometres of our continental land mass and surrounding marine Exclusive Economic Zone, and the 42 per cent of Antarctica claimed by Australia. Earth observations from space are the single most important and richest source of information for doing this. (© NASA image courtesy of nasaimages.org)

EOS form the basis of all our maps and the GPS devices now in everyday use. EOS enable early warning of tropical cyclones before they get within striking distance of the coast and help us protect critical offshore oil and gas facilities. EOS information helps every aircraft in Australian airspace to fly more safely and economically. EOS help in mineral exploration, the development and economic use of solar energy, and the impacts of earthquakes, bushfires, floods and other natural disasters. EOS support the activities of the Australian Defence Force and our border protection programs. EOS data input has doubled the useful predictive range of Australia's national weather prediction models.[2]

Australia cannot do without EOS data if we want to sustain and improve our current economic status and standard of living. EOS provide 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. Without EOS, Australia could not comprehensively monitor the national, regional and local impacts of climate change at a level commensurate with that of the world's other major developed countries. EOS supports our National Carbon Accounting System (NCAS) and our fundamental research on how the oceans impact on climate change and changes in sea level along our coastlines.

The southern part of the globe visible in Figure 1.2 comprises more than one eighth of the total area of the planet. Australia is the largest country geographically, the richest economically, the least densely populated, and the heaviest user of EOS data in this area. As the world's 14th ranked country in terms of GDP, the international community looks to Australia to provide environmental stewardship for this region as part of its contribution to the global action being taken to monitor and adapt to climate change, in addition to ensuring that the wide range of social and economic benefits from the use of EOS are realised for Australia and adjacent South Pacific countries.

1.4 The international framework

Initiatives from the UN Framework Convention on Climate Change (UNFCCC), the 2002 World Summit on Sustainable Development, the Group of Eight (G8) leading industrialised countries, and various other international ministerial forums, resulted in the establishment in 2003 of the (initially ad hoc) intergovernmental Group on Earth Observations (GEO) to coordinate the planning and implementation of the Global Earth Observation System of Systems (GEOSS).[3] Australia is a member of GEO, which now comprises 79 UN member states, the European Commission, and 56 participating organisations, including several UN bodies with membership of more than 180 countries. The main space-specific observing system coordinating bodies such as the Committee on Earth Observation Satellites (CEOS), the Coordination Group for Meteorological Satellites (CGMS) and the WMO Space Programme are all GEO participating organisations.

GEO is now in the process of implementing its 10-year implementation plan for the Global Earth Observation System of Systems (GEOSS) whose progress is subject to ministerial review at key stages prior to its completion in 2015.[4] GEOSS is emerging as the overarching global framework for all purposes for nine major societal benefit areas (SBAs).[5] The G8 meeting in L'Aquila in April 2009 agreed to support the ongoing work on the development of GEOSS to address the increased threats of natural disasters and extreme weather phenomena caused by climate change.[6]

GEOSS integrates a large number of globally cooperative observing systems and coordination mechanisms in which Australian scientists from many disciplines and institutions are currently involved, and have been involved for a long time. Such systems include the World Weather Watch Global Observing System (GOS), the Global Ocean Observing System (GOOS), the Global Terrestrial Observing System (GTOS), the Global Climate Observing System (GCOS), and the Global Geodetic Observing System (GGOS). These systems have both surface-based and space-based observational components.

The importance of GEO and GEOSS for Australian activities in Earth observations is that they raise the level of international accountability and scrutiny of Australia's national use of EOS and our contribution to strategic global action involving EOS, from a level involving mainly scientists and their institutions to a level involving global political and economic leaders and the world's media organisations. As an active member of the Group of Twenty (G20) leading industrialised countries, Australia will need to be seen to be pulling its weight in using EOS to help address global problems and to provide leadership in areas in which we have special scientific, technological or community service expertise.

1.5 The need for a national strategy

The current absence of a national strategy for EOS means that there is no mechanism for the ongoing assessment, review and prioritisation of Australia's strategic needs for EOS data. There is currently no national focal point for international liaison on Australian access to, or participation in, the EOS missions of countries upon whose data Australia depends.

Australian space engagement has, historically, been viewed primarily as an industry development issue. The significant public interest and public good aspects of EOS acquisition and application have been considered to be the responsibility of individual government agencies and departments such as the Bureau of Meteorology, Geoscience Australia, CSIRO, the Department of Defence, and the Department of Climate Change. While these bodies coordinate their activities on an ad hoc basis, there is no formal mechanism to facilitate their collaboration on common standards, infrastructure, archives, data policies, distribution systems and services.

The government role in space activities has been addressed from time to time by individual initiatives in the industry, science and innovation sectors including the National Collaborative Research Infrastructure Strategy (NCRIS), and the EOS research and development activities and related industry associations of CSIRO, Cooperative Research Centres (CRCs) and universities. The government has been advised on a wide range of space and Earth observation matters, on an ad hoc basis, by many different stakeholder bodies.

Under this decentralised approach, each public and private sector organisation has adopted its own individual approach to EOS data acquisition and utilisation, but there has been no overall coordination and no national strategic plan. An agreed strategic framework is urgently needed, within which all key EOS organisations and stakeholders, from both the Earth observation and space communities, can work together in the overall national interest.

1.6 Preparation of this national strategic plan

In light of the Commonwealth government's 2009–10 Budget initiatives on space science and a series of other important recent developments, including the report of the 2005 Space Policy Advisory Group (SPAG),[7] the preparation by the AAS National Committee for Space Science (NCSS) of the 2008 draft First Decadal Plan for Australian Space Science,[8] and the 2008 Senate Economics Committee Report *Lost in Space?*,[9] and in response to the need for coordinated Australian participation in the work of the intergovernmental Group on Earth Observations (GEO) in planning the Global Earth Observation System of Systems (GEOSS), the Australian Academy of Science (AAS) and the Australian Academy of Technological Sciences and Engineering (ATSE) agreed to sponsor the preparation of this *Australian Strategic Plan for Earth Observations from Space*.

The plan has been prepared by a working group of Academy Fellows, representatives of the AAS National Committees for Earth Science, Earth System Science, and Space Science, and a number of Earth observation and space science experts from a range of relevant public and private sector organisations, research establishments and universities. The terms of reference (ToR) of the working group are at Appendix 1 and its membership at Appendix 2.

The preparation of the plan was supported by a number of Commonwealth government agencies with an interest in achieving a more strategic approach to Earth observations in Australia. They provided advice, but not direction, on the preparation of the plan through their representation on an informal steering committee. The working arrangements, including the composition of the steering committee, are summarised in Appendix 3. A list of those in the broader space science and Earth observation communities who assisted with advice, comment and critical review is given in Appendix 4. A draft of the plan was reviewed at a stakeholder workshop in Canberra on 3 July 2009 and was made available on the AAS and ATSE websites for stakeholder comment during the period 18 June to 20 July 2009.

The plan is set out in six chapters and six appendices, as follows:

- **Chapter 1** (this chapter) provides a brief introduction and gives the essential background;
- **Chapter 2** presents a strategic analysis of Australia's current EOS activities (ToR (a));
- **Chapter 3** assesses Australia's future needs, capabilities and opportunities (ToR (b));
- **Chapter 4** analyses the major strategic issues and sets out the essential elements of a strategic plan for meeting the identified needs (ToR (c));
- **Chapter 5** deals with institutional and coordination arrangements for implementation of the Plan and suggests an implementation timetable (ToR (d));
- **Chapter 6** provides the working group's consolidated recommendations (ToR (e));
- **Appendices 1–5** summarise the administrative and working arrangements;
- **Appendix 6** tabulates a sample of major state programs reliant on EOS data sets.

Scientific, technical and institutional abbreviations are used extensively throughout this report. They are, in general, explained on their first appearance in a chapter and are consolidated, in alphabetical order, at the end of the report. Reference is also included to a large number of satellite missions. For the most part they are not explained in detail, but full information is available in the various cited references.

This report is not a comprehensive account of all the EOS activities in Australia. Rather, it is designed to provide an overall synthesis and the broad strategic perspective needed to help Australia begin the transition to full participation in the international EOS effort. It elaborates the essential elements of a national strategy that will set Australia on a sound course for provision and application of EOS data in support of national needs and priorities over the next 10 to 15 years. It is focused on overall policy and strategic issues and addresses both operational and research aspects. It does not contain budgetary proposals but it takes into account the Commonwealth government's space science policy initiatives announced in the 2009–10 Budget.

The plan set down in this report is intended to provide the relevant Australian Earth observation agencies and communities with an overall strategic framework to help determine their individual and joint priorities for EOS research, applications development, and service provision over the next decade and beyond. It complements the AAS draft First Decadal Plan for Australian Space Science, by elaborating its EOS component in the context of Australian needs for, and applications of, Earth observation data more generally. It recognises, however, that EOS activity represents only a part, albeit a very important part, of the comprehensive Australian space science program envisaged in the draft Decadal Plan.

Notes

1 In Box 4, reference to the Madigan Committee report can be found in Australian Academy of Technological Sciences (1985); reference to the GCOS and GOOS working group can be found in Bureau of Meteorology (1993); reference to CEOS can be found in Ward (2008).

2 Zapotocny et al (2007).

3 Group on Earth Observations (2005, 2007).

4 Zillman (2005).

5 Comprehensive information can be found at the GEO website: www.earthobservations.org.

6 Group of Eight (2009).

7 Chapman (2005).

8 Cairns et al (2008).

9 Senate Standing Committee on Economics (2008).

CHAPTER 2: **CURRENT ACTIVITIES**

This chapter provides a strategic assessment of Australia's current activities in EOS.[1] It summarises the EOS activities of Commonwealth and state agencies, universities, CRCs and the private sector and describes the extent to which the observations help to address major national challenges. It outlines the national infrastructure, EOS education, training and research activities and Australia's national coordination and international engagement. It does not discuss current institutional arrangements in detail.

2.1 Introduction

One of the first major uses of EOS in Australia occurred when the first weather satellite (the USA's TIROS 1, launched in 1960) photographed a tropical cyclone in the Coral Sea. The meteorologists of the day knew from surface and upper air balloon observations along the Queensland coast and a few isolated ship reports that 'there was something out there', but the satellite picture showed what we now know to be the classic structure of a severe cyclone with a well-formed eye. The dawn of the space age had delivered Australia a major new observational tool; one which, in retrospect, could truly be described as a transforming technology for almost all fields of application of Earth science for societal benefit.

There were problems with TIROS 1 though. Its cameras often took pictures of the Earth on very oblique angles, which gave distorted views of cloud systems and the Earth's geometry. We received our pictures by mail from the USA, which was welcomed for research purposes but too late for community warning purposes. The satellite's pictures of the Coral Sea were captured irregularly, from different angles and often with gaps of a few days between pictures of specific weather features. The pictures were fuzzy and hard to interpret. Scientists wanted quantitative measurements of specific physical and geophysical parameters, not only for meteorology but for many other applications such as mapping, land use and navigation. The instruments on TIROS 1 could not do that, but the potential community benefits of satellites had been clearly demonstrated and the scientific and technological challenges were exciting.

From these beginnings almost 50 years ago, rapid advances in science and technology have solved many of the problems of the TIROS 1 era and its counterpart pioneering satellites of the former Soviet Union. Australian ground stations for the reception of US weather satellites began to be established in the 1960s which revolutionised Australia's national weather services. CSIRO became involved in satellites as a major new tool for research in a wide range of disciplines. In the 1970s, the Department of National Mapping (now part of Geoscience Australia) established a ground station at Alice Springs for the Australian Centre for Remote Sensing (ACRES) to receive imagery from the USA's new Earth Resources Satellite. This initiated the modern use of this technology by many Commonwealth and state government agencies for improved mapping, natural resources management, the monitoring and regulation of land use, and the monitoring of the impacts of climate change on the land and ecosystem environment.

Satellites are now used not only for observing the Earth and its environment, but also for vastly improved communications, navigation and timing systems, and for national security purposes. There are many satellites orbiting the Earth now, so much so that space debris has become a significant threat to major new satellite systems upon which we now critically rely, and military strategists warn about the threats of space warfare.[2]

As time has gone by, people have realised that satellites can be used for many purposes other than those for which they were originally designed. For example, Japan's MTSAT series which provides the familiar cloud pictures we see on Australian television news programs every day, is a dual function meteorological and transport satellite; the Global Navigation Satellite System (GNSS) is used to derive vertical profiles of atmospheric structure and to determine the state of the Earth's ionosphere; many environmental satellites are also used to relay information from automated data collection platforms to track the movement of wildlife or to collect ground-based information in remote areas of Australia, the oceans and Antarctica.

The November 2009 Senate Economics Committee report reviewed Australia's reliance on communications satellites, noting that Australia has five satellites operated by Optus. It also considered national security aspects, noting that, to date, Australia has not operated any satellites for these purposes. It examined the explosive use of the GNSS, whose applications have the potential to generate Australian benefits of more than $130 billion cumulatively over the next 20 years, contributing to an increase of between 1 and 2 per cent in GDP by 2030.[3] It examined the use of EOS by the spatial information industry whose overall value of data use (all data, not just EOS) was found, in a separate study, to contribute an accumulated gain of up to $12 billion, equivalent to more than 1 per cent of national GDP.[4] The Senate Economics Committee report and the NCSS draft First Decadal Plan for Australian Space Science both examined space science and its associated EOS activities and applications, whose benefits are unquantified, but are accounted for partially in the GNSS and spatial information estimates and undoubtedly contribute many billions of dollars to increasing our national GDP.

The AAS-ATSE working group acknowledges the importance and wide community use and benefits of all these applications but, in accordance with its terms of reference, it has focused its attention almost exclusively on the use of environmental satellites for observing and understanding the behaviour of the whole Earth system and thus has made only limited reference to the use of other major satellite systems whose missions and applications are primarily for other purposes.

The summary of activities presented in this chapter highlights the fact that, although Australia is a major user of EOS and has developed a high level of expertise in the use of EOS science and technology in some fields, in general, we are under-utilising the potential capacity of the EOS information currently available; and that good awareness in the policy and senior management levels of governments of the value of EOS data is only just starting to emerge.

2.2 The scope of current activities

EOS data are currently used in Australia for a diverse range of purposes and by a wide range of Commonwealth and state government agencies, as well as the university research community and the private sector. Australia also makes extensive use of airborne remote sensing data, gathered mostly by local operating companies using imported and in very few cases locally-built EOS technologies. The Department of Defence has begun substantially upgrading its use of space-based capabilities for national security programs, but the use of such technologies for dual (civilian and defence) purposes has been little explored to date. Australia's use of EOS also embraces the extensive activities of the Australian Antarctic Program.

The level and scope of current EOS activity in the public sector dwarfs that of the private sector, but the private sector plays an important role in the provision of specialised satellite data and consultancy services across government in areas such as satellite image processing and computer-based mapping. A small number of private spatial information companies also have exclusive reception and/or distribution rights to commercial satellites.

There are pockets of activity and some areas of excellence throughout the nation in all aspects of the use of EOS, except for the provision and operation of spacecraft. Australia has established world leadership in the use of EOS for carbon accounting and there is some excellent work being done in universities and other research institutions on EOS data calibration, validation and assimilation. Australia's research capabilities in EOS are of high quality and well respected internationally, but they are fragmented. There is opportunistic involvement of Australians scientists in the international mission science teams associated with next generation EOS missions.

Australia is still fully dependent on foreign countries to provide us with EOS information for our national needs and our huge area of national and regional environmental stewardship. We are critically dependent on the continuity of EOS information flow for the compilation of long period data sets currently used for mapping and monitoring changes in land use, natural resources, coastal and ocean ecosystems, and the impacts of weather and climate change. Appendix 6 provides a sample of the extent to which major programs in state agencies depend on continuity of EOS information. In addition, the CRC for Tropical Savannas Management cooperates with Bushfires NT and the Cape York Peninsula Development Association in the use of EOS for twice-weekly fire mapping over the northern one third of the continent.

Overall, Australia currently has a critical day-to-day dependency on the flow of EOS information from the satellite programs of USA, the European Union, Japan, China and Canada. We have an important research interest in the missions of Russia and India, but no major day-to-day dependency, and we have an emerging research interest and potential operational interest in the planned EOS missions of South Korea, Indonesia, Thailand, and the Brazil-China partnership. There is an EOS activity link with all the above nations (and with several not listed above) in Australia's international programs for cooperation in science and technology.

To obtain the most timely overall national EOS information, a series of ground stations for direct EOS data reception is operated by Commonwealth government agencies and two consortia comprising Commonwealth and state agencies and universities. The extensive EOS data needs of Western Australia are catered for through the Perth-based WASTAC consortium, while many of the needs for Australia's Antarctic Program and for research and applications over the Southern Ocean are met through the Hobart-based TERSS consortium and the Casey satellite ground station operated by BoM. EOS information, for supplementary purposes or for areas beyond the coverage of Australian ground stations, is collected via the internet or special purpose high-speed international communications links.

The benefits of EOS are delivered to the Australian community primarily through Commonwealth and state departments and agencies, supplemented by a small private sector. There are too many EOS-critical programs to list separately, but some significant examples of Commonwealth and state activity include:

- the national defence and border security programs, and the national and state emergency services disaster mitigation programs (eg, GA's Sentinel fire monitoring system);
- the national weather forecasting and warning services for the general public, aviation, defence, marine, and agricultural sectors;
- the National Geospatial Reference System, the National Mapping Program, and the Australian Collaborative Land Use Mapping Program;
- the National State of the Environment Monitoring System, the National Carbon Accounting System, and national programs for the monitoring and management of the Australian and Antarctic EEZs and World Heritage areas;
- state-based programs such as the Queensland Land Use and Regional Ecosystem mapping programs, the NSW Groundwater Dependent Ecosystems quality and mapping program, the Victorian Regional Water Resources Management Program, the South Australian state-wide Native Vegetation Detection program, the Northern Territory Fire Mapping programs in National Parks and Arnhem Land, and the Western Australian Carbon Watch, Pastures from Space, Flood Map, and Land Clearing and Compliance programs; and
- the Australian Antarctic Program and the operation of the Australian National Antarctic Research Expeditions (ANARE).

2.3 EOS support for key national challenge areas

This section provides a brief strategic assessment of how EOS are being used to help address each of the eight key national challenge areas identified in Chapter 1. EOS information has multipurpose applications and can be used to varying degrees in several, or all, of these eight areas. The use of meteorological satellite and GNSS data are prime examples.

EOS activity has not previously been classified this way, and it will be important to conduct a more detailed audit of EOS applications in consultation with government, business and the broader user communities in each of these sectors. However, it is the working group's strong impression that the use of EOS information in each of these areas of major national challenge is well below potential capacity.

2.3.1 Climate change

Responding to Australia's key challenges on climate change, its variability and impact, requires EOS data to continuously observe the state of the atmosphere, the land surface, ecosystems, and the oceans in our region, as well as the Antarctic cryosphere. There are more than 90 organisations in Australia significantly involved in climate science related activities,[5] many of them using EOS as one of their data sources. This includes agencies and departments in all three tiers of government, universities and CRCs in all states, emergency management organisations, water and energy authorities and private companies.

The largest Commonwealth users of EOS data for climate change purposes are BoM, GA, CSIRO, the Australian Antarctic Division (AAD), the Bureau of Rural Sciences (BRS), the Department of Climate Change (DCC), and the Department of the Environment, Water, Heritage and the Arts (DEWHA). The states are also large users of EOS data, especially of Landsat data, for monitoring the impacts of climate change through their various departments of climate change, the environment, land, water and conservation.

There is a large number of EOS missions now monitoring weather and climate change in our region, but we are only accessing a few of them for operational purposes and not fully exploiting any of them. Thus the major Australian EOS operational agencies have prioritised their activities to focus on the collection, maintenance and use of selected data sets from missions such as the Japanese GMS/MTSAT and Chinese FY-2 geostationary satellite series, the European MetOp and CryoSat-2, and the USA's NOAA, QuikSCAT, Aqua, Terra, Landsat, GPS, and GRACE low Earth orbiting satellite series.

The science community that is involved in strategic research into many aspects of climate change – especially in identification of anthropogenic versus natural climate shifts – also accesses multiple satellite data sets from the satellite missions noted above. For climate research and development purposes the science community also accesses data from many additional EOS missions, including ALOS, Aqua, CALIPSO, CryoSAT, Envisat, GOCE, GOSAT, ICESat, PARASOL, Terra, and also the Topex/Poseidon and Jason series of satellite altimeters. There are many more instruments currently available, including polarimetric and interferometric radars, which have yet to be used operationally in Australia, thus limiting our ability to more effectively analyse and predict the state of the atmosphere and the climate system. These instruments include the Atmospheric Infrared Sounder (AIRS), the Infrared Atmospheric Sounding Interferometer (IASI), the Special Sensor Microwave Imager/Sounder (SSMIS) and radio-occultation systems using CHAMP, COSMIC, MetOp, GRACE, Terra, and SAC-C to track GPS signals.

Scientists from universities, the Centre for Australian Weather and Climate Research (CAWCR),[6] and other institutions are advancing EOS data assimilation techniques for climate, weather and ocean models, but have insufficient capacity to consider more than small subsets of the available missions. They are also developing the new Australian Community Climate and Earth System Simulator (ACCESS) model, which will link various dynamic models of the chemical and physical structure of the atmosphere and the ocean, with models of the biosphere, cryosphere and land exchange. Information on changes in the Antarctic ice sheet is an important inclusion. One of the goals of ACCESS is to produce ocean forecasts, seasonal weather forecasts for up to several months, and climate change scenarios for up to 50 years or more.

Satellite altimeter data provide the optimum way of estimating global and regional rates of sea-level rise. Australian scientists are actively engaged in sea-level rise research, elucidating the mechanisms for sea-level rise and its regional and temporal variability. CSIRO and Australian university researchers operate the only southern hemisphere calibration site for the international ocean altimetry missions.

Satellite sea-surface height data are also used to improve our understanding of the ocean processes in both the Pacific and Indian Oceans that control Australia's drought/flood cycle, with the aim of providing more robust prediction of inter-annual climate variability and also the timing and regional impact of climate change but there is as yet little operational use of these data.

The Antarctic Climate and Ecosystems CRC (ACE CRC), the AAD and universities currently undertake research on the Antarctic ice sheet, using the unique capabilities of satellite remote sensing to detect, monitor and better understand changes in such things as surface elevation and mass balance occurring in the highly dynamic periphery of the ice sheet. Such information is ultimately required in order to constrain and validate ice sheet models, with emphasis on the need to decrease uncertainties in current estimates and predictions of the ice sheet contribution to global sea-level rise. This work is supported by ICESAT and high-resolution visible-thermal IR imagery, including Landsat, to evaluate drift evolution and the iceberg calving process; by SAR to measure ice motion and dynamics and the accretion of marine ice onto the ice shelf base; and by GRACE and GPS to measure mass balance changes and present-day isostatic responses of the Antarctic continent to melting over the past 20,000 years.

The global scientific community is operating several major international programs which involve using EOS to observe and help understand the role of the oceans in climate change. Australian scientists have played a key role in the design and implementation of the WMO-IOC-ICSU World Climate Research Programme (WCRP) and the joint WMO-IOC-UNEP-ICSU Global Climate Observing System (GCOS).

2.3.2 Water availability

National responsibility for operational hydrological services resides now with BoM's Water Division, which operates major national services programs for water data management, water resources accounting and reporting, and water resources forecasting. In parallel with this, there is also a great amount of activity amongst various state, cross-state, and state-private partnerships involved in drought monitoring, water storage monitoring and management. All these organisations use EOS data to map the extent of bodies, levels and quality of water, including wetlands, water courses and water storage, and to monitor their change over time.

The main EOS-related hydrology research activities are currently being undertaken at the CSIRO Land and Water Division, the CAWCR, a joint CSIRO-BoM program called WIRADA, and in the universities, particularly at the University of Melbourne and the University of NSW. In the past 5 years considerable cooperative research has been focused on the data validation and assimilation of EOS satellite data into hydrological models for stream-flow forecasting. The researchers expect that by assimilating multiple types of high-frequency spatial data (including EOS data such as the NASA/JAXA Tropical Rainfall Research Mission (TRMM)), catchment-scale hydrologic models will improve, and in turn lead to more efficient water use, a reduction in water losses and shortfalls on irrigation orders, and better monitoring and prediction of flood events.[7]

Currently, data from the following EOS missions are used to variously address Australia's national challenges in water availability: China's FY-2; NASA and DLR's GRACE; Japan's ALOS, MTSAT-1 and -2; the USA's Aqua, Terra, and LANDSAT; and CNES's STELLA, STARLETTE, and SPOT. Australian scientists are also involved in important data calibration and validation activities associated with NASA's Soil Moisture Active Passive (SMAP) mission; and the ESA/CDTI/CNES Soil Moisture and Ocean Salinity (SMOS) mission.[8] In general, these satellite sensors are now beginning to provide better information on rainfall patterns, surface soil moisture, surface skin temperature, snow cover, snow water equivalent, evapotranspiration, and total water storage changes, all of which are needed to extend the data coverage of ground-based observational systems for our national water resources management. Additional satellite-derived mapped products, such as vegetation type, normalised difference vegetation index (NDVI), solar radiation, surface albedo, and fire scarring are of considerable value as input to hydrologic models.

In contrast to the mature state of the operational transition of EO technologies into weather and climate models, the operational transition of EOS data into catchment hydrologic and stream-flow models is still at an early stage of development. The assimilation of changes in total water storage from the GRACE space gravity mission (see Figure 2.1) into hydrological modelling is now being attempted, but with new rainfall monitoring missions planned by Japan and the USA, Australia has not yet engaged in a formal way in gaining direct and rapid operational access to such data. Additional research is needed on satellite data assimilation, and improvements must be made on the timeliness of some of the satellite data input.

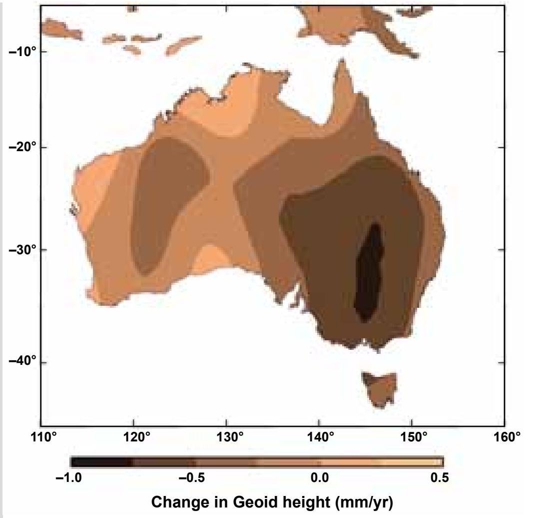

Figure 2.1: This image is based on data from the Gravity Recovery and Climate Experiment (GRACE) space gravity mission, and it shows the rate of change of gravity across Australia (expressed as a rate of change of geoid height required to generate the observed gravity signal) over the period 2002 to 2009. The loss of water as a result of the drought in the Murray-Darling Basin is clearly visible (Leblanc et al., 2009) along with a steady increase in northern Australia. The GRACE mission is a pair of satellites orbiting at approximately 450 kilometre altitude. Measurements of the change in distance between the satellites are used to derive changes in the gravity field from which crustal deformation, ocean signals, total water storage and mass balance of polar ice sheets can be deduced.

2.3.3 Natural disaster mitigation

To reduce the community impact of disasters, emergency services authorities at Commonwealth, state and local government level use EOS information in all four phases of disaster management: planning, preparedness, response and recovery. Timeliness is critical in the response and recovery stages because disaster events often disrupt communication and transportation services, making the relief efforts even harder. Information is needed at various scales over all of Australia and its surrounding oceans, not just in major population centres.

EOS imagery now has a very high public profile in natural disaster events associated with bushfires, tropical cyclones, severe thunderstorms (with tornadoes or damaging hail), floods, tsunamis, droughts, earthquakes and their aftermaths. Animated images from Japan's MTSAT satellite of tropical cyclones and flood rains are a regular feature of free-to-air and cable television news and weather programs and are heavily accessed by the public via BoM's website. While there continues to be great public and media interest in high-quality satellite images of the aftermath of such disasters as floods, bushfires and major oil spills, the use of the information in real-time, direct decision-making is, relative to other countries, still below optimal.. In part, this is due to problems associated with inter-agency coordination and the timely availability of information to managers and public dissemination mechanisms.

The UN International Charter on Space and Major Disasters aims to provide a unified system of space data acquisition, processing and delivery to those affected by natural or man-made disasters. Australia can only have access to the system when a certified national body makes a formal request to the UN or a space-agency member of the Charter. The Asia Pacific Regional Space Agencies Forum (APRSAF) have developed a similar system, called 'Sentinel Asia', for which GA, CSIRO and BoM are participating members and are able to directly trigger emergency data acquisitions. GA, in its capacity as the Advanced Land Observing Satellite (ALOS) data node, can also activate ALOS satellite data acquisitions in case of disasters. Meteorological EOS information and related products are well integrated into natural disaster reduction management systems and associated web-delivery systems.

Flood footprint information derived from satellite imagery is used within the National Exposure Information System (NEXIS) being developed at GA, and via Landgate's *FloodMap* project[9] which has developed a near real-time flood mapping visual tool which couples satellite imagery with various geospatial data sets and other available data to help reduce the vulnerability of communities at risk of flooding in remote parts of northern Australia. Recent flood events in various parts of Australia have led to the development, by GA and other agencies, of satellite-based operational flood information delivery systems for federal and state emergency services agencies. These systems commonly use data acquired by the AVNIR2 and PALSAR instruments on ALOS, by the Thematic Mapper (TM) onboard Landsat-5, and by the MODIS instrument on the Terra satellite.

Several EOS-based bushfire monitoring systems have also been developed. The Sentinel system currently operating from GA, was jointly developed by the CSIRO, GA and the Defence Imagery and Geospatial Organisation (DIGO), as a demonstrator research project in 2002, and now provides valuable bushfire monitoring information to the general public and a large number of fire authorities (see Figure 2.2). It provides input to the North Australia Fire Information (NAFI) system operated by the Tropical Savannas CRC, the Emergency Managers Spatial Information Network for Australia (EMSINA), the Australasian Fire and Emergency Service Authorities Council (AFAC), and the Indji online hazard monitoring system developed by the CRC for Spatial Information.

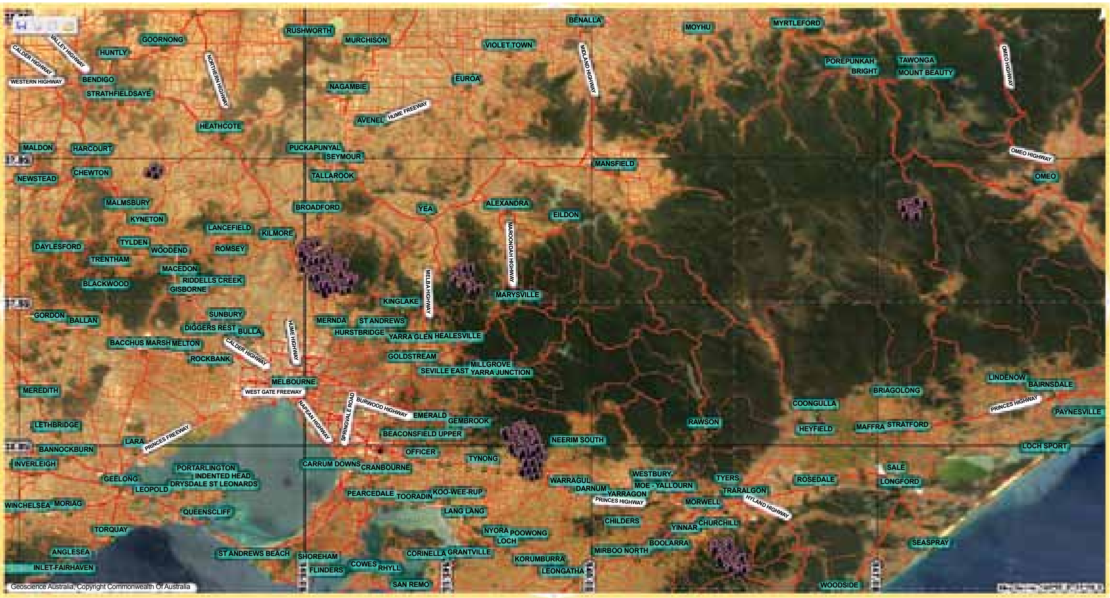

Figure 2.2: This image shows Geoscience Australia's Sentinel website as it appeared at 4.30 pm on 7 February 2009. On the image dark areas are forests (un-burnt) and light-brown areas are grasslands. NASA's Aqua satellite passed over Eastern Victoria at approximately 3.50 pm, sending data to Geoscience Australia's receiving station at Alice Springs. Automatic analysis of the data at Alice Springs detected 270 'hot spot' anomalies (purple symbols, each ~ 1km x 1km) corresponding to the widespread and intense forest fires in eastern Victoria. By 4.30 pm the hot-spots appeared on the Sentinel website to give a synoptic map of the fires. (Image courtesy of Geoscience Australia)

Landgate, the WA state government land authority, has also developed 'FireWatch', a similar operational system to Sentinel, based on real-time and archived AVHRR and MODIS satellite data collected by WASTAC. The Landgate system includes a fire scarring history service based on archived NOAA AVHRR information, a fire hotspot service similar to Sentinel but which also has an associated fire fax service in which fax or email alert messages on fire hot spots in specific locations are issued.

Accurate tsunami inundation modelling is crucially dependent on shallow coastal water bathymetry data sets. GA has implemented a satellite remote sensing methodology based on a suite of state-of-the-art software under development at CSIRO Land and Water. GA is using this capability to assist Australia's Pacific partners to improve their tsunami disaster mitigation programs.

2.3.4 Safe and secure transport

Space-based information is making a significant contribution to the safe and economic operation of Australia's road, rail, air and sea transport systems. For example, all these modes of transport utilise Global Navigation Satellite Systems (GNSS) in their daily operations and, on many occasions, these modes of transport operate in areas where EOS provides the only source of environmental information. EOS-based services are especially important for aviation and marine transport operations, which are critically dependent on real-time weather information and for which Australia has international service support obligations under the Chicago Convention on Civil Aviation and the International Convention for the Safety of Life at Sea.

Vertical profiles of atmospheric winds, temperature and moisture are derived from GNSS and other satellite data over all Australian domestic and international air space, and are used, together with the output from BoM's numerical weather forecasting systems, by airline companies to calculate flight fuel requirements and to identify in-flight hazards such as icing and turbulence. Satellites are especially useful in identifying Australia's high-level winter westerly jet stream, often extending from about Perth to Sydney and reaching speeds well in excess of 200 km/hr. The jet stream is either used or avoided by aircraft, depending on which direction they are flying, because of the huge impacts on flight time and fuel load during very long flights.

Satellites also identify a large number of potential aviation hazards in our region. For example, BoM and CSIRO scientists pioneered the development of a satellite-based Volcanic Ash Advisory Service now operating worldwide under the auspices of WMO and the International Civil Aviation Organization (ICAO). The Australian component is based in Darwin, which has real-time MTSAT geostationary satellite coverage over the major active volcano zone stretching across the Indonesian and New Guinea archipelagos, which intersect several major international air routes. Satellites also identify hazards such as clusters of severe thunderstorms which are often beyond the range of detection by aircraft radar.

EOS information also supports Australian marine transport operating in coastal waters or on the high seas, sometimes through the application of imagery showing features such as the extent of major weather systems, coastal fog or Antarctic sea ice, but mainly by adding value to ocean and weather analysis and prediction models whose capabilities are rapidly improving.

The Australian Antarctic Division (AAD) now routinely receives EOS information through the Antarctic node of PolarView, one of the services established under the European Community and ESA's Global Monitoring for Environment and Security (GMES) program. This generates products, mainly from ESA's Envisat mission, which show ice conditions around Antarctica, and are used in the planning and navigation of the voyages and activities of the Australian National Antarctic Research Expeditions (ANARE). Australia's Antarctic Climate and Ecosystems CRC (ACE CRC) is a member of PolarView.

EOS data help the safe and secure operation of road and rail transport, through their contribution to the derivation of weather-related safety warnings (see Figure 2.3) such as road weather alerts, and of climatologies used for planning the development of road and rail networks. EOS data are also used to help monitor and predict extreme surface temperatures which can buckle railway lines and melt road surfaces.

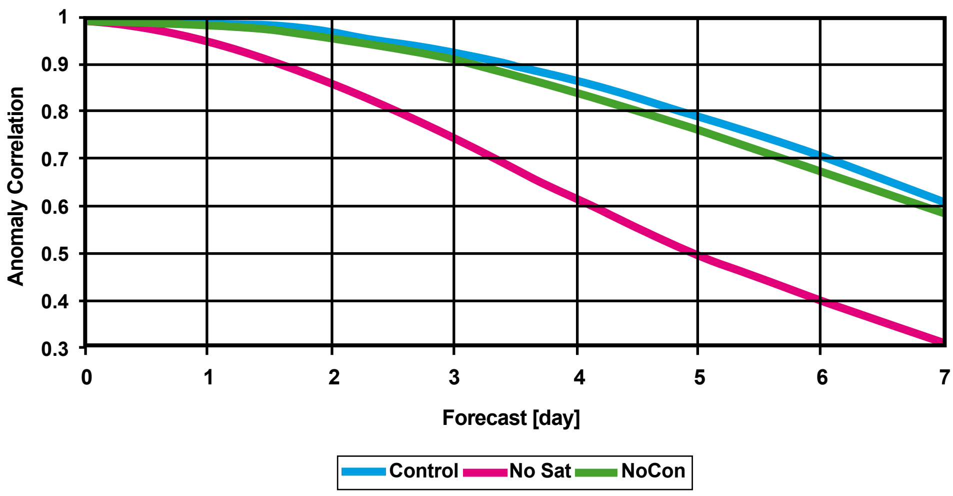

Figure 2.3: This figure highlights the importance of satellite-based observations for accurate weather prediction. Sensitive measures of the accuracy of numerical weather prediction (NWP) models are found by considering the difference between the model result and the climatological value of a variable, such as the geo-potential height at 500 hPa in the atmosphere (a few kilometres above the ground). The anomaly correlation is the correlation between this anomaly in a model prediction on a given day and the anomaly in the actual value, averaged over a specified area. The figure shows the anomaly correlation in the 500 hPa geo-potential height for an NWP model averaged over the region from 20 to 60°S in the southern hemisphere. Values are averaged over a month in the summer and are shown for forecast lead times extending from 0 to 7 days ahead. The Control case (blue) includes all the available conventional and satellite observations to specify the initial conditions for each prediction. The NoCon case (green) is found when the conventional observations are withheld from the initial conditions, while the NoSat case (magenta) is found when the satellite observations are withheld. It is clear that the forecast accuracy drops off most quickly in the NoSat case; that is, the satellite data are extremely important for weather prediction in the southern hemisphere and they essentially double the useful prediction range. (From Zapotocny et al., 2007)

Because of their immediacy, continuous availability, and broad area of coverage, EOS data are invaluable in aviation and marine search and rescue operations, and in some road and rail emergency situations in remote parts of Australia.

2.3.5 Energy and resources security

Australia's strong energy and resources sectors are also major users of EOS data. To ensure Australia's energy security, all these industries and associated government regulatory bodies need to have comprehensive environmental information, both to enhance industry development and to monitor the environmental impact of ongoing industry operations.

Increasing use is being made of EOS information for exploring the geological structure of the Australian region, which is relevant for identifying areas suitable for geothermal and marine petroleum sources of energy. The assessment of natural hydrocarbon seepage on the sea surface can be an important tool for the petroleum exploration industry. Under suitable viewing geometry and meteorological conditions, space-based Synthetic Aperture Radar (SAR) has been shown to detect the surface slicks formed from natural hydrocarbon seeps. Collaborating researchers are currently developing a semi-automated system for screening large SAR data sets for potential seepage slicks.

Conventional high spatial resolution (approximately 30 metre pixels) satellite systems, such as Landsat and ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), are routinely used in mineral exploration. Multispectral ASTER data have now been acquired from most of Australia. Efforts are now underway through national and international government agency coordination (CSIRO, GA, State Geological Surveys, ERSDAC-Japan, and AuScope) to transform the raw ASTER reflectance and emissivity data into higher level geoscience products of greater value and accessibility to the Australian geoscience community.

Hyperspectral data are now available for routine use across Australia using airborne systems such as that provided by Australia's HyMap airborne sensor. Hyperspectral systems (also called imaging spectrometers) provide much more specific geoscience and environmental information compared with multispectral sensors such as the ASTER sensor, including information on the abundances of specific minerals (like kaolinite and illite) as well as their chemistry. To date, satellite-borne hyperspectral sensing across geologically-tuned wavelengths has been restricted to a US sensor called Hyperion which has limited spatial and signal-to-noise. A suite of new hyperspectral satellite sensors is currently being developed by Japan, Germany, India, South Africa, China, US and Italy and will provide global-scale coverage/access for science applications of the Earth's land surface. Australia is establishing better inter-agency relationships with the related international satellite technology agencies to help establish priority access to upcoming hyperspectral data from these sensors from over Australia, as well as developing national and international product standards through related science communities and coordination mechanisms such as GEO.

Surface geoscience maps generated from these remote sensing systems can be used by explorers (minerals, hydrocarbons and geothermal) as well as other scientists (eg, soils) to characterise Earth system processes using spectral-mineralogy which is complementary to other commonly used gamma-radiometrics and magnetic airborne survey data. Mineralogy is sensitive to resource-forming processes such as those associated with hydrothermal fluids passing through rocks. These remote sensing surface mineral maps can also be integrated with subsurface drill core spectral-mineralogy now being assembled by the government geosurveys across Australia as part of the AuScope Virtual Core Library. Combined, these data can ultimately be used to produce a 3-dimensional mineral map of the Australia continent, which is the focus of the newly established Western Australian Centre of Excellence for 3D Mineral Mapping.

New geothermal, wind, solar, and ocean energy industries are now emerging. The location and economic operation of wind and solar energy sources are greatly influenced by specific meteorological conditions. Some of this information is being provided directly from EOS, some is provided through the output of meteorological models to which EOS contributes to improved performance, and some is provided from surface observations.

Accurate forecasts of the solar resource on time-scales from minutes to seasons or longer, are required to enhance the economic operation of large-scale solar power plants and the impact of their integration into the broader power grid. Concentrating Solar Power (CSP) generation and Photo Voltaic (PV) generation also have slightly different data support requirements. Historical and current processing of hourly GMS and MTSAT geostationary satellite data has enabled limited spatially explicit mapping of the solar energy resource across Australia. To date this has been done for a very small number of parameters, either on a time-specific daily basis, or at hourly time-scales on a climatological basis.

The physical security of our offshore oil and gas facilities on the Northwest Shelf and the Arafura Sea are prone to threat from time to time by tropical cyclones, storm surges and tsunamis and, in Bass Strait, by major mid-latitude storms, huge ocean swells and tsunamis. EOS data are being used to help mitigate these impacts, as described above. The Ionospheric Prediction Service (IPS) warns about space weather events which potentially can have a catastrophic impact on Australian power grids.

The evolution of planet Earth cannot be unravelled without the ability to link many different types of satellite observations to other geological and geophysical data via plate kinematic models. The University of Sydney's new Geological Virtual Observatory, supported by the AuScope NCRIS project, develops ocean basin reconstructions which depend critically on satellite altimetry data. This work has enabled research into the origin of seafloor roughness, continental paleo-stress, microcontinent and continental margin evolution, long-term sea level variations and coastline change, and it is also used to couple surface kinematics to mantle convection models.

2.3.6 Agriculture, forestry and ecosystems

Some of the biggest dependencies for EOS data by volume are with Commonwealth and state government programs, and associated private sector services. They routinely undertake agricultural, forestry, natural resources and environmental monitoring, in support of food and fibre production, as well as federal and state regulatory programs and international treaties.

Operational EOS mapping programs here include routine yield monitoring, land-cover and land-use mapping, drought monitoring, forest mapping, monitoring of riparian vegetation, coastal ecosystems, coral reefs and state of the environment reports. Most of the satellite information is supplied by mid-resolution imaging satellites, and down-linked and distributed via Geoscience Australia and the private sector. Applications-development programs at GA, CSIRO, various state agencies and private companies then provide underpinning research into adequate use and interpretation of these data. A recent review[10] of the use of Earth observation data at moderate spatial multispectral (MS-MSR) scales (10 to 30 metre pixels), found that the major land-cover, land-use, vegetation structure and condition mapping activities listed above are routine activities which rely heavily on the continuous and reliable supply of such data. In the national context, this includes the vegetation structure and biomass maps used to drive the national carbon accounting system, various map products used to support the national land-use mapping program and the state of the environment reporting process, and the national topographic mapping process.

One of the largest applications of 20 to 30 metre resolution satellite remote sensing data in Australia is in generation of annual land-cover change and forest-cover maps, which serve as inputs, together with ground information and ecosystem models, to the generation of Australia's national carbon accounts, under the National Carbon Accounting System (NCAS) operated by the Department of Climate Change (see Figure 2.4). While traditionally NCAS has used satellite-data analysis methods developed by CSIRO for Landsat satellite data, the availability of new optical satellites data (eg, from India, China, ESA), combined now with operational Synthetic Aperture Radar systems (eg, from Japanese ALOS satellites), is enhancing NCAS's ability to use inter-operable optical/SAR satellite data as input.

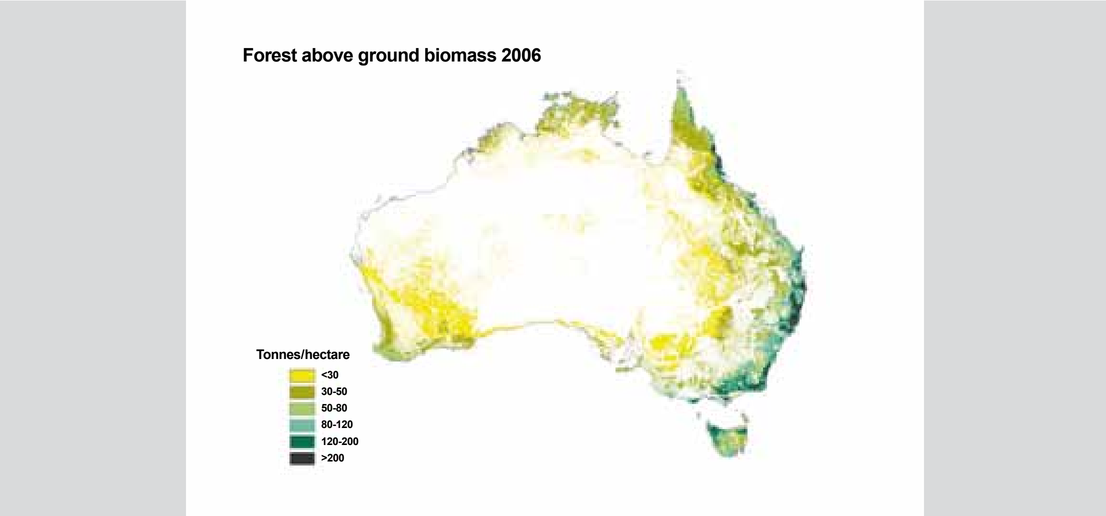

Figure 2.4: This image shows the forest above ground biomass across Australia. It is an integration of ecosystem modelling utilising climate and site information with forest extent analyses derived from Landsat satellite data. Such integrations allow for optimal use of several forms of data to provide robust estimation of emissions and removals of greenhouse gas from the land sector. EOS data play an important role in implementing the global network of national forest monitoring and carbon accounting systems. (Image courtesy of The Department of Climate Change, Australian Government 2009)

The Australian government has also recently launched the International Forest Carbon Initiative (IFCI) and established the Global Carbon Monitoring System (GCMS), which is a key requirement to achieving monitoring, reporting and verification objectives of the IFCI. The vision for a GCMS is to form part of a global network of consistent and compatible national forest monitoring systems that meet national reporting requirements, and can be linked to support carbon trading initiatives at a sub-national scale. This information is also used in Australia's climate negotiations and UN reporting, and is likely to underpin future carbon emissions trading activities in Australia.

Since 1994, the Bureau or Rural Sciences (BRS), part of the Department of Agriculture, Fisheries and Forestry (DAFF) has also been conducting drought and exceptional circumstances evaluations for the National Rural Advisory Council. These evaluations assist in the decision-making process for the provision of multi-million dollar Australian government drought assistance to farmers. DAFF-BRS also operates together with CSIRO, the Australian Water Availability Project (AWAP) and the National Agricultural Monitoring System (NAMS) which deliver, via the web, information on climate, available water resources, agronomic and production information for Australian agriculture; much of which is underpinned by EOS data. Other high-volume users include land-use mapping programs under the Australian Collaborative Land Use Mapping Programme (ACLUMP), a consortium of Australian and state government partners funded under the National Land and Water Resources Audit. DAFF and state agencies are also large users of satellite imagery for regular locust plague monitoring across most of Australia. EOS data are used from time to time in Australia to help mitigate the adverse impacts of major animal health emergencies such as can occur with the outbreak of foot and mouth disease. EOS data are assimilated into specialised meso-scale weather models which help predict the direction and extent of the spores which spread foot and mouth disease.

The Environmental Resources Information Network (ERIN), a unit within DEWHA, is also a heavy Commonwealth government user of satellite information. ERIN produces and maintains spatial databases on threatened ecological communities, native vegetation, marine protected areas and wetlands across Australia, all of which have some input derived from satellite remote sensing.

Several other natural resource management agencies, primary industries and environmental protection agencies from each state in Australia also use EOS data in productivity and ecological models to derive maps of biophysical parameters or processes, which are used to produce state-wide resource inventories of items such as vegetation communities, animal population estimates, forage availability and pasture condition. Most notably, the 30-metre resolution scale is the one at which activities associated with farm and land-management decisions are made which are tied to operational mapping systems, such as Australia's National Carbon Accounting System (NCAS), Western Australia's Pasture Monitoring, and Queensland's Statewide Landcover and Tree Survey (SLATS). A serious problem here has been the recent faults in the Landsat-7 satellite, thus forcing large-scale users to rely more heavily on other international satellites such as the rapidly ageing Landsat-5 satellite, or other sources such as the China-Brazil CBERS-series, French SPOT, the Indian IRS satellites, and Kompsat (South Korea). The upcoming GMES Sentinel-2 series is also expected to begin filling this serious gap.

The Australian Antarctic Division (AAD) has a substantial satellite data archive which complements ERIN's data bases. AAD uses this information to monitor changes in vegetation, and glaciers on the remote Australian territory of Heard, Macquarie and McDonald Islands. It is much more cost effective to use EOS data for these monitoring purposes than to mount frequent expeditions.

2.3.7 Coasts and oceans

The largest component of Australia's territory is covered by coastal waters, oceans and Antarctica. EOS technologies are pivotal in routine monitoring and mapping these areas. Spaceborne synthetic aperture radar (SAR) systems have the capability to regularly monitor fishing fleets and shipping around Australia and the southern ocean.

Satellite altimeter measurement of sea-surface height is the most important data stream for monitoring and predicting the energetic turbulent flows that are the 'weather' of the ocean. Satellite-derived sea-surface temperature and satellite altimeter data are being used by researchers to measure the strength of the ocean currents off the east and west coast of Australia and to measure the variations in the strength of the Antarctic Circumpolar Current and its eddies in the Southern Ocean. This information is being used to help design oceanographic experiments such as the fertilisation of the ocean with iron to test the ability of the ocean to sequester additional carbon dioxide.

Sea-surface heights from satellite-derived altimeter data (both the JASON series of satellites and the Envisat data), along with satellite-measured sea-surface temperature and a variety of in situ data streams, are currently assimilated into the BlueLink ocean forecasting system developed by BoM, the Royal Australian Navy and CSIRO. This system, which is one of just a handful of such systems worldwide, provides hindcasts for the period since 1993, and short-term forecasts of coastal and ocean currents and eddies, in the Australian region. This system has recently become operational. Satellite observations of surface waves and winds are assimilated into operational models used for forecasting surface waves.

In coastal waters, data from optical satellite sensors are being used to estimate concentrations of phytoplankton chlorophyll, turbidity, surface water temperature and coloured dissolved organic matter, often as a tracer of freshwater river plumes. In preparation for upcoming hyperspectral satellites with adequate spectral sensitivity, additional products are being developed, which have the potential to dramatically improve our ability to cost-effectively monitor coastal water quality, as well as potential impacts on highly sensitive submerged ecosystems such as coral reefs and seagrasses. Satellite Earth observation data have been used to map the Great Barrier Reef since the 1980s, and are now also used to monitor water quality in the Great Barrier Reef lagoon, and are under development for other coastal regions around Australia. The Great Barrier Reef Marine Park Authority (GBRMPA), CSIRO and BoM have developed a way of monitoring heat stress on coral reefs, known as ReefTemp.[11] DEWHA has recently provided funds to upgrade ReefTemp to cover all Australian reefs.

Open ocean concentrations of chlorophyll-a and temperature are measured routinely from satellite data and used heavily by the fishing industry as a proxy for phytoplankton biomass and, indirectly, primary fish production. Satellite-derived calcite estimates are providing a baseline of coccolithophorid abundance over broad areas of the oceans and are used to provide insights into the potentially disastrous effects of ocean acidification on the abundance and distribution of calcareous phytoplankton.

Understanding the geological history of sea-level change is relevant not only for adding a longer term perspective to recent sea-level change, but also to better understand continental flooding, major coastline shifts, sedimentation and erosion through time. Thus altimetry data are also used to derive marine gravity information to aid ocean basin reconstructions and reconstruct changing ocean basin volumes through geological time.

Australian sea ice research is based largely at the ACE CRC and the AAD. Given the remoteness and vast scale of the Antarctic sea ice zone (expanding each year from 3–4 million km^2 in February to 19–20 million km^2 in October, and then contracting again), this research is heavily reliant on satellite remote sensing. Of fundamental importance are time series of sea ice concentration and extent from passive microwave radiometers on NASA satellites and the US Department of Defense satellites (to be combined in the new NPOESS program). This is enabling a better understanding of trends and changes in Antarctic sea ice distribution in response to changes in large-scale weather patterns and climate change. Another important satellite application is the tracking of icebergs using SAR and scatterometer data, to examine their dissolution rates and drift behaviour, which determine their ultimate fate.

Cloud-free moderate-resolution images from MODIS are used to map and monitor East Antarctic coastal landfast ice to determine, for example, its impact on Emperor penguin breeding success, and to better understand its response to changing wind conditions. Extensive use is also made of the higher resolution imaging capability of wide-swath SARs onboard RADARSAT, Envisat and ALOS, which provide information for air-sea-ice interaction studies within coastal polynyas and the relationship between physical and biological processes within the highly productive ice-edge zone.

2.3.8 National security

Australia's national security activities rely heavily on the ongoing global coverage of classified and unclassified EOS information from sources in Australia and all over the world, to support the intelligence and daily operations of the Australian Defence Force (ADF) and the Border Protection Command (BPC), the services of the Directorate of Oceanography and Meteorology (DOM), and the research and development activities of the Defence Science and Technology Organisation (DSTO) and the Defence Imagery and Geospatial Organisation (DIGO). EOS information is critical to enhance situational awareness and surveillance in combat operations and to help protect Australia's national interests against security threats such as those associated with illegal exploitation of natural resources, illegal activity in protected areas, marine pollution, compromises to biosecurity, and unauthorised maritime arrivals.

Very high resolution multispectral satellite imagery is used extensively for mapping, charting, navigation and targeting. Virtually the entire current capability of Earth observation satellites, including the US Defense Meteorological Satellite Program (DMSP), is used to obtain measurements of atmospheric, ocean, and land parameters in support of the tactical employment of aircraft, ships, submarines, land-based vehicles and personnel. Extensive archives of EOS data have been established, from which a range of climatological assessments of areas of interest or potential interest to the ADF are produced. SAR images from RADARSAT-1 have been used by BPC for ship detection and newer radar satellite constellations such as Terra SAR-X, COSMO SkyMed and RADARSAT-2 are being evaluated for operational detection of vessels and to classify their approximate size and heading.

Several years ago the Department of Defence began to progressively upgrade its use of satellites for communications, surveillance and Earth observations. The 2008 Senate Economics Committee Report on Australia's space science and industry sector noted that more than half of the Department of Defence's major capability projects for the period 2006–15 have a critical dependency on services that are derived from space. Several thousand ADF members and Defence civilians are directly employed in the processing and analysis of EOS data and in operating and maintaining satellite communications facilities in both fixed and deployed locations.[12]

The Department of Defence has a large range of contracts and working arrangements with the private sector and public sector agencies involving the use of EOS. The spatial information private sector provides a range of specialised image processing services. The Bureau of Meteorology provides defence weather services and related EOS information, and trains personnel for Defence's operational Meteorological and Oceanographic Centre (METOC).

GA and DIGO cooperate on the provision of mapping support. CSIRO Land and Water, GA, and DIGO jointly developed the Sentinel satellite-based bushfire monitoring system. CSIRO, BoM, and the Royal Australian Navy jointly developed the BlueLink ocean forecasting system. BPC cooperates with the Australian Customs Service, the Australian Fisheries Management Authority, the Australian Quarantine and Inspection Service, and various state and territory agencies, to deliver a coordinated national approach to Australia's offshore maritime security.

2.4 The national EOS infrastructure

The national infrastructure supporting Australia's use of EOS comprises networks and systems for collecting EOS data from foreign-operated satellites, the systems and facilities for data transfer, processing and archival, and the systems for user access to EOS data and related products and services. Much of this is further supported by significant high-performance computing infrastructure.

2.4.1 National network and systems for satellite data reception

Across Australia there are more than 300 Earth observation satellite ground stations of various sizes and levels of sophistication. However, more than 250 of these are small meteorological data utilisation stations purchased by companies, small businesses, educational institutions or private individuals. These stations will be superseded in 2010 when the WMO introduces a new system for satisfying the needs of these users. Most of the remaining 40 to 50 stations have larger receiving antennae which can collect more widely useful higher resolution data

The most sophisticated stations in the public domain are operated by major Commonwealth government agencies (BoM, GA, CSIRO and AIMS), and by the TERSS and WASTAC consortia and, collectively, these comprise the national ground station network infrastructure supporting various operational and research needs for EOS data throughout the country. The network provides direct data reception and full Earth disc coverage from geostationary satellites monitoring our region, and direct reception from low Earth orbiting satellites enabling contiguous EOS data coverage of the entire Australian continent, its surrounding oceans, New Guinea, Indonesia and other island countries to the north, New Zealand and other island countries to the east, and Antarctica to the south. About seven stations in this network are capable of directly receiving the highest quality and volume of EOS data available today.

Additional global EOS data coverage is obtained mainly by internet and dedicated WMO international communications networks under various international and bilateral EOS data exchange arrangements. The timeliness and the quality of globally available data and products have been improving rapidly commensurate with the advances in available internet bandwidths. BoM has quasi-real-time access to global meteorological satellite imagery under the WMO's World Weather Watch program and also imports EOS-derived data on the vertical structure of the atmosphere for assimilation into Australian weather and climate models.

While individual EOS ground station operators prioritise and are selective in what they download, there is little coordination among them with respect to things like the scheduling of data downlinks from different low Earth orbiting satellites. There is, however, good coordination between GA's Alice Springs operation, and the TERSS Hobart operation in overcoming reception conflicts from multiple satellite passes. With the plethora of current and future Earth observation satellites quickly rising, ground station operational coordination will become crucial to minimise duplication and avoid loss of critical data access opportunities.

2.4.2 Satellite data processing, archival and access

Due to the dispersed nature of receiving stations and operations by different organisations, it is difficult to calculate the amounts and associated costs of the terabytes of EOS data downloaded directly to Australian ground stations each month. Each station is separately linked to data processing hubs operated by different agencies in somewhat different ways, using satellite communications channels, microwave links, AARNet, PARNet, and (in situations where real-time data processing is not a priority) by the shipping of data on super digital linear tape. Communications and processing of large data volumes are expensive in Australia, so much so that the various agencies involved cannot afford to download and process all the data from all the satellites.

Each ground station operator has one or more data processing hubs to service its prime organisational EOS data needs. Processing includes calibration and validation, sensor geo-referencing, and application of various algorithms for specific product development. The ground station operators exchange raw and/or value-added data and derived products with each other and also make them available to all other Australian users under data exchange and access agreements. CSIRO, for example, obtains non-commercial access to Australian X-band satellite data for research and development from BoM, GA, AIMS, TERRS and WASTAC.

BoM, GA, CSIRO, AIMS and AAD all maintain EOS data archives in accord with their respective sectoral needs. These are precious national assets whose value continues to grow as more and more information is collected. GA, for example, has established a unique high-quality national EOS data set documenting the changes in Australian landscape over the last three decades. Many of these data are available at reproduction costs, depending on the level of pre-processing required.

Public access to these real-time or archived data and products is made available via web-based services but some of the information is rudimentary.

WASTAC has an extensive satellite data archive and access arrangements. AAD and the ACE CRC maintain archives of data streams collected from NASA and ESA, but the originating agencies have various restrictions on the further dissemination of some of this information. BoM, GA, CSIRO and AIMS all maintain and provide public access to EOS data, products and services, but with some restrictions to archives of various EOS satellite data and products covering the Australian region. Some users are very dissatisfied with the current overall national status of EOS archive and access arrangements.

Special infrastructure facilities have been established as part of the National Collaborative Research Infrastructure Strategy (NCRIS) which will help custom-build EOS data sets and derived information products for new marine and terrestrial observation programs. Similar initiatives have been taken under the Integrated Marine Observing System (IMOS) and the Terrestrial Ecosystem Research Network (TERN). The AusCover Facility of TERN will soon begin distributing time-series of validated land cover information across the Australian continent from five 'nodes' in Perth, Darwin, Brisbane, Canberra and Melbourne operated by different organisations and will also enable the enhancement of Australia's geodetic infrastructure.

2.5 Underpinning research and related space science activities

While most of the current EOS research activities in Australia have been summarised variously in sections 2.2 and 2.3 above, there are some other important research activities which underpin all others. These include basic science to identify new Earth system phenomena which can be monitored via EOS, design of specialised EOS instruments to detect such new phenomena, establishment of the necessary ground-based tracking infrastructure, as well as algorithm development and calibration and validation of EOS data for Australian conditions. A critical factor in future operational use of new EOS technologies will be to establish more effective mechanisms for transfer of research into operational service delivery systems.

2.5.1 Data calibration and validation activities

The calibration and validation of EOS data for the Australian region is a fundamentally important scientific activity to ensure that the data can be used to a high degree of accuracy. The satellite sensor data are calibrated and validated against high quality ground-based measurements taken at specially designated sites selected in accord with specific internationally agreed scientific criteria. Importantly, involvement in calibration and validation has enabled a number of Australian scientists to join international EOS science teams at the highest level. This has provided early access to data streams that would otherwise be unavailable to Australian researchers for considerable periods of time.

Several well-known sites in Australia, such as Lake Frome, Lake Argyle, Lake Lefroy, Bass Strait and the future Lucinda Jetty, serve as stable targets for calibration of sensors on EOS satellite missions. Areas of Antarctica near permanently occupied Australian stations, have also served as important calibration sites of polar satellite missions. Several scientists, from government agencies and research institutions, are members of international calibration and validation teams for EOS missions operated by the USA, Japan, India, Europe and Brazil. Their individual activities for Australian sites are too numerous to mention here, but they embrace altimetry, atmospheric physics and chemistry, conventional meteorological parameters, vegetation and carbon dynamics, soil moisture, gravity fields, topography, bathymetry, ocean colour and water quality, Antarctic continental and sea ice, navigation and high-precision monitoring.

Dedicated funding and involvement in mission teams and calibration/evaluation activities is generally limited and ad hoc. Some scientists have raised limited funds through ARC Discovery and/or Linkage projects; some have received travel assistance from foreign space agencies. Many other scientists have no identified funding to support their field programs and involvement in planning and evaluation meetings. This is a serious problem that needs to be addressed. By doing so, Australia could make a systematic contribution to a range of international public-good satellite missions.

2.5.2 The transfer of research into operations

Much of the research and development undertaken in the satellite remote sensing arena is done not only to solve fundamental scientific questions, but also to develop observational techniques and products which can be used operationally for community benefit in many fields. There are two basic pathways for the transition of satellite data research into operations:

- **Via development of new satellite-based applications and operational products and services:** In this pathway the operational outcome is usually some form of enhanced satellite imagery and/or analysis product designed to help meet the needs of a particular user sector. Examples of this transition path include the Sentinel bushfire monitoring system; systems for monitoring the health of the Great Barrier Reef; the Volcanic Ash Advisory System for international civil aviation; various flood mapping, flood hazard mitigation and water resources assessment systems; and the Vegetation Watch System.
- **Via data assimilation into major operational weather and climate monitoring and prediction models:** In this pathway the operational outcomes and the ongoing provision of satellite data add value to an integrated computer modelling system containing many other data sources and research streams. Examples of this transition path include BoM's Operational Numerical Weather Prediction (NWP) system, the BlueLink ocean forecasting system, and the new ACCESS whole Earth modelling system.

The transition of research to operations is a fundamental challenge for all research and development programs. To quote the US National Research Council:[13] 'For technology investments, the transitions from development to implementation are frequently difficult, and, if done improperly, these transitions...can seriously inhibit the implementation of good research leading to useful societal benefits.' Australia is currently lagging in this area.

2.5.3 Space science and related applications

Solar activity and associated space weather buffeting the Earth can exact a costly toll on modern technological systems that industry and society have come to rely on, including satellite operations, navigation systems, high-frequency communications and electrical power grids. It can have a significant adverse impact on maritime services, airlines and general aviation, and the operations of the Department of Defence, Australian Customs, the Australian Antarctic Division, the Bureau of Meteorology, and various police, fire and emergency services organisations. Some publicised examples of serious incidents include the silencing of a US communications satellite in 1998 and disruptions of high frequency communications between aircraft and ground stations in Australia and New Zealand in 2003.[14] Incidents are actually common but for commercial and security reasons are not widely reported.

Use can be made of Australia's rapidly expanding GNSS ground station infrastructure (which will have hundreds of GPS receivers), not only to permit atmospheric water vapour profiles to be determined on an hourly basis, but also to determine total electron content (TEC) in the ionosphere, which is an important parameter of space weather.

The BoM IPS Radio and Space Services is the Australian space weather agency. IPS operates an extensive network of monitoring stations and observatories within the Australasian region and in Antarctica to gather information on the space environment in support of satellite and spacecraft operations, and to support international and national research into the space environment. It exchanges this information with similar organisations worldwide as well as making the data widely available through the IPS World Data Centre for Solar-Terrestrial Science.

Australian universities and other government organisations (eg, GA and AAD) also operate many instruments and observatories across Antarctica and Australasia that gather data and generate services related to, or affected by, space weather and to space more generally. They provide these data to IPS and to domestic and international collaborators.

The sun is the ultimate driver of Earth's biosphere, human society, and the whole Earth system, including the circulation properties of the atmosphere and oceans. The sun's variability influences climate and leads to space weather effects. Accordingly, many EOS data depend intrinsically on space: this is not just because of the observing location and space weather effects on the acquisition and transmission of EOS data, but also because many terrestrial regions probed with EOS data are coupled to space via radiation, energetic particles, and varying magnetic and electric fields. Understanding these effects is vital to Australia's use of EOS data and necessitates having a wider space program than for EOS alone.[15]

2.6 Education and training

The 2008 NCSS First Decadal Plan for Australian Space Science identified a serious and growing gap in trained scientific and technological personnel in all areas of space science, and proposed several initiatives regarding high school, undergraduate and postgraduate education, community outreach programs, and improved scientific literacy of government and industry groups. The recent rapid increase in public awareness of climate change and the environment has led to these aspects being given much more prominence in school and university curricula and has renewed interest in the involvement of satellite Earth observations and applications. Some of these issues have been addressed in the 2009–10 Commonwealth Budget, with the creation of the Australian Space Research Program administered within DIISR, which will provide grants for specific space-education purposes.

Universities are experiencing problems in attracting additional personnel trained in the analysis and interpretation of EOS data. It is common for university research projects to fill postdoctoral positions with international applicants because of a lack of a suitably qualified Australian candidate. This highlights the need for an improved education program at the secondary and tertiary level to enable Australia to develop the scientists that are required for the future.

The 2008 Remote Sensing Business Analysis by the Department of Environment, Water, Heritage and the Arts (DEWHA)[16] found that satellite and other remote sensing technology is used in almost all business processes within DEWHA requiring scientific inputs. It provides an information source for issues across the full extent of Australia's sovereignty, but a lack of knowledge across groups about the fitness-for-purpose use of remote sensing is one of the current barriers to effective and increased use of satellite remote sensing in much of DEWHA.

One useful model is provided by the meteorological community, where the World Meteorological Organization (WMO) has established a global network of Centres of Excellence in Satellite Education and Training, supported by space agencies and satellite operators servicing the region in which the centre is located. The Bureau of Meteorology Training Centre (BMTC) has been designated as a WMO Centre of Excellence and regularly conducts international satellite training workshops attended by personnel from Australia and the Asia-Pacific region. BMTC also conducts annual EOS training programs for some of its own personnel, and for staff of the Directorate of Oceanography and Meteorology who provide weather and marine services for the Department of Defence.

2.7 National coordination

EOS activities in Australia are currently coordinated through a range of forums and committees. The Australian Government Space Forum (AGSF) has become the forum for information sharing among government departments with interests in space technologies, but it is not a vehicle for decision-making on behalf of the Commonwealth. The AGSF is chaired by the Department of Innovation, Industry, Science and Research, with attendance from all Commonwealth government portfolios. Further coordination of government activities in Earth observation also occurs through a number of interdepartmental committees (IDCs), including an IDC on GEO, and an IDC on commercial satellite capabilities. Space-science coordination of national and international engagement on new scientific opportunities occurs through the Australian Academy of Science's National Committee for Space Science (NCSS), and in some cases through other AAS National Committees. The Australian Chamber of Commerce provides a forum for information sharing among space industries.

There is low awareness and little or no national coordination of the involvement of Australian scientists in calibration/validation experiments to support international space missions, or as members of mission steering committees or advisory panels. There is no collective record of such involvement, either at the government, private or university level. Such activity is an integral component of the efficient use of EOS data and the maintenance of the scientific value of EOS data archives.

2.8 High-level international coordination

Since 1984, Australia has been a member of the Committee on Earth Observation Satellites (CEOS), and has benefited through improved access to key satellite data as well as financial and programmatic support for implementation of research missions such as Australia's FedSat satellite. Since 2003, Australia has also been a member country of the intergovernmental Group on Earth Observations (GEO) implementing the Global Earth Observation System of Systems (GEOSS), and currently serves on the GEO Executive Committee. GEOSS provides a broadly-based framework for integration of Earth observation activities which has subsequently absorbed the former informal Integrated Global Observing Strategy Partnership (IGOS-P).

Because of the ministerial and intergovernmental origins of GEOSS, the formal coordination of Australian involvement in the GEO mechanism has been mainly handled through interdepartmental committee processes with a small secretariat supported by BoM. In light of the increasing significance of the GEO process, it is important to ensure that Australia's Earth observation scientists and technical experts are more actively involved in GEO activities.

2.9 EOS activities in industry and the private sector

The Australian Earth observation industry, closely associated with the wider spatial information industry, is composed of about 100 small and medium enterprises engaged in base data acquisition and sales, data value-adding, consulting on the interpretation and use of the spatial information products and, in only a few cases, in actual sensor design and development. By volume of transactions and sales, the majority of clients here tend to be Commonwealth (civilian and defence), state, territory and local government users and in some specific cases also the mining and resources sector, purchasing mostly higher-resolution air photography, digital multispectral, hyperspectral or SAR commercial imagery (spaceborne and airborne) in support of higher resolution or tactical mapping and surveillance programs. Only in two known instances are locally built and operated imaging technologies used in procurement of such data. The majority of technologies used are still based on foreign-built airborne cameras and sensors, or satellite technologies.

On rare occasions, governments (Commonwealth and state) have provided special industry incentives or subsidies to support the Earth observation industry, or to stimulate niche manufacturing of new sensors or other aerospace hardware or data analysis tools. Contrary to a worldwide trend where governments actively provide subsidies in terms of assured EOS data purchase, credit guarantees, R&D tax concessions or grants for development of new EOS technologies, the approach in Australia for the last decade or more, has rather been to allow market forces to determine the growth and development of this industry sector. This has resulted in an industry that is chronically underfunded and highly dependent on ephemeral government contracts and overseas work to support its workforce and its very limited R&D into new technologies. The industry sector even finds itself competing against internal government data acquisition and analysis programs in some instances.

The recent Cutler review[17] suggested that, in terms of stimulating complementary private sector innovation, the following areas deserve attention: resource industries, space and astronomy, finance and risk management, and marine industries. Thus, while in the eyes of industry there is still a long way to go, the Australian space industry sector has generally welcomed the establishment of the Space Policy Unit which will administer the Space Research Program within the DIISR Manufacturing Division, in the expectation that this new program will be representative of the whole industry and will place appropriate emphasis on the full value-chain of the space-based information flow and not just on the space segments.

2.10 Conclusions

The working group reached the following general conclusions based on a broad assessment of current Australian activities in the acquisition and use of EOS data:

1 Australian governments and the economy overall are dependent on EOS technologies, with critical national and/or state-based operational programs relying on the long-term continuity of consistent, accurate information derived from satellite missions. All of these missions are operated by foreign governments or companies. Applications here include defence and national security, natural disaster mitigation, water resources, geophysical and resources mapping, geodesy, weather forecasting and space weather services, and the monitoring of climate, ecosystems, and the marine environment.

2 Due to the rapid evolution of the technology and widening array of satellite measurements available, nearly all these operational government EOS uses are closely linked to specific research programs at the CSIRO, GA, BoM, AAD, CRCs and universities.

3 Recurring investments into Earth observation activities and facilities operated by the BoM, GA and CSIRO are primarily made into maintenance, operations and upgrade of ground satellite-communication facilities and associated processing and archival systems. There have been only two small contributions to space-based research infrastructure in the last decade.

4 While there is a large apparent variety in effort and range of applications for EOS data across Australia, it will be important to conduct a more detailed audit of the true capacity, costs and effectiveness to perform such EOS-derived services.

5 Significant new effort is needed also into inter-agency EOS coordination mechanisms (Commonwealth and state), to reduce costly duplication and exploit the potential synergies across portfolios. The current modus operandi has led to a situation where the agencies largely act separately, operating infrastructure and funding their own internal programs, with little cross-investment, cross-portfolio prioritisation and long-term strategic coordination.

6 Agencies responsible for delivery of EOS-derived services have traditionally funded the costs associated with direct international space-agency engagement, science meetings and participation in EOS-related intergovernmental coordination forums such as CEOS, GEO and the Asia-Pacific Regional Space Agencies Forum. In light of the rapid rise of new space enterprises (eg, in China, India, Indonesia, South Africa, Taiwan, Thailand, South Korea, Argentina), these efforts will not only need to increase, but will require significant strategic involvement by the Department of Foreign Affairs and Trade, as well as improved inter-agency coordination and support to achieve full national benefit.

7 While a wide range of activities and pockets of scientific excellence can be identified against most key areas of EOS science, the overall EOS sector (operational services and research) is generally operating below capacity. This limits Australia's opportunities to fully exploit the wide utility of available EOS data and to capitalise on extensive international collaborations and partnerships that are on offer. Serious skill shortages and reductions in educational opportunities exist in the sector as well.

8 The NCRIS, now superseded by the 'SuperScience' Program announced in the 2009–10 Budget, has enabled the development of new national programs (IMOS, TERN, ARCS, and AuScope) which link multiple activities at all levels of government and research in Australia in the integrated use of EOS and in situ observations. These programs are helping to determine which information and products are required to monitor, model and understand Australia's oceans, atmosphere, ecosystem and solid Earth resources, and will build publicly accessible data bases and data delivery programs to enable consistent and accurate long-term monitoring of each environment.

9 With climate change a serious challenge, Australia is moving to increase the use of sophisticated data assimilation techniques which help integrate EOS data ingested into analysis and climate prediction models such as the Australian Community Climate and Earth System Simulator (ACCESS) model, to be implemented in late 2009. By international standards, however, and relative to our area of stewardship responsibility, Australia is under-resourced in terms of personnel and computing power, limiting the benefits to the Australian community from these space-based observing systems.

10 Outside the weather and climate monitoring and forecasting sector, there are also significant observational opportunities for a more effective use of EOS data in monitoring systems and models which address our national needs, such as monitoring and accounting of Australia's

water resources, carbon emissions, state of the environment reporting, coastal monitoring, mineral exploration and solar and wind energy security. This requires ongoing and sustained support for research and development into new sensors and the coordinated, integrated use of EOS and *in situ* observations.

11 A recent assessment suggests that in the hydrology sector current infrastructure and methodologies are not technologically mature enough to support fully operational EOS data ingestion and modelling systems. The assimilation of changes in total water storage from the GRACE space gravity mission into hydrological modelling, for instance, has not yet been attempted; and with new rainfall monitoring missions planned by Japan and the USA, Australia has not yet engaged in a formal way in gaining direct and rapid operational access to such data. Additional research is also needed on satellite data assimilation, and improvements need to be made on the timeliness of some of the satellite data input. Furthermore, some current institutional and technological barriers need to be overcome before the benefits of this advanced model can be fully transferred to river operations.

12 The agriculture and natural resources sectors are heavily dependent on the supply of medium resolution (30 metres or better) EOS data. A serious problem here has been the recent faults in the Landsat-7 satellite. This has led to additional efforts into securing satellite data and re-adapting processing systems for data from other international satellites such as the rapidly ageing Landsat-5 satellite, or other sources such as the China-Brazil CBERS-series, French SPOT, the Indian IRS satellites, and Kompsat (South Korea). The upcoming GMES Sentinel-2 series are also expected to begin filling this serious gap.

13 Australia has leveraged its geographical advantage and scientific expertise to establish calibration and validation programs in support of foreign EOS missions. In return this has enabled Australian scientists to join various international mission science investigation teams and to secure favoured access to EOS research data. Australians also serve on steering or executive committees of foreign satellite missions. However, there has been no nationally coordinated process or supporting funding mechanism to support these important activities.

Notes

1 This assessment builds on and extends information compiled by several recent surveys: Athena Global (2006), Lewis and Reddy (2006), ACIL Tasman (2008), the Allen Consulting Group (2008), Biddington (2008), Cairns et al (2008), Kelly (2008), Senate Standing Committee on Economics (2008), Ward (2008), WMO (2001, 2005, 2009), Department of Defence (2009).

2 Biddington (2008) and Senate Standing Committee on Economics (2008).

3 Allen Consulting Group (2008), op.cit. pp x-xi.

4 ACIL Tasman (2008).

5 Bureau of Meteorology (2007).

6 CAWCR was established in 2007 as a partnership between the Bureau of Meteorology and CSIRO.

7 Barrett et al (2008).

8 For example, Merlin et al (2008).

9 http://floodmap.dli.wa.gov.au/landgate_floodmap_public.asp.

10 Phinn et al (2008).

11 www.cmar.csiro.au/remotesensing/web.

12 Biddington (2008).

13 US National Research Council report (NRC, 2000).

14 Bureau of Meteorology (2009).

15 Cairns et al (2008).

16 Kelly (2008).

17 Cutler (2008).

CHAPTER 3: **FUTURE NEEDS AND OPPORTUNITIES**

This chapter summarises, in broad terms, Australia's national needs for the use of EOS over the next 10 to 15 years. It discusses the new global and national operational EOS framework that is now emerging; summarises future needs in each of the eight areas of key national challenges; identifies major opportunities and threats; examines the national infrastructure needs; assesses the education, training and research support required; and discusses the strategic needs for industry, and for the coordination of state and national EOS activities and international engagement. It also addresses the need for coordination between civil and defence EOS activities. Thirteen broad conclusions are made.

3.1 Introduction

It is difficult to succinctly and authoritatively assess future national needs for EOS because Earth observation is exceptionally diverse and complex in its associated science, technology, system management, users and user applications. The international EOS community has been wrestling with the needs assessment process for more than 20 years and has now got to the stage where, at a global level:

- The fundamental scientific space-based observational requirements are now reasonably well defined for all major components of the whole Earth system, and for all major scientific disciplines, in terms of requirements for precision, spatial resolution and temporal resolution for each observational parameter.[1]
- The users and user needs for EOS data and related products and services are reasonably well known and have been categorised into a number of areas in which there are major global benefits for society.
- Mechanisms are in place for observational requirements and user needs to be regularly reviewed and for dialogue to occur between major user bodies and the space program operators on the extent to which needs can be met within the economic and technological capacities of the providers.
- The EOS missions of the space programs of individual nations are becoming increasingly better coordinated, harmonised and publicised. Globally coordinated information is currently available for all known operational and planned EOS missions out to 2025.
- Joint civil and defence use of EO satellites and their products is being adopted by countries with major space programs.
- An integrated global system of space-based and in situ observations is now emerging, aimed at better satisfying user needs.

It is clear that the global community is addressing future needs for EOS via an integrated, coordinated and consultative approach which transfers the global benefits of observational science and technology to the community. Australia has not assessed its national needs for EOS using mechanisms adopted by the global community. Until very recently, Australia had simply accepted that its future EOS needs would automatically be provided by the global space-based system, the goodwill inherent in free international data exchange protocols, and the security of international bilateral and agency agreements for access to specific satellite data. While historically we have leveraged goodwill through other forms of contribution to the total Earth observation system, for all intents and purposes Australia is a free-rider on the international system.

Under this approach, successive governments have seen no need to centrally focus Australia's EOS activities, despite extensive dependence on EOS data to support the day to day activities of numerous national and state agencies. Consequently, our future national EOS needs have been assessed almost independently of each other by agencies and scientific institutions in five major streams: national security, meteorology, geospatial mapping, multidisciplinary research, and space-based industry and commerce. Australia's needs have been input to the global system via the diligent efforts of individual scientists and leading institutions and their involvement in international working groups.

Advancements in EOS technology and a global focus on environmental change have elevated EOS data and their products to an essential component of information infrastructure for governments to monitor and manage their natural environments. It is emerging as a transformational technology for governments around the world to inventory their natural resources, to monitor how they change over time, and to form the basis for sustainable management. Several of the applications outlined in Chapter 2 have used EOS data as a transformational technology in our carbon assessment, fire monitoring, and enforcement of state vegetation management legislation.

This philosophy of approach is now changing as a result of the outcome of the 2008 Senate Economics Committee review of Australia's space science and industry sector and action taken by the government in the 2009–10 Budget to create a Space Policy Unit and an Australian Space Research Program. Furthermore, the Department of Defence decided strategically in the early 2000s that its space-based capabilities needed substantial upgrading, which has eventually led to the announcement in the 2009 Defence White Paper that Australia will acquire a satellite for defence use with a remote sensing capability.

The working group has taken these developments into account in the assessment of Australia's future needs outlined in this chapter. It is intended to provide a basis for the future development of a more comprehensive nationally coordinated statement of our strategic EOS needs. The present assessment must be regarded as preliminary. Further work will be required by a national coordinating body on the key challenges considered in section 3.4 to identify how the total needs can be assessed, especially in relation to interactions with planned EOS missions.

3.2 Opportunities from global EOS missions 2010 to 2025

The world is entering another period of major change in the science, technology and mode of use of observations from space. Australia has a great opportunity to expand its current use of EOS information, and to benefit from the progressive introduction of a whole new generation of globally coordinated Earth observation satellite missions in the period 2010–25 that will substantially improve the continuous observation of the whole Earth system.

Australia has a firm global framework upon which to plan its national strategy for better exploiting EOS. The plans and status of all global EOS missions for 2010–25 are catalogued[2] and updated regularly. The GEOSS 10-Year Implementation Plan[3] provides a broadly based international framework for integration of Earth observation activities. The intergovernmental Group on Earth Observations (GEO) disseminates information on how various countries are using, and planning to use, Earth observations, including those from space-based systems.[4]

More than 90 new missions are either approved or in advanced stages of planning for the period 2009–15, and a further 30 new missions are already planned for launch in the period 2016 to 2025. (This does not include more than 100 GNSS satellites that can also be used to monitor particular characteristics of the troposphere and ionosphere.) These missions will employ more than 385 different instruments and will introduce new types of measurement technology such as hyperspectral sensors capable of sensing in hundreds of spectral bands. There will be a substantial improvement in spatial, spectral and temporal resolutions and in the accuracy of measurement compared to current systems. Collectively, these missions have a strong focus on measuring the Essential Climate Variables[5] required to support the work of the Intergovernmental Panel on Climate Change and the UN Framework Convention on Climate Change, and a large number of these already form the basis of ongoing resource science and management programs in Australia.

3.2.1 Opportunities for climate change monitoring

A national framework for Australian climate change science[6] has just been developed by the Department of Climate Change, which identifies key areas where science must deliver information to inform important decisions over the next decade. This includes information on changes in greenhouse gases, better projections of future rainfall, sea-level rise and acidification, cloud physics, and extreme weather events. The Prime Minister has said that climate change is an overarching issue and it will shape the context influencing much done by individuals, government and private organisations.[7]

It is essential that Australia embraces the opportunity to fully incorporate the current and next generation EOS data into the national framework for climate change science. This is because these new systems will provide much of the required environmental information, especially the information needed for the national regulation and monitoring of Australia's greenhouse gas emissions, the reduction of carbon emissions, sea-level change, and to assist in tackling major problems such as the Murray-Darling water management, the health of Australia's reefs, including the Great Barrier Reef and its surrounding waters, and the development of more efficient solar and wind energy generation systems. EOS information needs in this area span solar, atmospheric, terrestrial, cryospheric, oceanic and coastal environments, and biophysical parameters relevant to each of these.

Australia has some capability in whole Earth system modelling and spatial data analysis which are essential to assimilate the next generation of EOS data and convert them into products and services at all scales and for all sections of the community. We have research programs in these areas and some of the high-performance supercomputing capacity necessary to handle the explosive increase in data volumes and the associated requirements for running advanced climate models. The EOS user community is increasingly more sophisticated and is demanding access to more and more information in real time, so we need to improve web-based services, interfaces and bandwidths.

The ongoing development of all these aspects needs to be well focused and adequately resourced if we are to meet Australia's future needs in this area of overarching national significance. In particular, strategic action is urgently needed to redress Australia's chronic shortage of post-doctoral personnel to engage in climate research.

3.2.2 Opportunities for partnerships in new EOS missions

Australia is under substantial international pressure to make a greater contribution to the operation of the global space-based observing system. A cost-effective way of doing this is to enter into partnerships with international space agencies in the operation of EOS satellite missions. This can be achieved through co-investment in the whole, or specific components of, EOS system development and implementation, or co-investment in data delivery systems associated with satellite constellations. The benefits include opportunities to leverage priority access to EOS data specifically tailored to meet our key national challenges.

The Department of Defence has already taken an initiative involving Australian investment of more than $900 million for the capital and incremental operational costs of one satellite in the US Department of Defense's wideband global satellite constellation, which will operate out to 2029. The proposed Australian satellite has an Earth remote sensing capability which could be used for civil purposes if appropriate access arrangements and conditions could be agreed. The US already has in place arrangements for duality of use of defence satellite systems and several other countries are now following suit. However, caution has been expressed from several sources about problems associated with priority conflicts and other aspects of defence procedures. One area where cooperation might be fruitfully explored in Australia is in relation to disaster response, in which the Department of Defence is often called upon to assist.

Other partnership opportunities are emerging for both public good and commercial satellite missions. These range from involvement in missions using constellations of micro-satellites, to missions in which Australia might modestly share some of the costs, or provide one or more of the satellite sensors, or one of the micro-satellites.

It should also be noted that airborne prototyping for testing, calibration and validation of EOS sensors and their processing algorithms is an essential component of other EOS programs around the world. Australia has several internationally recognised private and research organisations capable of building sensors and conducting these evaluations, especially for the validation for measurement of biophysical parameters

The working group was informed that several foreign space agencies are currently seeking Australian involvement in future missions whose objectives variously include climate change, enhanced space gravity measurement, and improved systems for monitoring to the west of Australia. The working group also noted that several groups in Australia are proposing micro-satellite project initiatives in Earth observations. The extent of Australia's climate zones from the tropics to Antarctica suggests that there is potential for partnerships to support the efficient testing of prototype instruments in different zones, as well as calibration and validation of mission instruments. Australia urgently needs to have a recognised national EOS authority as a focal point of contact to consider and assess such proposals.

3.2.3 Opportunities involving data access and reception systems

The massive increase in new generation EOS data volumes and the expected demand for rapid access to information is such that new low-cost environmental information delivery systems are now being planned, in which EOS and *in situ* information will be transmitted using a multicast, access-controlled broadband, capability. This area also has significant capacity for shared use of defence facilities in terms of receiving systems. GEO is developing a global system called GEONETCast[8] which will link to regional systems for the Americas, Europe and Asia via communication satellite broadcasts using a standard protocol interface, such as is used for direct-to-home television transmission. China, through its FENGYUNCast system, is planning to provide coverage of Australia and New Zealand.

Different data streams or products can be made available on separate channels, and the user decides which data are to be received, managed and saved locally. No internet connection is required and the receiving station is simply a standard personal computer, a few computer cards and an off-the-shelf satellite television dish. This could be of considerable interest to general information users of environmental data throughout Australia as community interest in climate change and the environment continues to grow. There could be associated development, marketing and service industry opportunities.

The needs of higher level information users in Australia will not be satisfied by the GEONETCast system. A system for high bandwidth data access via a Tracking and Data Relay Satellite (TDRS) could address some of the needs of these users and would provide users with more control over the type of data they choose to access. There could be opportunities for industry in the development of such systems.

3.3 Future needs for addressing key national challenges

In exploiting the new generation of satellite Earth observations, Australia needs to build on its advanced data assimilation and environmental modelling capabilities in weather, climate, ecosystems, water management and the oceans, and its significant investments in infrastructure, image archives, processing routines and skilled people. This provides a sound platform for enhancing Australia's capacities in high spatial resolution image processing and long time series image processing which are essential for assessing and mapping environmental trends, and in separating human and naturally induced environmental change. It is important to recognise that these capabilities exist not only in national agencies but also in various state government agencies, but their capacity to continue operating, and to effectively use new data and newly released archives needs to be significantly enhanced.

The following sections outline the needs and capabilities for EOS applications in all eight of the key areas of national challenge identified in this report. They link with the outline in Chapter 2 of Australia's current EOS activities in these eight areas. The needs for EOS for applications in weather and climate are a common thread. There is also a rapidly growing need in all areas for real-time access to products and services and for expanded EOS-based spatial information data sets and products on all scales.

3.3.1 Climate change

The new generation of satellite sensors on EOS missions is about to release a flood of long awaited information to enable Australia to better monitor, understand, and measure the impacts of climate change. Overall, future missions eventually will be able to measure the essential climate variables that can be obtained from space-based observations for monitoring climate change. Hyperspectral information on atmospheric composition as well as the Earth's surface properties will soon be available along with new and better data from advanced lidars, altimeters, gravity measurements and synthetic aperture radars. Both satellite and *in situ* observations provide major contributions to the Global Climate Observing System (GCOS). The GCOS Steering Committee and secretariat report regularly to the United Nations Framework Convention on Climate Change on the adequacy of climate observations for the purposes of the Convention.[9]

The transition from the current to the new generation of EOS weather and climate missions has just started. It will be completed by about 2015 and then sustained and progressively modernised over the period 2015 to 2025 through harmonised global operations aimed at ensuring ongoing continuity and consistency of weather and climate monitoring from space.

The critical importance of developing more accurate seasonal, annual and decadal climate forecasts in support of management of natural and production environments cannot be overstated. Therefore, it will be vitally important for Australia to enhance its current scientific and technological capabilities, infrastructure and skilled workforce, to more effectively use the current and next generations of satellite sensors on EOS missions to improve the monitoring and understanding of climate change, and its impacts on Australia.

One of Australia's most immediate needs is to prepare its data reception, processing, quality control, analysis and assimilation systems and its specialist EOS personnel for this flood of new data so that we can take advantage of this new information as quickly as possible. We are ill-prepared and under-resourced to undertake these complex, highly specialised tasks.

There will be a huge increase in diverse space-based observations available for use in Earth system modelling. Data from up to 50 space-based instruments will be available to be used to establish the basic climate state which anchors the predictive aspects of climate models. For example, there will be thousands of radiance measurements available from ultra-spectral sounders and occultation information from the GNSS constellations, as well as information from ground-based GNSS receivers. However, the current capability and capacity to deal with this information are limited. Considerable resources will be required to enable assimilation of the full complement of current and future sensor data in a timely fashion. With existing resources, it could take up to 7 years for the full complement to transit into operational use in weather and climate models. This is unacceptably long.

There is a concurrent urgent need for national coordination to establish the extent to which all of the data sets required for defining Australia's climate are being collected, stored, validated and distributed. This is essential for the development of nationally consistent products from which to determine the magnitude of climate change in our atmospheric, terrestrial and oceanic environments including Antarctica, and to assess the effects of Australia's climate change mitigation actions. We also need to have sufficient personnel, equipment and facilities in place to validate these data sets and to make them easily accessible to the communities which will depend on them.

In view of the national significance of climate change, Australia now needs to move rapidly towards the integrated use of space-based and *in situ* data for climate change monitoring in all application areas. There is a clear strategic need to move towards the establishment of a national, all-embracing environmental data supply framework, to provide coordinated data services and advice for whole of government, public and industry use. Other major developed countries have already done this in addressing their key national issues associated with climate change.

The new generation of EOS missions will provide new information on the vertical and horizontal profiles of greenhouse gases and other atmospheric constituents in the Australian region. The derivation of these profiles will require an expansion of the current data assimilation capability and a related increase in ground-based monitoring to enable effective calibration of the satellite instruments. The harmonising of assessments of the carbon budgets measured looking up from the bottom of the atmosphere, and the satellite-based carbon budgets measured looking down from the top of the atmosphere is an important scientific step in the ongoing development of the National Carbon Accounting System.

The assimilation of these greenhouse gas profiles and the new EOS hyperspectral information discussed earlier would significantly enhance the capability of environmental monitoring and prediction models such as the Australian Community Climate and Earth System Simulator (ACCESS). Such models will become increasingly more sophisticated over the next 15 years and, together with the enhanced use of EOS-based spatial information services, their output would help address many of the key challenges Australia now faces in its management of climate change. Over the next 15 years the benefits should flow through to the Australian community in terms of the better definition and prediction of Australia's climate and the impacts of climate change on regional and local scales, and a much greater understanding of the influences of our surrounding oceans and Antarctica. Exploiting this potential will require significantly increased computing power and related infrastructure and personnel.

In addition to improvements in predictions of future climate, new EOS data will be critical in the detection of climate change, including changes in temperature, rainfall, winds, sea level, sea ice, ice-sheet mass, volume and motion, and other climate parameters. Active engagement with relevant missions, including continued and expanded local calibration and validation activities, is one component of attempting to assure continued access to EOS data sets.

From an overall perspective, Australia is already having difficulty in using the full complement of EOS data currently available for climate change modelling and is now faced with the immediate problem of having to manage an even greater range of sensor information. In the first instance we will certainly have to be quite selective in the data we choose to download into our ground station network or access via the internet. In the longer term, though, global changes in EOS climate data access and processing infrastructure, combined with our national advances in supercomputing and super-fast broadband communications systems should enable much more EOS-based climate data, or derived products, to be received and delivered to users in real time.

3.3.2 Water availability

Improving available information on current and future water resources as well as future climate projections will be highly important in Australia to help us manage this often scarce resource into the future. Historically, the monitoring and management of water resources in Australia have relied predominantly on a conglomerate of surface-based observation networks operated by public and public-private entities at the national, state and local level. Data are collected on surface water resources, including precipitation, runoff, evaporation, discharge, soil-moisture, river height, extent and quality of water in storage facilities, condition of catchments draining into storage facilities, and wetland extent.

More recently, EOS data have been introduced to assist in mapping the extent of bodies of water, including wetlands, water courses and water storage, and to monitor their change over time. Water management authorities and researchers are aware of the potential impact a wider range of EOS information could have in supplementing ground-based observations, but they need these EOS data to be timelier and to have better spatial resolution and accuracy. There is an associated need to make more use of satellite-based data collection systems as a cost-effective means of collecting observations from the more remote parts of Australia.

The new generation of EOS sensors will provide more accurate and spatially detailed information on rainfall patterns, surface soil moisture, surface skin temperature, snow cover, snow water equivalent, evapotranspiration, and total water storage changes. They will enhance the accuracy and spatial resolution of the existing range of satellite-derived mapped products, such as vegetation type, normalised difference vegetation index (NDVI), solar radiation, surface albedo and fire scarring, which are ancillary for hydrological applications.

There are several core sets of EOS hydrological data and information that need to be compiled for user access on a regular basis over all of Australia. One category of data sets must enable the location and extent of surface water resources (water storage facilities, from large dams to individual ring-dams, streams and lakes) to be mapped and monitored at annual or more frequent time scales. Collecting these data over time will enable active monitoring and more precise accounting of variations in precipitation, water storage, stream flow and flooding events to be captured. These aspects are still poorly understood.

Another data set category needs to cover information on the condition and form of catchments draining into water storage facilities and in specific areas of the landscape to enable assessment of water flows and exchanges. This includes topography, land cover and land use, vegetation cover, bare ground cover and soil moisture. Provision of regularly collected regional to continental-scale data in these areas will allow accurate and consistent monitoring of the extent and condition of Australia's water resources and the hydrologic dynamics of our natural and managed landscapes.

Many of the major challenges for the management of Australia's water resources over the next 15 years will also be addressed through the assimilation of EOS data to enhance the performance of catchment-scale hydrological models. Rainfall is a major input for these models, and missions such as the Global Precipitation Measurement (GPM) will provide improved estimates of rainfall on catchment scales. A key variable in hydrological models is soil moisture, and continued work on the assimilation of EOS data from missions, such as Soil Moisture Active Passive (SMAP) and Soil Moisture and Ocean Salinity (SMOS), will be essential to the accurate simulation and prediction of catchment water budgets. Benefits will flow, not only from the direct assimilation of EOS hydrological parameters, but also from the additional assimilation of EOS enhanced model output of meteorological and other environmental parameters from Australia's new Earth system simulators.

There should be a significant impact on river and stream flow modelling performance when Japan's next generation geostationary meteorological satellite becomes operational in 2015. This will provide rapid scanning of weather systems at 10 minute intervals over the whole of Australia at spatial resolutions of 0.5 to 2.0 kilometres. The impact of this higher spatial and temporal resolution capability will improve output of parameters from the weather and climate models required for use in hydrological modelling.

At about the same time (2015 or 2016) the expected next-generation GRACE mission could potentially achieve gains in measurement accuracy of 3 to 10 times compared to the current mission, which would lead to the provision of space-based total water storage estimates over Australia at the sub-catchment level. GRACE detects changes in groundwater resources after the soil moisture and surface water resources have effectively dried up, which improve drought assessments in major catchment areas. This has recently been demonstrated in a basin-wide study of the Murray-Darling.[10] Australia can potentially contribute a new, inter-satellite laser measurement system technology to the next GRACE mission, along with the assimilation of the new observations into the analysis and generation of data products.

3.3.3 Natural disaster mitigation

There is an ongoing national need for continuous improvement of space-based observations in all four phases of disaster mitigation management (planning, preparedness, response and recovery). This is also a major ongoing global need which has been addressed to the same degree of prominence as climate change in the objectives of global EOS missions for 2010–25. For example, by 2012 the European Union plans to launch a multi-mission flagship program called GMES (Global Monitoring for Environment and Security)[11] and there are disaster support initiatives for the Asia Pacific region, such as Sentinel Asia.[12] The UN International Charter on Space and Major Disasters provides global overarching support, but Australia needs to improve the inter-agency coordination and ability to trigger EOS acquisitions in the event of disasters.

Australia's needs for continuous improvement in the use of EOS for natural disaster mitigation should be addressed in an integrated manner by all EOS operational and research institutions. This is also an area where the upgraded Earth observing satellite observational capabilities of the Department of Defence could be involved in the broader national interest. The use of meteorological satellite information is already well integrated into natural disaster preparedness systems and there is a clear pathway for meeting our national needs for continuous improvement for weather-related disasters (cyclones, storms, flood rain, and the rapid spread of bushfires), but there are some key needs to be addressed in the timely delivery and uptake of information from other satellite systems.

Weather-related disaster mitigation improvement is critically dependent on retaining the highest possible level of access to the next generation Japanese and Chinese geostationary satellite missions and the USA's NPOESS program. South Korea soon plans to launch two geostationary meteorological satellites (in 2009 and 2014) which give overlapping coverage to the Japanese and Chinese missions. Australia must maintain close EOS data access arrangements with these countries in order to meet our national needs. The benefits from these next generation EOS systems will arise through their improved capabilities (eg, 10-minute rapid full Earth disc scanning at 0.5 kilometre resolution) and the linking to smart tools and improved meso-scale weather prediction models whose integrated output is linked to emergency management decision-making systems.

Apart from meteorological satellite input, information from other satellite systems mainly involves the use of high resolution spatially-mapped EOS products which are of major significance in the planning, recovery and response phases of all natural disasters and are especially important in all aspects of disasters due to floods, earthquakes and tsunamis. There are significant problems concerning the rapid delivery of these data from multiple sources in response to disasters within appropriate timeframes, and in transforming data into useful information and products. There are also difficulties with feeding information to relevant decision makers, incident-controllers, and the community. Although there are national agencies such as Emergency Management Australia (EMA) and the Australian Maritime Safety Authority (AMSA), and there are disaster response agencies in each state and territory, there is a need for improved coordination between all agencies for establishing and meeting their critical EOS data requirements for this type of information.

It would make sense for all national and state agencies responsible for disaster response to coordinate their spatial information requirements and the requirements for additional hardware and personnel. Such an approach would enable a clear assessment of the Earth observation data needs, and a direct link for the data-providing agencies to establish with users at national and state level. This network would also allow direct collaboration and communication between those working the same area but in a different state.

3.3.4 Safe and secure transport

There are diverse needs for EOS information to contribute to the safe and economic operation of Australia's road, rail, air and sea transport systems over the next 15 years. Many of these are weather-related and will be progressively addressed as the new generation of weather satellites begins to enhance the effectiveness of national meteorological and oceanographic services. Accurate, real-time positioning requirements are expected to be met from increased navigation constellations with the introduction of the European GALILEO and Chinese Compass systems to augment the existing GPS and GLONASS GNSS constellations.

The ongoing review of EOS needs for international and domestic air transport and for the general aviation industry in Australia is inherent in the consultative arrangements established between the Bureau of Meteorology, the major airline operators and airline industry representatives. The new EOS ultra-spectral atmospheric sounding instruments will help provide increased accuracy and density of wind, temperature and moisture information, which is critical for safe and economic in-flight airline operations. In conjunction with improved meteorological modelling, this will also contribute to the better analysis and forecasting of major aviation hazards such as icing and turbulence.

To operate safely at the rapid speeds attained by high flying aircraft, pilots need a real-time awareness of hazardous conditions well beyond the range of current aircraft radar. Awareness of thunderstorms and volcanic ash clouds are especially important. The next generation of Japanese and Chinese geostationary weather satellites will increase the weather scanning frequency over the Australian region to every ten minutes and at a better spatial resolution than the current system which scans at hourly intervals. It should be possible for aircraft to access this new information in real-time and in-flight. This new scanning capability will also contribute to safety and improved air traffic control at Australian air terminals.

EOS monitoring is a major need to support Australia's Antarctic re-supply operations, surface and air transport operations within the very harsh and hazardous environment of Antarctica and its extensive sea ice zone, and to support the air and sea transport of personnel to and from Antarctica. Satellite ground station facilities are being upgraded at the Australian station at Casey to ensure access to the capabilities of advanced satellite sensors in support of these operations. These data will enhance the performance of new environmental monitoring and prediction models for Antarctica and its surrounding sea ice and oceans. It will be important to maintain and extend the existing access to the international Polar View service, particularly to access products that relate to critical variables, such as sea ice thickness.

More frequent and higher resolution EOS information is needed from a large array of satellite missions to support the safety of recreational and commercial boating in inland and enclosed coastal waters as well as for shipping activities in coastal waters and on the high seas. The unique capacity of EOS instruments to measure sea state, sea surface temperatures, ocean currents, and surface wind fields over the ocean is already having a major impact on the planning of ship routes and safer marine operations. New generation EOS satellite data will enhance these impacts and further improve the predictive capacity of oceanographic models in support of marine operations.

Less dynamic but highly precise EOS information is required on coastal and offshore bathymetry, to help maintain accurate navigation charts for shipping activities on inshore and offshore waters and to help improve tsunami warning services for major ports whose operations in north-west Australia are especially vulnerable. A nationally consistent coastal and offshore bathymetry product needs to be developed and provided, along with the ability to update dynamic coastal regions.

The EOS needs for the safety and security of rail and road transport in Australia are less clearly defined. Both modes of transport are particularly vulnerable to the impacts of flash flooding, prolonged water inundation, and severe wind storms. Road transport needs to have good awareness of hazards such as fog, dust and bushfire smoke, which reduce visibility. Real-time positioning of vehicles and trains can improve safety in these cases, as well as achieve fuel efficiencies through controlling vehicle operation (acceleration/braking etc.) based on knowledge of position and accurate topography. The AuScope national GNSS infrastructure provides the basis for such systems. The safe transport of food can be greatly affected by extreme temperatures and heat waves. All these needs are addressed to varying degrees through the improved capabilities of the next generation of EOS missions.

There is a growing and ongoing need to build systems to deliver real-time access to all data sets, image and product archives for long-term analysis in support of all forms of transport operations and for the development of algorithms for the assimilation of new generation EOS data, especially the data supporting marine operations.

3.3.5 Energy and resources security

Australia needs to use EOS data more effectively to support the strategic development of its strong energy and resources sectors. These industries and associated government regulatory bodies need to have comprehensive specific environmental information to enhance industry development and to monitor the environmental impact of ongoing industry operations. All major developed countries are now reassessing their national EOS information needs in these sectors, especially those in relation to support for renewable energy. Australia's current support activities (described in Chapter 2) will need to be enhanced and require a national focal point of contact and for integrated advice to government and industry.

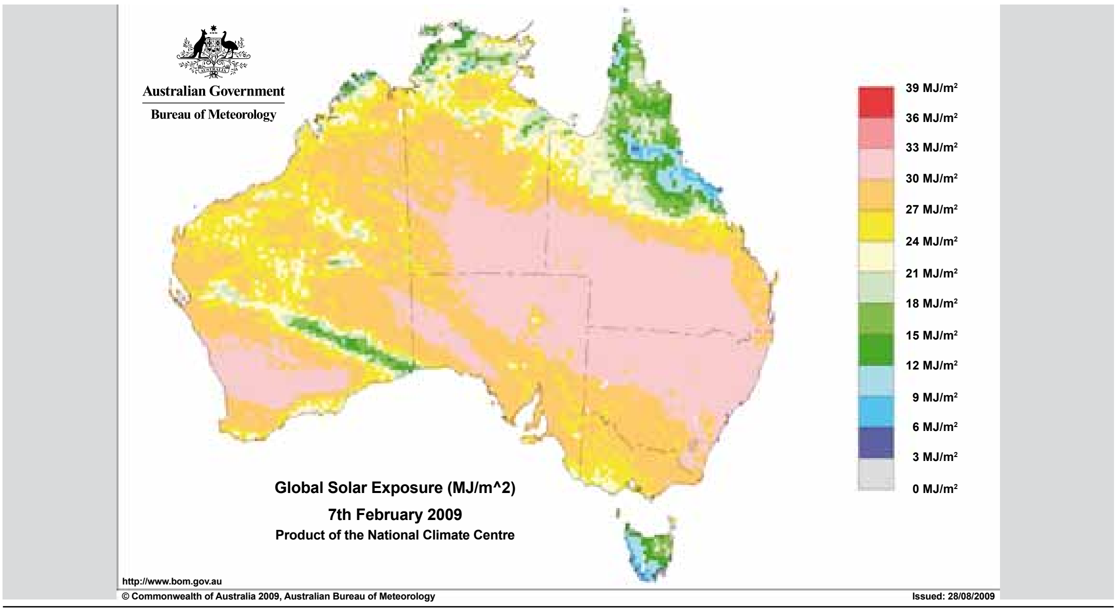

Figure 3.1: Solar power generators need to be located at sites with high and reliable sunlight. Climatological records based on regular satellite observations provide the data for such site assessment. This image shows a map of the global solar exposure across Australia on 7 February 2009, when there were bushfires in south eastern Australia and heavy rain in northern Australia. Global solar exposure is the amount of solar energy accumulated on a horizontal surface over a day. (The map was derived from satellite imagery processed by the Bureau of Meteorology from MTSAT-1R operated by JMA.)

The operation of wind and solar power generators require detailed knowledge of the simultaneous spatial meteorological observations of solar exposure, cloud cover, wind and temperature (see Figure 3.1). EOS data will increasingly contribute to improving the specification of the initial state of the structure of the atmosphere and its interaction with the Earth's surface, which is critical to determining the accuracy of environmental analysis and prediction models. The tailored output of these models should be sufficiently detailed and comprehensive to address some of the needs of the renewable energy sector in the immediate future and will improve over time.

The suite of new EOS missions will provide new information to assist with the assessment by regulatory authorities of atmospheric emissions from coal, oil and gas energy installations in Australia as part of the broader framework of future EOS applications for the monitoring of climate change. The new EOS data will also improve our disaster mitigation programs for protecting the physical security of our offshore oil and gas facilities on the Northwest Shelf, the Arafura Sea, and in Bass Strait.

Australian agencies are making arrangements to obtain priority access to a suite of new hyperspectral satellite sensors developed for use in the next generation of EOS missions. This will expand our national capability for the use of hyperspectral imaging for exploring the geological structure of the Australian region, including mineral, hydrocarbon and geothermal exploration, and will help identify areas suitable for geothermal and marine petroleum sources of energy. These hyperspectral systems will also provide much more specific geoscience information on such things as the abundances of specific minerals such as kaolinite and illite. A challenge for the future is the development of imaging satellite sensors that capture geologically-tuned wavelengths not currently measured by current or planned sensors, especially the longer thermal infrared wavelengths where diagnostic mineral information about quartz and other minerals is present.

Surface maps of minerals and structural features generated from advanced EOS systems can be used in mineralogy to identify resource-forming processes such as those associated with hydrothermal fluids passing through rocks. These mineral maps can also be integrated with subsurface drill core spectral-mineralogy data being assembled by the government geosurveys across Australia as part of the AuScope Virtual Core Library and, under a special project by the WA Centre of Excellence for 3D Mineral Mapping, will eventually be used to produce a 3-dimensional mineral map of the Australia continent. The ultimate challenge is to combine all of these data into in a quantitative mineral system analysis to better understand the geological evolution of the Australian continent.

3.3.6 Agriculture, forestry and ecosystems

Australia now has a substantial opportunity to build on its significant investment at national and state levels in developing the science and capability to integrate EOS data with in situ vegetation measurements and ecosystem models to better map, monitor and predict changes related to agriculture, forestry and ecosystems, as impacted by natural or human-induced factors. There is a renewed focus on environmental monitoring to understand and adapt to issues associated with climate change and to assess the effectiveness of management regimes and legislation. In part, this includes a wider recognition across resource management agencies that EOS image data and their derived products are important complements to ground data to map, monitor and understand these changes.

There is an urgent need, however, to continue to act strategically to maintain Australia's long-term access to moderate spatial resolution, multispectral image data. As a contingency to the 2003 failure of Landsat-7 and limited performance of the ageing Landsat-5, Geoscience Australia has established a formal agreement with the Indian Space Agency to enable IRS LISS data to be accessed at the ACRES ground stations, and is also closely linked into US discussions in terms of Landsat-data continuity. CSIRO and the DCC are also investigating the use of CBERS and Kompsat data from Chinese and Korean resource satellites, respectively. A joint project underway between the Queensland and New South Wales resource management agencies, the University of Queensland, GA and Landcare New Zealand has developed automated geometric, radiometric and atmospheric correction routines for application to the entire Landsat time series and will establish similar corrections for SPOT, IRSS and CBERS image data.

It will also be important to better engage with ESA in the planned GMES program as one of the missions, Sentinel-2, will begin to provide Landsat-type land-surface mapping information from about 2013 onwards. The proposed international CEOS Land-Surface Imaging Constellation represents a good start towards international coordination, and the relevant Australian government agencies now need to become much more formally involved in the process to provide funding and active implementation by national agencies.

The use of EOS data in spatially explicit plant productivity models, operating at local to continental and international scales, will continue to improve a number of ongoing operational agricultural, forest ecosystems and natural resource management systems used by local, state and national bodies and private agencies in Australia. An important transition to development and use of spatially explicit models is also occurring in all areas of natural, agricultural and social sciences, including local-scale population projections, urban growth models, predictive models of crop production, faunal distribution, hydrologic models, energy and hydrological flux models for urban areas, to name a few.

Specific agricultural and rangeland applications require regularly updated high to moderate spatial resolution images to support precision farming activities, in relation to crop condition assessment, yield forecasting, and harvest monitoring. Spatial information on the composition and structure of these environments will be essential to assist various management agencies in their attempts to understand how predicted climatic changes may impact our natural and built environments, and the processes involved.

New modelling applications will develop as nationally consistent data bases and long-term monitoring programs are better established through national level multi-agency projects, such as NCRIS, IMOS, TERN, AuScope, and the Water Resource Observation Network (WRON). These applications will feed into local, state and national projects to predict changes to climatic conditions, carbon emissions and sequestration, available water resources, available pasture resources, incidence of natural hazards, and available renewable energy resources. EOS data assimilation will also become more common, especially in the context of producing biophysical properties derived from remotely sensed variables such as vegetation physiology, vegetation growth, combustible fuel load and pasture condition. It is important that these national infrastructure programs continue to receive the necessary funding (including operating costs) in order to guarantee the essential longevity of the monitoring programs.

There is a major need to develop a set of nationally coordinated, calibrated and validated EOS-based data sets of specific biophysical parameters. A number of default national products have been developed but there is no standardised map of vegetation cover, biomass, Leaf Area Index (LAI) or other structural properties. Rangeland relevant parameters have been developed by state agencies in QLD, NSW, NT, SA and WA for pasture biomass, condition and grazing pressure, but there is no nationally consistent product. NCRIS TERN will initiate a system for defining spatial data sets with high levels of shared use across all states and a process for deriving and validating them. However, significant additional coordination will be required to identify required data sets, then to set up the mapping, calibration and validation programs.

There are some important national needs for the use of EOS data in Australia, in addition to those involving the application of high resolution spatial data sets. The agricultural and forestry sectors especially require better real-time climate information and short to seasonal time-frame climate forecasts of aspects such as soil moisture, land and lower atmosphere temperature and moisture, rainfall, frost, heat waves, droughts, and the relative dryness of forests and grasslands. This information is essential to determine optimal planting and harvesting time, to estimate seasonal crop yields, to protect livestock, and to take action to mitigate the effects of the sudden onset of plant diseases or bushfires.

The new generation of EOS data should be especially helpful in addressing these needs through the provision of more accurate, detailed and timely information in the form of improved, specially tailored and easily accessible products for the agriculture and forestry sectors. These could be in the form of maps identifying areas of threat and also through EOS enhancements to the performance of national environmental prediction models, with specially tailored outputs of sets of information for these sectors.

3.3.7 Coasts and oceans

EOS data are in many cases a critical source of information for detection, monitoring and trend analysis for the management of Australia's vast and highly dynamic expanses of coastal waters, benthic habitats (coral reefs and seagrasses) continental shelf and oceans. The multiple use and adaptive management of these environments require sound knowledge of past and present conditions across the many interacting issues, and the use of robust models to allow future impacts to be anticipated. Given the difficulty of observing in the marine environment and the many interacting time and space scales, the full spectrum of satellite remote sensing capabilities is required. Satellite and complementary in situ observations are essential components of the Global Ocean Observing System (GOOS), an important component of the Global Climate Observing System (GCOS) and the Global Earth Observation System of Systems (GEOSS).

The oceans play a central role in Australia's climate variability and change, in absorbing CO_2 and absorbing, transporting and releasing heat. The timing and regional impact of climate change is critically dependent on the oceans, and El Niño and positive Indian Ocean Dipole conditions increase the likelihood of drought in Australia. Other impacts come through global and regional sea-level rise. Improving our understanding of climate conditions, attributing observed changes in climate and predicting future climate are all critically dependent on ocean remote sensing capabilities.

The above climate and ocean weather conditions will impact both inshore and offshore marine ecosystems, including acidification of the oceans. Rising sea levels will directly affect coastal developments by changing the frequency and intensity of flooding events and the impacts of chronic coastal erosion. Addressing this challenge requires improved EOS observations and projections of the regional distribution of sea-level rise, and improved EOS data on the local environment (topographic and bathymetric maps, coastal vulnerability and the distribution of human and natural coastal resources).

Climate and human-induced impacts are likely to include shifts in phytoplankton functional types and algal blooms, increased coral bleaching events, impacts on calcifying organisms, more extreme rainfall events leading to increased extreme runoff events from catchments, impacts of changing catchment land and water use on ecosystem health and seafood safety, eutrophication, loss of amenity and coastal infrastructure development and shipping. Biogeochemical processes control the transformation, sources and sinks of nutrients and carbon, the primary production of organic matter by phytoplankton and benthic plants, and the consumption of organic matter by secondary consumers and detritivores. These processes underpin marine food webs which support shelf fisheries, and the spatial and temporal pattern of dominant plant and animal communities which structure benthic ecosystems.

Thus, physical and biogeochemical processes form the dominant cause and effect pathways between the major physical and chemical drivers of marine ecosystems, and the ecosystem services we value. The challenge for remote sensing is to detect and monitor as many of the variables (both causative and resultant) as possible, with the highest degree of reliability and the highest frequency possible. Some of these relationships are direct (surface temperatures, sea level, algal pigments, suspended matter, coloured dissolved organic matter) and some are through proxy relationships such as eutrophication assessment based on algal biomass and species.

Such issues can only be addressed through comprehensive and integrated measurement and modelling systems which must address a range of needs and spatial and temporal scales, from the highly dynamic (near real-time information on floods, river floodplumes, algal blooms, cyclone damage, coral bleaching, oil spills and related calamities) through specific project-based needs, to the accurate assessment of longer term trends (eg, changes in Great Barrier Reef lagoon oxygen content and changes in Southern Ocean ecosystems). With each change in temporal scale the emphasis shifts from fast data provision to reliable data provision with consequences for receiving infrastructure, calibration and validation, and fast or reliable data turnaround.

There is need for a seamless transition to the new ocean and coastal optical sensor systems that will replace the current ageing fleet of SeaWiFS, MODIS and MERIS sensors. These new sensors will challenge us in offering data from new providers (eg, China, Korea and Japan) at higher temporal frequency (VIIRS-NPOESS, SENTINEL-3), at higher spatial and spectral resolutions (HYSpIRI), and greater sophistication (ESA's Sentinel suite). Securing access to a wider range of data will be a challenge and there is an increasing need to secure and better exploit 15-minute 'snapshot' data from geostationary satellites to capture dynamic and episodic flooding events. The calibration and validation of primary geophysical (eg, radiance) and derived (water quality and ecosystem threat) products will be essential. Earth observation and its associated in situ measurement systems will need to be increasingly integrated into hydrodynamical and biogeochemical modelling systems as well as with other in situ measurement systems (gliders, UAV's, moorings, coastal observatories, smart sensor networks). Early involvement in the design and operational use (needing knowledge of detailed performance aspects) of new satellite sensor systems is crucial to guarantee intercompatibility and integrated use of these various data sources.

In open ocean waters, remotely sensed sea-surface height (altimetry) and sea-surface temperature are vital inputs into ocean monitoring and forecasting. This includes the highest accuracy missions (the Jason series of satellite altimeters) for sea-level studies (see Figure 3.2) and new missions such as SWOT for resolving smaller scale ocean circulation features, particularly those affecting the coastal zone. EOS data on surface conditions (currently surface temperature and, in the future, surface salinity) and air-sea fluxes (momentum, heat, freshwater) will become increasingly important. At present, little use is made in Australian studies of new information coming from improved knowledge of the Earth's gravity field (higher resolution geoids and time variable gravity) for both open ocean and near coastal studies.

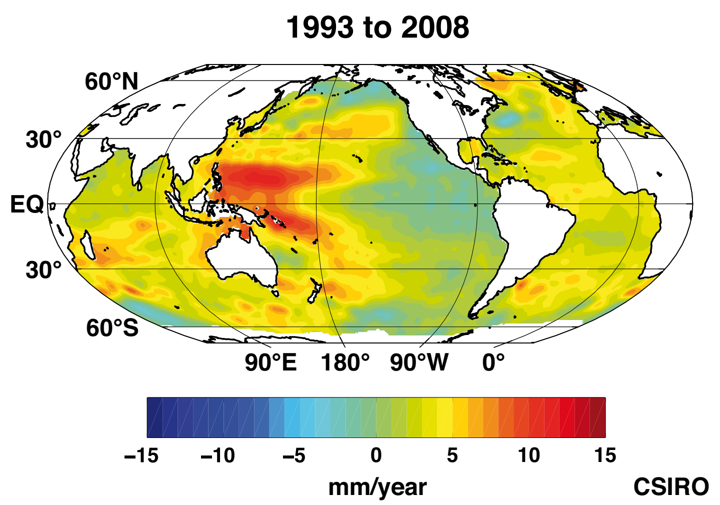

Figure 3.2: This image shows the rate of sea level rise since 1993 based on satellite data. While the average rate of rise is about 3.3 ± 0.4 mm/year, there is considerable geographical variability. High-quality measurements of global sea level have been made since late 1992 by satellite altimeters, in particular, TOPEX/Poseidon (launched August, 1992) and Jason-1 (launched December, 2001) and Jason-2 (launched June, 2008). (Image courtesy of CSIRO)

New satellite products and improved assimilation schemes of both satellite and *in situ* data will be important for operational prediction of surface wave conditions in the open ocean and in the near coastal zone. Satellite sea-surface temperature data will continue to grow in importance operationally, to direct fishing effort and warn of coral bleaching.

Ocean colour data are a particularly valuable source of coastal and deep water information, and data from ocean colour satellites have been routinely acquired since 1997. Standard international products such as chlorophyll a and light attenuation will continue to be of importance in Australia. Access to these products has been limited, and continued investment (from, for example, IMOS) is required to ensure that these products (and state-of-the-art SST products) are widely available. These products, combined with EOS data on atmospheric carbon concentrations, will be important for estimating ocean uptake of CO_2. However, these international standard products are regarded as valid only in ocean waters, where optical properties are not directly influenced by terrigenous inputs of inorganic sediments and coloured dissolved organic matter. In inshore waters, more sophisticated and robust physics-based algorithms, linked to *in situ* coastal observing systems (including specific calibration/validation studies), will be required to separate the contributions of algal pigments, suspended sediments and coloured dissolved organic matter. Concentrations of these constituents are all valuable indicators of coastal water quality. Robust algorithms of this type have been derived for the Great Barrier Reef, and the resulting ocean colour products are being used there to monitor water quality. The challenge, now, is to identify a practical strategy to roll out these methods at the national scale.

3.3.8 National security

The Australian government and the Department of Defence have given high priority to ensuring that Australia's space-based needs for national security purposes are met over the next 15 years, and that our space-based capabilities are upgraded to help provide Australia with superior combat effectiveness through enhanced situational awareness and decision-making, and to support Commonwealth and state authorities in carrying out national security functions. The sensors that can meet these needs can also assist with the other civilian challenges outlined in this section.

The government has now decided to improve Australia's intelligence collection capabilities by acquiring a satellite with a remote sensing capability, most likely to be based on high-resolution, cloud-penetrating, synthetic aperture radar. This will provide high-quality space-based imagery to support Defence's needs for mapping, charting, navigation and targeting data. This new capability will add to Australia's standing as a contributing partner within our alliance framework with the United States, which will be given access to the imagery collected by this system.

To complement this new capability, over the next 15 years Australia's national security authorities will still need access to EOS data from foreign-operated satellites in the public domain and therefore have needs for improved capabilities in common with those mentioned elsewhere in this chapter. In particular, this includes the need for better inter-calibration between multiple satellite sensors and for replacement, next generation sensors, and an expanded need for very high spatial resolution hyperspectral mapping capabilities and related applications.

Unfortunately, the recent initiatives will raise the profile of three major strategic threats to Australia's use of EOS, identified in the 2008 Senate Economics Committee Report: the impacts of space debris, space warfare, and threats to the use of the necessary parts of the radiofrequency spectrum.

3.4 The needs for systematic EOS data management

It is clear from all recent strategic assessments[13] and the working group's current assessment of EOS data requirements, that there is a major need in Australia to improve the systematic management of EOS data utilisation across all phases, from the initial data access to data processing and assimilation, research, operations development, and eventual transfer of processed information to users. In this context the major future needs are to:

- ensure continued access to a timely, regularly updated, and consistent stream of EOS data, covering Australia's atmospheric, terrestrial, urban, aquatic, oceanic and cryospheric environments, including Antarctica;
- ensure that all these data are calibrated for Australian conditions and that EOS mission-to-mission transition is managed in such a way that there is no disruption to the continuity of the growing number of major national and state-based environmental monitoring programs and data sets which are critically dependent on EOS information;
- ensure our capacity to transform EOS data to essential information is developed from the current few key areas in natural resource management, to a broader whole of government (including defence) solution;
- ensure that the highly specialised scientific activities for EOS data assimilation and management are adequately resourced and sustained;
- ensure greater effort and urgency in developing EOS-based operational systems and services to support Australia's national challenges in climate change, water availability, natural disaster mitigation, safe and secure transport, energy and resources security, agriculture, forestry and ecosystems, coasts and oceans, and our overall national security;
- ensure a nationally coordinated approach to preparing the Commonwealth and state level infrastructure for imminent major changes in the operation of the global EOS system; to improving the education and training of personnel; and to keeping policy and decision makers informed with respect to the current and future capabilities of EOS;
- strengthen the links, communications and support between current extensive state and national government agency EOS-based programs; this includes dissemination

of existing national EOS data sets held by government agencies such as GA's Landsat archive and CSIRO's AVHRR and MODIS data sets;

- sustain EOS strategic research and development programs which support the incubation of new techniques and technologies, and extend research systems and tools into operational systems, including enhanced education and training programs in all sectors of the community on the nature, value and specific use of EOS data in achieving socioeconomic benefits for Australia;
- ensure there is a coordinated national response to Australia EOS needs; and
- develop a process for setting national priorities for EOS activities, recognising the contributions from all levels of government, from educational and research institutes, and from the private sector.

3.5 The needs for education and training

Our own analysis, the 2008 NCSS findings, and recent assessments of the state of professions, and government and industry areas in Australia, all identify the lack of suitably trained personnel and educational programs at school and university levels for EOS activities and for engagement with international EOS training. The lack of a skilled workforce, coupled with no coordination between teaching, training and research programs with industry and government requiring these skills, has created a significant gap in the supply of entry and mid-level scientists, technicians and engineers with the necessary skills to collect, process and communicate EOS data.

There is no Australian university with a set degree program delivering graduates with the basic skills and knowledge necessary to build the EOS data-based applications required by government and private industry. Students may select individual subjects, but there is no defined undergraduate or postgraduate coursework program delivering students with these skills. There are several postgraduate research programs delivering these skills, but the fundamental undergraduate skill and knowledge base is missing. As a result, Australian agencies source the majority of their EOS personnel from overseas and do not have the capacity to force change in educational programs to fill this gap. Training and research expertise is concentrated in less than five facilities, with most Australian expertise at the senior levels.

There is no successional planning in place through relevant professional bodies such as the Surveying and Spatial Sciences Institute of Australia, to work with state and Commonwealth education agencies, and relevant maths, science, and geography teachers associations to build Earth observation-related science into school curricula. Similarly, there is no unified approach through universities to structure the content of their undergraduate, postgraduate coursework, and research training, to provide graduates with the skills, knowledge and professional networks to pursue a career in Earth observation-related science.

3.6 The EOS-related needs of industry and commerce

The future EOS-related needs of industry and commerce are a sub-set of the needs of Australia's space industry as a whole, which were examined in the 2008 Senate Economics Committee's review and the 2008 Cutler review of Australia's national innovation system,[14] and were addressed, in a narrower EOS context, in the 2006 Athena Global report.

It is crucial for industry and commerce to know whether or not Australia is going to have a national space agency or to become a nation that operates satellites in the near future, because these are widely perceived as focal points for industry development.

The 2006 Athena Global report suggested that in the absence of a national space agency the most promising opportunities for satellite data providers are in servicing the needs of end users of EOS data in the resource sector, public lands management and national security. In Chapter 2 of this report, we indicated that this is currently occurring in Australia in the spatial information service industry, mainly driven by the requirements of the Department of Defence, albeit on a tiny scale in comparison to the Senate Economics Committee's suggestion that the global space industry currently generates global revenues of around US$250 billion per annum.

The Senate Economics Committee noted that Australia's involvement in the space industry should be focused on niche areas and that Australian firms can make more commercial use of data from satellites. It recommended the gradual evolutionary development of an Australian space agency, without setting a specific target date for it, and commented that firms within the Australian space industry may be willing to contribute to it. As a first step, the committee recommended the establishment of a Space Industry Advisory Council comprising industry representatives, government agencies, defence and academics.

The working group believes that there is now reason for industry to be more optimistic about satisfying some of its future needs in the light of several significant changes that have occurred or whose occurrence is imminent:

- the government decision in the 2009–10 Budget to create a Space Policy Unit and an Australian Space Research Program;
- the Department of Defence announcement in the 2009 Defence White Paper that Australia will acquire a satellite for defence use with a remote sensing capability as part of broader action to upgrade its space-based capacity extending out beyond the year 2025;
- the clear signals from these two developments that Australia is moving towards a national space program of some type;
- the opportunities developing for various levels of Australian involvement in international partnerships for future EOS missions; and
- the assessments earlier in this report that there is a rapidly growing Australian community demand for real-time access to EOS data, that we are entering another period of major change in the science, technology and mode of use of EOS, and that we are facing an imminent flood of new information from Earth observations satellite missions which will have an impact on Australia's increasingly extensive activities in climate change and in seven other key national challenge areas where EOS data can have an impact.

3.7 Underpinning infrastructure, research and development

Australia is so dependent on observations from space and its future EOS needs are so critical and diverse, that it is absolutely essential to ensure we have a robust, well-coordinated national infrastructure for EOS data access and well-structured research and development programs focused on using EOS to help solve fundamental scientific problems and to assist in developing new systems for transferring information into easily accessible products to meet the needs of governments, industry, commerce and the broader community. It is clear from the handful of highly successful state and national programs using EOS data that national access to EOS data and the capacity to collect and process them for use in the country's information infrastructure, will be a transformational technology enabling Australia to develop leading sustainable resource science and management activities.

There is an urgent need for a detailed technical review of the adequacy and efficiency of operation of Australia's existing array of ground stations for the direct reception of EOS data in the light of the increasing data volumes and the management of priorities for acquisition of data satellites with overlapping pass times. This needs to be done in conjunction with a strategic assessment of the optimum design of the infrastructure for EOS reception in Australia in the light of the impact of the proposed global introduction of new modes of data access and delivery, and the impact of ACMA's strategies for managing the radiofrequency spectrum. These reviews should also address and specify the strategic requirements for fully supported maintenance of all elements of the national infrastructure.

Another key task in establishing how to best build Australia's EOS capacity to meet national and state needs is an identification and prioritisation of future EOS missions in which Australian agencies and institutions should become involved to address the national challenges identified in section 3.3 above.

The national EOS data access infrastructure needs to be supported by the regular upgrading of major shared supercomputing and high bandwidth communications channels to transfer and process the massive increase in data volumes expected from the next generation of Earth observing satellites and to support advances in environmental modelling. This needs to be done in conjunction with substantially upgraded EOS data processing, archive and access systems operated by several major Commonwealth and state agencies and satellite data consortia. All these facilities will need to be upgraded at intervals of no more than 3 to 5 years.

The key strategic EOS needs for the underpinning research and development programs are for high bandwidth internet connections between users of remote sensing data, model developers and distributed data archives, improved storage capacity allowing for data assembly and remote data servers, improved quality control and calibration of all satellite data sets, and greater computing capacity to allow for the assimilation of increasing volumes of complex data into high resolution environmental monitoring and prediction models.

3.8 Conclusions

The working group has concluded that Australia's major future EOS needs, opportunities and capabilities can be summarised, at a broad strategic level, as follows:

1 EOS has been clearly established as a transformational technology, enabling nations to establish comprehensive Earth observation programs to support national civilian and defence activities. Considering the geographical size of Australia, its surrounding expanses of ocean, and its interests in Antarctica, it is absolutely critical that we rapidly embrace this transformational technology, and fully engage in EOS applications to address our major national needs.

2 The global community is addressing future needs for Earth observations via an integrated, coordinated and consultative approach which aims to transfer the global benefits of observational science and technology to the community. Governments are taking a strong lead. Australia needs to align itself with this global approach that has been adopted by almost all other major developed countries. In the first instance, this requires the establishment of a national coordinating mechanism for the strategic planning of EOS activities.

3 The world is entering another period of major change in the science, technology and mode of use of EOS. Australia has a great opportunity to expand its current use of EOS information, and to benefit from the progressive introduction of a whole new generation of globally coordinated Earth observation satellite missions. The transition from the current to the new generation of EOS weather and climate missions has just started. It will be completed to some extent by about 2015 and then sustained and progressively modernised in the period 2015 to 2025 through increasingly harmonised global operations.

4 The next generation of Earth observation satellite missions addresses the key areas in the government's new Australian National Framework for Climate Change Science under which science must provide information to assist important decision making over the next decade. Amongst other things, space-based observations will provide critical information for the national regulation and monitoring of Australia's greenhouse gas emissions, and will assist in tackling major problems such as the Murray-Darling water management, the health of the Great Barrier Reef, the monitoring of sea ice and ice sheets, the monitoring and prediction of the impacts of sea-level change, and the development of more efficient solar and wind energy generation systems.

5 Access to, and extensive use of, the full spectrum of next generation satellite remote sensing capabilities are essential national requirements to support the understanding, monitoring and management of Australia's highly dynamic expanse of coasts, oceans and Antarctica. The accurate observation and understanding of ocean conditions is critical for initialising climate analysis models and for determining the (at present unknown) accuracy of their projections of climate change over Australia for 50 to 100 years ahead.

6 Australia has already invested significantly in building capacity to acquire these data and use them in legislated programs at state and national levels, but we are wholly dependent on other countries for access to suitable data.

7 Australia has some capability in whole Earth system modelling and spatial data analysis, which are essential to assimilate the next generation of Earth observation satellite data and convert them into products and services at all scales and for all sections of the community. We are, however, not well prepared to access and assimilate the flood of complex new data streams that will soon become available to improve the capabilities of these models. This problem needs to be urgently addressed or Australia will lag well behind other developed countries in the uptake of this important new environmental data essential for the monitoring and prediction of the Earth system.

8 The Australian EOS user community is extensive at national and state government levels, and is becoming increasingly more sophisticated and is demanding access to more and more information in real time. Web-based services, user interfaces and communications bandwidths need to be upgraded and improved in parallel with the improvements being made to environmental modelling and spatial data analysis. The ongoing development of all these aspects needs to be adequately resourced.

9 There is an urgent need for a strategic national assessment of the optimum design of the infrastructure for EOS reception in Australia in the light of the impact of the proposed global introduction of new modes of data access and delivery, and the impact of ACMA's strategies for managing the radiofrequency spectrum. This assessment should also address and specify the strategic requirements for fully supported maintenance of all elements of the national infrastructure.

10 The national EOS data access infrastructure needs to be supported by the regular upgrading of major shared supercomputing and high-bandwidth communications channels to transfer and process the massive increase in data volumes expected from the next generation of EO satellites and to support advances in environmental modelling.

11 There is now good reason for industry to be more optimistic about satisfying some of its future needs in the light of several significant current and imminent developments associated with the government's 2009–10 Budget decision to create a central Space Policy Unit and an Australian Space Research Program, the plans for the Department of Defence's substantially upgraded space-based capabilities, the new opportunities for various levels of Australian involvement in partnerships for future Earth observation satellite missions, and the new period of major change in the science, technology and mode of use of EOS which we are now entering.

12 The major threats identified in the 2008 Senate Economics Committee's review of Australia's space science and industry become increasingly significant as Australia becomes more dependent on EOS to address key national challenges, especially with respect to climate change and national security. These threats are from the impacts of space debris, space warfare, and threats to the use of the necessary parts of the radiofrequency spectrum. There is an additional ever-present threat from the disruption to satellite operations by space weather events.

13 Accurate and timely scientific observations form the basis of almost all scientific research as well as the development of new systems and services to improve the prosperity and operation of our society. To use EOS to address our critical national challenges, we need to ensure that Australia has continuing access to a timely and consistent stream of EOS data that are calibrated for Australian conditions and that EOS mission-to-mission transition is managed so that there is no disruption to the continuity of national and state-based programs and data sets which are critically dependent on EOS information. We also need to ensure that Australia's capacity to transform EOS data to essential information is developed from the current relatively few key areas in natural resource management to a broad range of applications.

Notes

[1] There is still some work to be done in terms of measuring mean sea-level pressure from space and determining a final specification for soil moisture measurement. Discussions are also continuing about specification of the characteristics of a climate satellite.

[2] Ward (2008).

[3] Group on Earth Observations (2005).

[4] Group on Earth Observations (2007).

[5] The GCOS Steering Committee has defined more than 40 Essential Climate Variables (ECV) in the atmosphere, ocean and land domains.

[6] Department of Climate Change (2009).

[7] The Hon. Kevin Rudd, quoted in *National Framework for Climate Change Science*. DCC (2009) op.cit.

[8] Moodie et al (2007).

[9] GCOS Steering Committee (2009).

[10] Leblanc et al (2009).

[11] European Union (2007); Liebig (2007).

[12] Kozawa and Kaku (2007).

[13] See references cited in footnotes 2, 3 and 4 in Chapter 2.

[14] Cutler (2008).

CHAPTER 4: **STRATEGY FOR THE NEXT DECADE AND BEYOND**

This chapter elaborates the main strategic issues identified by the working group and suggests the essential elements of a national strategy to set Australia on a sound course for the provision and application of EOS data in support of national needs and priorities, and full participation in the international EOS effort by 2025. It identifies a strategic goal, eight strategic objectives and seven major strategies designed to strengthen Australia's capabilities to fully utilise EOS information in support of major national challenges.

4.1 Major strategic issues

In developing a national strategic plan for EOS, it is necessary to consider Australia's future needs for EOS and the opportunities and threats identified in Chapter 3, in the light of a large number of strategic issues which will bear on our ability to meet the identified needs over the next 10 to 15 years. The working group has concluded that the following seven major strategic issues need to be explicitly addressed in such a plan.

4.1.1 National policy framework for EOS

The overarching issue in respect of Australia's future access to, and application of, EOS is the establishment of the essential overall national policy framework for EOS which has been conspicuously and damagingly absent in the past. Governments have traditionally viewed Australian space engagement primarily from an industry perspective. The significant public interest and public good aspects of EOS have been viewed as the responsibility of the various individual Commonwealth and state government departments and agencies with Earth observation and application mandates. For the most part, their EOS activities have been established and maintained within the context of their broader Earth observation and/or service responsibilities and budgets. Government support for the space sector has included industry, science and innovation policies and related programs such as the National Collaborative Research Infrastructure Strategy (NCRIS) and the research programs and related industry associations of CSIRO, Cooperative Research Centres (CRCs) and universities. There has, however, been no overarching policy framework linking space science and Earth observation.

The establishment of the Australian Space Science Program through the 2009–10 Budget provides the essential context for the development and consolidation of a national policy framework for EOS. It should now be possible to develop a policy framework to define: national needs and priorities for EOS applications; the role of science, technology, innovation and industry in addressing these needs; national contributions to global EOS activities including Australia's contribution to GEOSS; and guidelines for managing the overlapping Commonwealth-state interests in EOS exploitation for their communities.

The Australian Space Science Program should stimulate local industry and provide a national focus for both public and private sector activities. This process should also help define Australia's international role in EOS programs. A more strategic engagement with the international space science and Earth observation communities is essential for Australia to benefit optimally from overseas satellite programs.

The prospects for a coordinated national policy framework for EOS are also increased through the recent defence initiative to invest heavily in space-based technology, including the funding of a satellite. The current investment in both defence and civil EOS provides an opportunity to introduce dual-use technology, where space-related infrastructure is applicable to both defence and civil stakeholders. This approach has been successfully used in countries such as Canada and Italy, and it is seen as a means of achieving efficiencies in the development and exploitation of infrastructure.

The invigoration of both defence and civil EOS activities opens the way for the development of vitally important synergies and a new over-arching policy framework which links policies governing Australia's global and regional roles in international EOS programs with national policies relating directly to Australia's community needs and priorities. The framework should also underpin the gradual development of a dedicated national space agency as the key step towards Australia emerging as a strong influence in international space science and technology more generally. The Canadian Space Agency (CSA), which operates under the Canadian Space Agency Act of 1990, could provide a model for the full development of a national space program that delivers social and economic benefits to Australia, especially those from space-based Earth observations.

4.1.2 National priorities for EOS

National priorities are essential to guide Australia's limited current investment in EOS and to concentrate Australia's efforts to gain access to those space capabilities that most directly relate to our current and future needs. Authoritative statements of national priorities are necessary for governments to make informed decisions on the choices between the many options they are faced with every year, and are also needed to guide industry, commerce, public-sector service agencies, and research and educational institutions in the development of specific program and project plans which involve EOS data and products. Without national priorities, Australia cannot effectively progress an agenda for improved outcomes from space science in general and from space-based Earth observation in particular.

A rigorous process is required to build and maintain an agreed set of national priorities for the acquisition and use of EOS. These priorities need to be reviewed regularly and must have a long-term outlook (at least 10 to 15 years) reflecting the lead times associated with the science and infrastructure of space-based systems. The priorities for EOS should be assessed in terms of their potential to contribute to Australia's evolving national challenges, especially those identified in Chapters 1 to 3.

Under the Australian Space Science Program, the Australian Government Space Forum (AGSF) supports a whole-of-government dialogue on space science. In developing national priorities, structured input is essential from across the private and public sectors. There is also an important potential role for the learned academies to play in the priority-setting and review process and the subsequent channelling of advice to the Chief Scientist, the Chief Defence Scientist and the government generally. A national EOS priority development mechanism is needed, possibly along the lines of the model operating in the USA.[1]

4.1.3 EOS data infrastructure

The infrastructure required to collect EOS data for use in Australia comprises the ground stations for direct data reception from satellites, the facilities for processing, storing and retrieving the data, and the associated communications systems for transfer of EOS data and products within Australia and internationally. This infrastructure needs urgent modernisation and rationalisation to cope with at least a million fold increase in EOS data volumes over the next decade and to respond to expected major changes in the operation of the global EOS data access and distribution system within the next 5 years. It will need periodic review and upgrade at approximately 5-year intervals thereafter as Australia becomes increasingly more dependent on rapid access, processing and distribution of EOS information.

Traditionally, Australia has relied on its ground stations to collect EOS data which are required for immediate use (such as weather satellite imagery and atmospheric vertical profiles), for very high spatial resolution purposes (such as the imagery used for various mapping programs), and for specialised research purposes (such as experimental data from EOS research missions). Increasingly, however, EOS data are being accessed internationally via the internet. For example, much of the EOS data used in numerical weather prediction systems is now accessed in an acceptable time frame via the internet or via specialised international meteorological data links.

Data from Japan's next generation geostationary meteorological satellite, due for launch in 2015, will only be accessible from a website operated by the Japan Meteorological Agency (JMA). Planning for several other major system changes is also well underway. China plans to provide the Asian hub of the GEONETCast system which will provide a cheap way of delivering EOS data and products directly to Australian users who do not necessarily need specially tailored or much higher resolution information. Major global and regional data processing and distribution centres are being planned around the world, linked and accessed via very high speed internet channels and via communications satellites.

As well as developing strategies to cope with the changing mix of ground station and internet data reception, Australia will need to utilise its expertise and infrastructure capacity in very high-speed communications and supercomputing to modernise and improve the efficiency of its national EOS data transfer systems, its data processing and archival systems, and its web-based access services. Australia has the technological capability to build and host a regional EOS data processing and distribution centre which would also provide major benefits for national services.

4.1.4 Strategic research and education to support operational EOS activities

Strong national capabilities in EOS strategic research are required to optimise the benefits from existing operational EOS systems in industry and government agencies and to enable these systems to be tested, refined, combined with new research tools, and developed into future generations of operational EOS systems. These strategic capabilities need to be based on research programs involving theory, simulation, data assimilation, and the design and construction of instruments and space hardware.

These strategic capabilities and associated research programs need to be sustained between periods when new EOS systems are developed and deployed. One aspect of this is the incubation and support of new techniques and technologies, while another is the extension and development of research tools into operational systems. Both involve long term and competitive support programs for industry, research and education facilities and other stakeholders in Australian EOS capability.

Given the low level of Australian investment in these areas over recent decades, it will be necessary to establish and maintain a critical mass and viable capability in the research and development of EOS science and technology and in systems that enable Australia to achieve its national requirements and complement and leverage the capabilities of our international partners. International engagement will be extremely important. The process will also need to include a comprehensive program in secondary and tertiary education to ensure that the EOS industry is underpinned by a workforce with appropriate training in science and mathematics.

Several mechanisms could be applied to achieve these goals. One is to create virtual centres of excellence or academic-government-industry partnerships, partially funded by the ARC, industry, and government stakeholders in EOS. A complementary approach that recognises the strong national security benefits of EOS is to fund a civilian version of the Rapid Prototyping and Development (RPD) process of the Department of Defence. A third approach is direct funding under the Australian Space Science Program, which includes both Space Education and Development Grants to support secondary and tertiary education and Space Science and Innovation Project Grants to promote collaborative research. The ARC's new Super Science Fellowship program and its existing National Competitive Grants Program will also provide opportunities to support EOS research.

4.1.5 Australia's EOS industry capability

The EOS industry in Australia is composed mainly of small and medium enterprises engaged in data acquisition and sales, data value-adding, and consulting on interpretation and use of information products. There is only a small amount of work on sensor design and development. The past approach of allowing market forces to determine the development of the sector has led to an industry that is chronically under-funded and very dependent on ephemeral government agency contracts. In other countries, governments seek to correct such market failures by providing subsidies for local development of advanced technologies through assured EOS purchases, credit guarantees and R&D tax concessions or grants.

As part of the Australian Space Science Program, the Space Science and Innovation Project Grants program provides for grants of up to $5 million for projects involving consortia with at least one industry partner. This program should provide a foundation for further development of the EOS industry in Australia needed to underpin our enhanced participation in the international Earth observation satellite community. The critical driver for industry and commerce, however, is to provide some certainty that Australia is moving strategically towards a significant level of national engagement in the construction and operation of satellite systems and in the EOS missions which provide essential data and services for the Australian community.

4.1.6 Radio spectrum requirement for EOS

Certain key frequencies in the radio spectrum, determined by the laws of physics and the basic properties of matter, are uniquely capable of application, through EOS instrument technologies, for observation of particular characteristics of the Earth's atmosphere, ocean and land areas. Other permanently allocated radiofrequencies are also needed to optimise the downlink of EOS data to ground stations. The 2008 Senate Inquiry into Australia's space science and industry identified the increasing difficulty now being experienced in securing the necessary access to the essential parts of the radiofrequency spectrum as one of the major threats facing Australia's access to EOS in the next 15 years.

The radio spectrum is a finite resource which must be shared by all users. Use of the spectrum is regulated by international and national authorities. Australia's regulator is the Australian Communications and Media Authority (ACMA) which is tasked with balancing the conflicting requirements for spectrum use as new devices are introduced for national security, commercial and public-good purposes. ACMA collects considerable revenue from spectrum licensing.

ACMA recently published a detailed spectrum demand analysis for 2009–13[2] which, in part, addresses spectrum use for space science services. This deals with radio astronomy (including the Canberra Deep Space Communications Complex; the CSIRO facilities at Narrabri, Parkes, and Mopra; and the University of Tasmania's facilities at Mt Pleasant and Ceduna), Earth exploration satellites (including EOS ground stations operated by BoM, GA, CSIRO and the Australian Institute of Marine Science (AIMS)) and space research services which communicate with space stations. It also considers the needs of possible future services such as GEONETCast and the Square Kilometre Array (SKA).

ACMA recognises that, because the space science sector delivers community benefits that are difficult to quantify financially, it is vulnerable to pressure from commercial users seeking to takeover allocated frequency bands for purposes such as the use of mobile phones and radio telephony. ACMA's solution is to encourage satellite Earth station operators to relocate to areas where spectrum demand is likely to be low. ACMA notes that the costs of doing this may be prohibitive to operators or might reduce their ability to provide scientific services that could be of great value to the community, but it is still strongly advocating relocation as a solution. One such Australian EOS facility which is currently being targeted for relocation is shown in Figure 4.1.

Figure 4.1: The Bureau of Meteorology's EOS satellite ground station facility at Crib Point, about 40 kilometres from Melbourne, which is targeted for relocation due to competing radio spectrum demands. This complex, established in a safe, low interference area in 1992, contains a critical tracking station for the operation of China's FY-2 geostationary meteorological satellite missions which are of immense importance for public forecasting in China and in the Asia-Australia region more generally. The complex also has ten satellite downlink antennae for data supporting Australia's weather and climate services. There would be substantial relocation costs (including capital and land acquisition costs) and the incremental operating costs of high speed, high bandwidth data communications from a more remote location. (Photo courtesy of Bureau of Meteorology)

Finding ways of permanently protecting for public purposes the essential Earth observing 'fingerprint of nature' frequencies and of funding the relocation of key public facilities, such as shown in Figure 4.1, represents one of the key challenges for Australian EOS policy over the next 10 to 15 years.

4.1.7 Australia's global and regional roles in EOS programs

Over the next few years, Australia is preparing to take a lead role in, and to make commitments to, international plans and action to reduce global carbon emissions and to deal with other aspects of the global, regional and national monitoring, mitigation of, and adaptation to, climate change, all of which will involve the extensive use of EOS data. Australia will also be a party to Ministerial Earth Observation Summit reviews of the 2005–15 GEOSS Implementation Plan at which stage it may be necessary to commit to Australia's role in an essential ongoing framework for international cooperation in integrated Earth observation.

From the regional viewpoint, Australia engages with our Asian neighbours to the north and west, and with our Pacific neighbours to the east, but there are stark contrasts in the way in which these two groups of neighbours are serviced by EOS programs. On the one hand, six of our Asian neighbours (China, India, Japan, Thailand, South Korea and Russia) already have their own national EOS satellites whose coverage includes large parts of Asia and Australia, and Indonesia now has launch facilities and plans to operate a satellite in 2014. On the other hand, none of our South Pacific neighbours operate national space programs and thus are entirely dependent on provision of EOS from the global system operated by foreign countries, principally by Japan, the USA and the European Union.

Enigmatically, Australia is more aligned with its economically and technologically weaker Pacific neighbours as a dependent user of EOS data and has not, so far, chosen to join the more economically developed countries in our region in sharing the costs of contributing to the provision of EOS missions within a global or regional system.

Australia could greatly enhance its international influence, its global and regional roles in EOS programs, and its own overall national benefits, by entering into partnerships or consortium arrangements in which we contribute, say, a satellite sensor, or make a modest financial contribution to sharing the costs of new missions which have a global impact but which also directly support Australia's special national needs and priorities. Under current international arrangements involving clusters of micro-satellites and the hiring of launch facilities, this form of engagement is becoming much more cost effective than in the past.

With many other countries much less well positioned than Australia now sharing the costs of provision of EOS as a global public good, there are reasons for serious concern as to how much longer the international community will accept Australia's historical free-rider status on the global EOS systems.

It is now well within Australia's economic capacity to undertake collaborative activities with regional and other international partners, as evidenced by the initiatives of the Department of Defence outlined in the 2009 Defence White Paper. This initiative could be taken up, to great national benefit, through the development of closer synergies between Australia's civil and defence EOS activities. Strategic partnership opportunities are available with many foreign space agencies, including NASA, ESA, JAXA and ASI and agencies of our six Asian neighbours referred to above. These partnerships need to be established now, before new EOS missions are formally approved by the host nations. Because of the long lead times in satellite mission planning and actual launch and operations, Australia will only benefit from the resulting operations in the period beyond 2015–20.

4.2 Strategic goal

As summarised in Chapter 2, Australia has been very effective in the past as a user of EOS but not as a provider. And, as noted in Chapter 3, the global volume of EOS data will increase by at least a factor of a million over the next decade, as countries invest in the global EOS system to ensure their own individual access to EOS in order to understand and address a wide range of challenges confronting modern societies. It is clear that, for Australia to gain a significant and influential role in international EOS forums and even to assure continuing access to essential existing data, it is now urgently necessary for us to become a provider as well as a user of EOS. We need to do this in a way which focuses on our own special needs while contributing also to the robustness and effectiveness of the total international system on which we, and all other countries, increasingly depend.

The working group believes, therefore, that the goal of Australia's EOS strategy for the next decade and beyond should be set down in clear and comprehensive terms as follows:

STRATEGIC GOAL

To maximise Australia's social, economic and environmental benefits from the acquisition and application of Earth observations from space (EOS).

4.3 Strategic objectives

The strategic objectives of a national plan should be strongly focused on maximising the use of EOS information to address challenges of major significance to Australian society and the national economy. The strategic objectives for the next decade should also be framed within the context of expected developments in EOS science and technology and in Australia's capabilities to exploit them up to 2025 and, as far as possible, for the decades beyond.

For at least the next decade, the working group believes that the national strategic plan should ensure that Australia has the capabilities to provide the essential ongoing EOS services to the nation in areas such as weather forecasting and national mapping as well as to address the eight key challenges elaborated in Chapters 1 to 3. Thus the working group proposes the following set of strategic objectives for EOS in Australia:

STRATEGIC OBJECTIVES

To use the critical value adding input of EOS to help Australia to:

- monitor, understand and predict climate change and variability, to assess the impacts of climate change, and to develop strategies to mitigate and adapt to climate change on national, regional and global scales;
- monitor, understand and predict the water balance across Australian catchments in order to optimise the management of water;
- monitor natural disasters and to develop strategies to manage and mitigate the impacts of natural disasters in the Australian region;
- monitor and predict weather and other environmental factors in order to ensure the safety and security of Australian transport systems on land and sea and in the air;
- assess sites for renewable energy sources and to predict weather and climate conditions relevant to overall load management and to expected energy demand in Australia;
- monitor, manage and plan agriculture, forestry and natural ecosystems in Australia;
- monitor, manage and predict the environment of the coasts and oceans around Australia; and
- monitor Australian borders and to assure national security.

4.4 Strategic initiatives

The working group has identified seven major strategic initiatives designed to strengthen Australia's capabilities to fully utilise EOS information in support of the strategic objectives outlined above, and to help Australia move towards full participation in the international EOS effort by 2025. These initiatives, which address, seriatim, the seven strategic issues identified in section 4.1, are summarised below:

STRATEGIC INITIATIVES

- Develop and implement a new overarching national EOS policy framework.
- Develop a mechanism to assess and review national EOS strategic priorities.
- Develop a national approach to optimising Australia's EOS infrastructure.
- Establish a critical mass of strategic EOS research and education capability.
- Enhance industry capability to support an increased Australian role in global EOS.
- Safeguard essential EOS use of the radio spectrum.
- Establish international partnerships in EOS provision.

These seven individual strategic initiatives are elaborated upon briefly below, along with the specific actions recommended by the working group to ensure their effective implementation.

4.4.1 Develop and implement a new overarching national EOS policy framework

This is the key enabling strategy. Policy development should build on the recent establishment of the Australian Space Science Program and the Government's decision to invest heavily in space-based technology for strategic defence purposes. The overarching policy framework should define:

- national policies for Australia's strategic engagement with the international community;
- national policies for the acquisition and use of EOS to support the national challenges;
- the role of science, technology, innovation and industry in addressing these challenges;
- national contributions to global EOS activities, including our contribution to GEOSS;
- guidelines for managing Commonwealth-state interests in EOS exploitation; and
- potential synergies from defence and civil acquisition and use of EOS information.

The working group recommends, therefore, that:

An Australian government policy on space science and industry development should include an explicit national policy on Earth observations from space (EOS) based on strengthening, broadening and coordination of existing EOS activities and strategic commitment to full Australian participation in the international EOS system by 2025. **(Recommendation 1)**

4.4.2 Develop a mechanism to assess national EOS priorities

The development of this mechanism should be guided by the Australian Government Space Forum (AGSF) with support from the Australian Space Science Program. Dialogue and structured input are essential from across the private and public sectors, and especially from the learned academies.

A rigorous rolling review process should be developed. The priorities for EOS should be linked to major national challenges facing Australia's society, economy and environment (as reflected in the strategic objectives identified in section 4.3 above) and should have a long-term outlook (at least 10 to 15 years) reflecting the long lead times associated with the planning and launch of new space-based systems. The foreign satellite missions of special relevance over the next 15 years should be identified and assigned a level of national priority and scheduling for support. The scope of EOS needed to address the key challenges facing Australia is very broad, and there will be overlapping requirements that will need to be optimised on a national basis.

The working group recommends, therefore, that:

A high level, cross-portfolio EOS advisory council should be established with the active involvement of the national EOS provider agencies, the learned academies and the EOS user community to advise on national priorities for EOS operations, research, education, and applications across all sectors and all levels of government. **(Recommendation 2)**

4.4.3 Develop a national approach to optimising Australia's EOS infrastructure

As the amount of EOS data increases and the means of communication, data processing, archival and service provision evolve, it will be important for Australia to have formal processes to ensure that the government's substantial investments in EOS infrastructure continue to be optimised, while the mission-related needs of the Commonwealth and state EOS service provider agencies continue to be met. The first step towards developing this approach needs to be taken immediately via coordinated action by all major Commonwealth civil and defence EOS data capture agencies, the two Commonwealth/state/university ground station consortia, and the major commercial entities currently engaged in EOS data capture, processing and distribution.

The working group recommends, therefore, that:

The main operational EOS agencies and ground station consortia should jointly establish a coordinated approach to strengthening and optimising the national investment in EOS data acquisition, processing, archival, distribution and applications infrastructure that will be needed to handle the massive increase in EOS availability and user needs over the next decade. **(Recommendation 3)**

4.4.4 Establish a critical mass of strategic EOS research and education capability

These strategic capabilities need to be based on EOS research programs involving theory, simulation, data assimilation, and the design and construction of instruments and space hardware, underpinned by a comprehensive secondary and tertiary education program to ensure that Australia's EOS workforce contains sufficient people with appropriate training in science and mathematics. Various strategies should be used to achieve this, including:

- the creation of virtual centres of excellence or academic-government-industry partnerships, partially funded by the ARC, industry, and government stakeholders in EOS;
- the development of a civilian version of the Rapid Prototyping and Development (RPD) process of the Department of Defence; and
- support for EOS secondary and tertiary education and for collaborative research initiatives via the Australian Space Research Program, the Cooperative Research Centre Program and the new ARC Super Science Fellowship program.

The working group recommends, therefore, that:

A national plan and funding framework should be developed to establish and maintain a critical mass of strategic research and education expertise in Australian universities to underpin the operational EOS systems, services and applications in industry and government agencies. **(Recommendation 4)**

4.4.5 Enhance industry capability to support Australia's global role in EOS

Current EOS industry capability must be progressively enhanced in order to underpin the proposed strategic move for Australia to become an established EOS provider and global contributor by 2025, as well as continuing to be a major user of EOS capabilities. The first step should be to expand the Space Science and Innovation Project Grants scheme with a specific EOS focus within the framework of a new national space policy. This will need to be followed by further action to stimulate industry, as the government's long-term strategic objectives for EOS provision and use become more clearly defined. The strategy of allowing market forces to determine the nature and scope of industry support for EOS has been found in other countries to be inadequate for meeting the national needs.

The working group recommends, therefore, that:

In order to support a strengthened Australian role in the global Earth observation satellite community, the Space Science and Innovation Project Grants scheme should be enhanced within the framework of the National EOS Policy to promote local industry capabilities in EOS systems development and applications. **(Recommendation 5)**

4.4.6 Safeguard essential EOS use of the radio spectrum

While the radio spectrum issue is recognised as a global threat to EOS operations and is being addressed internationally through GEO and various United Nations system channels, the particular Australian issues which relate to securing the essential parts of the radio spectrum for the operation of satellite-based remote sensing instruments and to the threat of costly relocation of satellite ground stations, should be taken up, as necessary, at the highest levels of government. The additional costs of relocation of EOS facilities to maintain this essential public good in the face of competing commercial pressures cannot be absorbed within the operating budgets of the provider agencies.

The working group recommends, therefore, that:

Given the enormous social, economic and environmental benefits to Australia from the use of EOS data, those parts of the radio spectrum that are uniquely required for satellite remote sensing of atmospheric and Earth characteristics should be permanently protected from interference, in the public interest. Means should also be found for meeting the costs of commercial sharing of those parts of the radio spectrum that are used for public-good transmission of EOS data from satellites. **(Recommendation 6)**

4.4.7 Establish international partnerships in EOS provision

The most cost-effective means for Australia to grow its scientific and technical expertise in EOS, and to stimulate Australia's EOS industry and commerce, is likely to be through partnerships in missions with the space agencies of other countries. There are important partnership opportunities with countries such as the USA, China and Japan, as well as the European agencies such as ESA and EUMETSAT, upon whose EOS missions Australia is now heavily dependent. But the rapid development of satellite and remote sensing capabilities in Asia, as well as the close economic links between Australia and Asia, suggest that partnerships with neighbouring countries in Asia will also be mutually beneficial investments. While developing cooperative partnerships with regional neighbours, it will be important to ensure that Australia continues to play its role in global forums, such as GEO, which ensure global consistency and efficiency of EOS systems, and to take up available opportunities for mutually beneficial bilateral partnerships with other satellite providers.

The working group recommends, therefore, that:

Australia should strengthen its role and influence in international EOS through development of bilateral and multilateral (including regional) partnerships in EOS provision, greater involvement in the Committee on Earth Observation Satellites (CEOS), and enhanced contribution to the implementation of the Global Earth Observation System of Systems (GEOSS). **(Recommendation 7)**

4.5 The long-term perspective

The strategy outlined above is designed to secure Australia's ongoing access to the international EOS system and to better focus its capabilities on Australian-specific needs for EOS information. It is intended to strengthen and broaden Australia's existing EOS utilisation capabilities, to strongly focus the use of EOS to help address major national environmental and economic challenges, and to improve the coordination of institutional activities and programs by about 2015.

This will put Australia in a much stronger position to utilise the substantially better observational capabilities of the next generation of EOS satellite missions expected to have been launched by 2015. It will also provide a sound foundation for a strategic commitment to full Australian participation in the international EOS system and the establishment of a comprehensive national space agency before 2020, by which time Australia should at least be an operating partner in one or more satellite missions whose benefits are more specifically tailored to Australia's special national needs.

Consequently, Australia should then be well positioned to take further evolutionary strategic steps towards meeting its challenges for the remainder of the 21st century. The government is already thinking well beyond 2025 in terms of our strategic defence plans and Australia's commitments to global carbon emission reduction targets. Scientists are thinking well beyond 2050 in terms of the predictive time scales for the impacts of climate change in Australia for which the nation must prepare.

The critical success factor for the implementation of this strategy will be the extent to which governments and major policy advisors recognise that EOS are the single most important and richest source of environmental information for Australia, enabling a wide range of essential services to the community with multi-billion dollar annual benefits to the nation as a whole.

Notes

1 US National Academies Space Studies Board (2007).

2 Australian Communications and Media Authority (2009), pp 97-105.

CHAPTER 5: **IMPLEMENTATION OF THE STRATEGY**

This chapter suggests appropriate institutional responsibilities and coordination arrangements to implement the strategy outlined in Chapter 4. It briefly reviews the current EOS-related institutional arrangements and proposes some evolutionary changes and a phased implementation schedule to underpin the gradual emergence of a dedicated national space program and space agency as a platform for Australia's further development of its EOS role beyond 2025.

5.1 Current institutional arrangements

Historically, national responsibility for EOS-related activities in Australia has resided with four main Commonwealth institutions (the Bureau of Meteorology, Geoscience Australia, CSIRO and the Department of Defence) each of whom has major ongoing needs to acquire and use EOS data in support of their respective national charters and statutory responsibilities. This has created four main foci of EOS activity in Australia: weather and climate; mapping, mineral exploration and land use; multidisciplinary research; and national security and border protection. All four foci collectively support natural disaster mitigation and a number of other cross-cutting national objectives. A fifth focus (EOS industry and commerce) emerged quite early but has remained much weaker due to the absence of the driving force of a substantial national space program.

This historical institutional framework remains strong, but with the expanded use of EOS data in many other application areas over the past 20 years, and the concurrent major upsurge of activity relating to climate change, ecosystems and the environment, the current organisational arrangements now involve a large number of Commonwealth and state government departments and agencies, universities, CRCs, and various consortia. Most of these organisations are dependent users of EOS data and products, for research or for the provision of major public interest service programs. Only a few are involved in systematic data capture and high-level international engagement in EOS activities. The Department of Innovation, Industry, Science and Research (DIISR) is the Commonwealth agency with formal responsibility for civil space matters.

5.1.1 Space engagement and space science policy

DIISR administers Australia's space engagement policy whose three major components relate to communications and broadcasting, global navigation satellite systems, and Earth observation. DIISR also administers a comprehensive space safety regulatory regime under the *Space Activities Act 1998* and related *Space Activities Regulations 2001*. From 1996 until 2009 the national space engagement policy framework specifically excluded a centrally-funded space office or a formal national space program. Instead it vested space policy and program development and delivery authority in the various individual government agencies. A change was initiated in the 2009–10 Commonwealth Budget when the government announced that DIISR would administer a new Australian Space Science Program and would establish a Space Policy Unit.

5.1.2 International EOS data access

In the absence of a national space office, current arrangements for Australian access to international EOS mission information for use in the public interest are mainly the responsibility of the four Commonwealth EOS organisations listed above. Sometimes these organisations act independently through the specialised international fora within which they operate, and sometimes on a coordinated basis through ad hoc arrangements which they initiate among themselves. Access arrangements are codified in a range of bilateral and multilateral agreements and memoranda of understanding, and in specific data licensing agreements.

The Bureau of Meteorology (BoM) engages in various bilateral data access and exchange arrangements with the National Meteorological and Hydrological Services (NMHS) and national space agencies of other countries within the overall framework of the WMO (World Meteorological Organization) Space Programme. WMO is a member of CGMS (the global coordination body for the global meteorological satellite system) and of CEOS. BoM supplies meteorological EOS data and products to the public and private sectors and incorporates EOS data and applications in its national severe weather warning, public weather, and marine weather services programs and its services to the aviation industry and the Department of Defence.

Geoscience Australia (GA) has international links with various global coordinating agencies in geosciences and engages in bilateral arrangements with agencies to obtain Australian access to specific EOS data to support a large range of mapping and related applications, including land use, assessment of mineral and natural resources, the impacts of climate change, and some aspects of natural disaster mitigation. GA supplies EOS data and value-added products to the public and private sectors and supports the EOS data needs of state government land, mineral, natural resources, climate change, and environmental agencies.

CSIRO engages in a large number of international activities in scientific aspects of EOS and is Australia's lead representative on CEOS. Australia gains special access to various research data due to the involvement of CSIRO scientists (often in partnership with academia) in the international scientific programs of EOS missions. CSIRO collects, maintains and provides special EOS data sets for use by the research community, and undertakes multidisciplinary fundamental, strategic and applied research functions in the public interest and with strong links to industry.

The Department of Defence (DoD) engages in bilateral arrangements with regard to the acquisition and use of classified EOS data. DoD also has arrangements with BoM and GA for access to EOS information obtained for civil purposes. DoD uses EOS to help undertake its public interest functions associated with border protection, the surveillance of various other illegal activities in and around Australia, as well as the combat and preparedness activities of the Australian Defence Force (ADF).

Scientists from government institutions, CRCs and universities, who become members of the science teams of specific foreign EOS missions, are granted conditional access to the data from those missions for use in Australia, mainly for research and development purposes.

Institutional arrangements for Australian access to EOS mission data are complicated by the existence of different data access policy regimes imposed by various countries contributing to the global EOS system. On the one hand, the implementation of Resolution 40 of the 1995 WMO Congress dealing with international meteorological data exchange enables Australia (through BoM) to have free and unrestricted access to meteorological EOS mission data for use in the public interest.[1] On the other hand, Australian access to EOS missions for land and resources monitoring purposes involves ground station licensing and commercial data distribution arrangements involving multiple institutions, including several in the private sector.

5.1.3 Commonwealth and state government activities

Apart from the activities of DIISR, BoM, GA, CSIRO and DoD described above, many other Commonwealth and state government institutions are involved in EOS activities relevant to the implementation of this strategic plan, mainly as policy and service arms for the delivery of major national or state programs.

The other Commonwealth departments and agencies include the Department of Climate Change (DCC), the Department of the Environment, Water, Heritage and the Arts (DEWHA), the Department of Agriculture, Fisheries and Forestry (DAFF), the Department of Infrastructure, Transport, Regional Development and Local Government (DITRDLA), the Department of Energy Resources and Tourism (DERT), the Defence Science and Technology Organisation (DSTO), the Australian Antarctic Division (AAD), the Australian Institute of Marine Science (AIMS), the Bureau of Rural Sciences (BRS), the Great Barrier Reef Marine Park Authority (GBRMPA), the Environmental Resources Information Unit (ERIN), the Border Protection Command (BPC), the Defence Imagery and Geospatial Organisation (DIGO), and the Directorate of Oceanography and Meteorology (DOM).

All state governments have multiple institutions involved in EOS activities, particularly those related to the monitoring of land use, water, natural resources, the environment, primary industries, and fisheries, as well as for emergency management purposes. Several of these have specific EOS or remote sensing organisational units, such as the Remote Sensing Centre in Queensland's Department of Environment and Resource Management. The key state government departments include:

- Queensland: Department of Environment and Resource Management;
- NSW: Department of Environment and Climate Change;
- Victoria: Department of Sustainability and Environment;
- Tasmania: Department of Primary Industries, Parks, Water and Environment;
- South Australia: Department of Water, Land and Biodiversity Conservation;
- Western Australia: Department of Regional Development and Lands; Department of Environment and Conservation; Department of Water;
- Northern Territory: Department of Natural Resources, Environment and the Arts.

Western Australia has stewardship for a geographical area larger than that of many of the world's sovereign nations and is far less densely populated. It is heavily involved in EOS data acquisition and utilisation through the WA Land Information Authority, a statutory authority trading as Landgate. WA has linked Landgate and the two Perth-based universities (Curtin University of Technology and Murdoch University) with three major Commonwealth agencies (BoM, GA and CSIRO) within the WASTAC consortium (see below) to ensure WA institutions have access to the EOS information they need. Landgate generates a large number of EOS-based products tailored to WA's state-wide needs.

5.1.4 Universities, CRCs and other consortia

Australia's universities are playing a strong role in EOS-related fundamental and applied research and actively seek involvement in EOS mission science teams to obtain data for research and for calibration and validation with ground-based observations in Australia. There are, however, several significant influences inhibiting the effectiveness of EOS education and training activities in the universities, as noted in Chapter 3 and addressed in the strategy elaborated in Chapter 4.

Over the past 15 years a number of cooperative organisational arrangements for EOS activities have emerged, involving universities and state and Commonwealth government departments. This reflects both the need for more coordinated public sector involvement in EOS activities and the need to make more efficient overall use of public resources.

Two consortia (TERSS and WASTAC) have been established to operate ground stations in Hobart and Perth respectively as part of the national EOS infrastructure, with each member drawing off the data for development of applications for its associated user needs. TERSS comprises the University of Tasmania, the CSIRO Division of Marine and Atmospheric Research, AAD, GA, BoM and CSST. WASTAC comprises the WA Land Information Authority, Curtin University of Technology, Murdoch University, BoM, GA and CSST. WASTAC has recently developed links to iVec's high performance data storage and computing facilities at the Australian Resources Research Centre in Perth.

There are 48 Cooperative Research Centres (CRCs) currently operating, including 33 in sectors covering the environment, agriculture and rural-based manufacturing, information and communication technology, and mining and energy. The potential exists for EOS applications in most of these sectors. Among the CRCs in these sectors the major current users of EOS data are: the CRC for Antarctic Climate and Ecosystems, the Bushfire CRC, the eWater CRC, the CRC for Spatial Information and the CRC for Tropical Savannas Management.

From time to time, BoM and CSIRO have established cooperative arrangements to pool their scientific and environmental modelling expertise and to share supercomputing and other major facilities. Current BoM/CSIRO cooperative ventures which incorporate the use of EOS information are the Centre for Australian Weather and Climate Research (CAWCR) and the Water Information Research and Development Alliance (WIRADA).

5.1.5 Government institutional links to industry and the private sector

The major EOS agency links to industry and the private sector occur through the extensive activities of CSIRO and the CRC program which operates under the responsibility of the Minister for Innovation, Industry, Science and Research. The government contributed about $22 million over the period 1998 to 2005 to the operation of the CRC for Satellite Systems, which constructed the Australian satellite FedSat to establish and demonstrate Australian capability in micro-satellite technologies.

5.1.6 National coordination and advice to government

National coordination of EOS institutional activities occurs mainly through DIISR, which chairs the Australian Government Space Forum (AGSF) and administers the CRC program. The Australian Research Council (ARC) is also located within the DIISR portfolio. The AGSF involves all Commonwealth government portfolios and meets twice a year. Additional coordination of Commonwealth government activities occurs through inter-departmental committees (IDCs) such as the IDC on commercial satellite capabilities, co-chaired by GA and DIGO, and the IDC for coordination of Australia's involvement in GEO. There are also many bilateral and multilateral coordination arrangements among and between various national and state institutions, especially with respect to scientific and technical systems issues.

DIISR's national coordinating role has been strengthened via the initiatives announced in the 2009–10 Budget which gave it responsibility, under the new Australian Space Research Program, for administering competitive grants for space education and development and for space science and innovation, and also established a Space Policy Unit within DIISR. This unit will provide advice to the government on civil space matters, including the coordination of Australia's national and international civil space activities and linkages to international space organisations.

The Australian Space Industry Chamber of Commerce provides, in part, a national forum for coordination of EOS activities in industry and an avenue of advice to government on these matters. The learned academies (AAS and ATSE) provide coordinated scientific, technical and policy advice on EOS matters from time to time through statements on major issues, such as climate change, energy and water. The 2008 draft of the First Decadal Plan for Australian Space Science, prepared by the AAS National Committee for Space Science (NCSS) provided important input to the 2009–10 Budget process. The Plan is expected to be finalised by the end of 2009.

Coordination of Australian initiatives for international cooperation in EOS science and technology occurs formally and informally. For example, the December 2007 India-Australia Remote Sensing Conference in Bangalore was co-sponsored by ATSE and the Indian National Academy of Engineering (INAE) and supported by DIISR's International Science Linkages-Science Academies Program under the Government's innovation policy framework.[2] As another example, in May 2009, an informal Australian EOS inter-agency group comprising CSIRO, GA, BoM, AAD and DCC, met with NASA to explore avenues for a more strategic partnership for Australian participation in future NASA missions.

5.2 Essential ongoing organisational functions

As Australia's national and international role changes over the next 15 years, it will be essential that the organisational and coordination arrangements enable the efficient ongoing discharge of the following core functions:

- assured ongoing acquisition of EOS information commensurate with Australia's national needs and priorities;
- provision of advice to Australian governments on EOS-related matters with respect to the interests of the public and private sectors, science and technology, industry and commerce;
- authoritative, focused, Australian representation internationally in EOS-related activities with respect to binding inter-governmental agreements, and administrative, scientific and technical cooperation in international matters at a variety of levels;
- provision of an unambiguous, authoritative focal point of contact for dealings with Australia by international organisations on EOS-related activities;
- strategic planning of EOS-related activities with respect to policies, priorities, future needs and capabilities, scientific standards, and funding requirements;
- coordination of Commonwealth, state, and local government EOS-related activities;
- provision of EOS-related infrastructure, services, research and education in the public interest;
- provision of EOS-related commercial services; and
- the stimulation of EOS-related activities with respect to Australian innovation, industry and commerce.

Decisions on changes to current institutional arrangements needed to discharge these EOS organisational functions over the next 10 to 15 years will depend on detailed inter- and intraportfolio analysis which is beyond the remit of this working group, but there are several macro-scale aspects of future arrangements which the working group believes will be essential if the strategy outlined in Chapter 4 is to be successful.

5.3 Institutional arrangements needed for strategy implementation

The institutions currently involved in various aspects of EOS data acquisition, research, applications and management are major strengths for Australia. Within the limits of available resources, these institutions have prioritised their use of EOS to help deliver their individual mission outputs. To some extent, however, this has contributed to a dilution of EOS expertise such that Australia now lacks the critical core mass of highly specialised EOS strategic research, education and operational implementation capabilities that will be needed for the future. Other major unmet needs are for EOS-specific arrangements for national coordination and national strategic planning, and for a clearly recognised national authority for dealing with EOS matters internationally.

The strategy outlined in Chapter 4 aims to maximise Australia's EOS institutional strengths and minimise the weaknesses. It adopts the approach, recommended by the 2008 Senate Economics Committee, of a gradual change in institutional arrangements commensurate with those needed to accompany the gradual evolution of Australia's national and international roles. In order for Australia to become a full participant in the international EOS effort, the operational and research mandates and international EOS liaison roles of the four key national EOS infrastructure providers (BoM, GA, CSIRO and DoD) should be reaffirmed and strengthened and they should be encouraged and assisted to collaborate with each other and with other Commonwealth and state EOS agencies and the universities in the development and provision of a more integrated national EOS data service and research framework. The specific organisational initiatives outlined below are needed to facilitate this transformation and strengthen existing EOS community service and research program institutions at the Commonwealth, state and university level.

5.3.1 EOS advisory council

An EOS advisory council should be established as soon as possible to guide the integrated strategic development of the application of EOS in Australia and to advise the Commonwealth government on strategic needs. Its functions should include the provision of advice on national priorities for the access and use of EOS data and advice on policy and funding for both operational EOS and research infrastructure. As indicated in section 4.4.2, its first tasks should be to establish an ongoing national EOS priority-setting mechanism, including the full involvement of the key EOS institutions, the learned academies and the broader community, and to assess priorities for the uptake of opportunities for Australian partnerships in international EOS missions and for enhanced global and regional cooperation. Formation of such an advisory council is proposed in the working group's recommendation 2.

5.3.2 National EOS office

A national EOS policy and coordination office is needed to support the proposed EOS advisory council, to enhance the national EOS profile within Australia's new Space Science Program and to drive and coordinate the implementation of the strategic initiatives outlined in Chapter 4. It would be logical to establish this office as a component of the DIISR Space Policy Unit. The first and most critical task of the National EOS office should be to work with the key EOS mission agencies to develop the new overarching national EOS policy framework and to bring it forward for consideration in the context of the 2010–11 Budget if possible. The national EOS office should play a supporting and coordinating role in any action taken by major EOS institutions, to optimise Australia's EOS infrastructure to cope with the new generation EOS missions. The office should also coordinate the implementation of plans to establish a critical mass of strategic EOS research and education capability.

The working group recommends, therefore, that:

An EOS national office should be established as part of the Australian Space Science Program, to support the EOS advisory council, to maintain links with the operational EOS agencies, and to serve as the national focal point for Australian EOS activities. **(Recommendation 8)**

5.3.3 EOS mission agencies

While the applications of EOS in Australia now extend far beyond the original Commonwealth institutions who pioneered their development in the 1960s and 1970s, the three main civil EOS mission agencies (BoM, GA and CSIRO) provide the essential core data acquisition, processing and archival framework required to support the total national needs for EOS data, as well as to underpin their own national research and service missions. While Australia would benefit greatly from the establishment of a well-funded national space agency encompassing operational Earth-observing satellite responsibilities, the working group believes that it would be neither efficient nor effective to attempt large-scale integration of the core national functions of the existing EOS mission agencies. What is most urgently needed is the substantial strengthening of the existing EOS mission agencies in conjunction with the improved coordination arrangements proposed above.

The working group recommends, therefore, that:

The EOS operational and research mandates of the Bureau of Meteorology, Geoscience Australia and CSIRO should be reaffirmed and strengthened, and they should collaborate with the Department of Defence, Commonwealth and state EOS agencies and universities in the progressive development of a more integrated national EOS service and research framework for Australia. **(Recommendation 9)**

5.4 Implementation time-scales

The implementation of the strategy set down in Chapter 4 and its associated institutional arrangements summarised above is proposed to occur in four phases. The enabling first phase should begin immediately and needs to be completed by no later than the end of 2011. This can be achieved if the proposed new national EOS office can be initiated under the umbrella of DIISR's Space Policy Unit and the Australian Space Science Program. Further implementation can then proceed in three further phases of approximately 5 years, leading to an eventual post-implementation situation in which Australia consolidates its new role and prospers from the accumulated benefits of becoming a full participant in the international EOS system. The key activities in each of these phases should be as follows:

- **2010–11:** New EOS policy framework approved; EOS advisory council and national EOS office established; optimised EOS infrastructure, research and education capability plans initiated; international EOS partnership opportunities formally assessed; defence EOS synergies established; EOS radio spectrum issues initially addressed.

- **2010–14:** Specific national EOS priorities established; international EOS partnerships approved; plans for Australian EOS missions developed and costed; industry engaged; Australian EOS service institutions well prepared for next generation EOS missions.
- **2015–20:** Benefits from new generation EOS missions start to flow to help address major national challenges; Australia develops new role as an EOS data provider and global contributor; a national space agency fully established; funding and launch dates confirmed for Australian EOS partnership missions.
- **2020–25:** Australian EOS missions launched and new ones planned; industry benefits realised; benefits of new Australia-specific data flow to major programs; Australia's role enhanced in South Pacific; further EOS partnerships developed in Asia.

Notes

1 US National Academies Space Studies Board (2007).

2 Australian Communications and Media Authority (2009), pp 97-105.

CHAPTER 6: **RECOMMENDATIONS**

The AAS-ATSE working group has undertaken a wide-ranging strategic review of Australia's current EOS activities and national EOS needs for the next 10 to 15 years. On the basis of this review and its analysis of EOS-related challenges, risks and opportunities for Australia, the working group has formulated the following nine recommendations whose implementation, it believes, would maximise Australia's social, economic and environmental benefits from the acquisition and application of EOS over the next decade and beyond.

1 **National EOS policy.** Australian government policy on space science and industry development should include an explicit national policy on EOS, based on strengthening, broadening and coordinating existing EOS activities and a strategic commitment to full Australian participation in the international EOS system by 2025.

2 **EOS priority setting.** A high level, cross-portfolio EOS advisory council should be established with the active involvement of the national EOS provider agencies, the learned academies and the EOS user community to advise on national priorities for EOS operations, research, education and applications across all sectors and all levels of government.

3 **National EOS infrastructure.** The main operational EOS agencies and ground station consortia should jointly establish a coordinated approach to strengthening and optimising the national investment in the EOS data acquisition, processing, archival, distribution and applications infrastructure that will be needed to handle the massive increase in EOS availability and user needs over the next decade.

4 **EOS research and education.** A national plan and funding framework should be developed to establish and maintain a critical mass of strategic research and education expertise in Australian universities to underpin the operational EOS systems, services and applications in industry and government agencies.

5 **EOS industry capability.** In order to support a strengthened Australian role in the global Earth observation satellite community, the Space Science and Innovation Project Grants scheme should be enhanced within the framework of the national EOS policy to promote local industry capabilities in EOS systems development and applications.

6 **Radio spectrum for EOS.** Given the enormous social, economic and environmental benefits to Australia from the use of EOS data, those parts of the radio spectrum that are uniquely required for satellite remote sensing of atmospheric and Earth characteristics should be permanently protected from interference, in the public interest. Means should also be found for meeting the costs of commercial sharing of those parts of the radio spectrum that are used for public-good transmission of EOS data from satellites.

7 **International engagement in EOS.** Australia should strengthen its role and influence in international EOS through development of bilateral and multilateral (including regional) partnerships in EOS provision, greater involvement in the Committee on Earth Observation Satellites (CEOS), and enhanced contribution to the implementation of the Global Earth Observation System of Systems (GEOSS).

8 **EOS national office.** An EOS national office should be established as part of the Australian Space Science Program, to support the EOS advisory council, to maintain links with the operational EOS agencies, and to serve as the national focal point for Australian EOS activities.

9 **EOS mission agencies.** The EOS operational and research mandates of the Bureau of Meteorology, Geoscience Australia and CSIRO should be reaffirmed and strengthened, and they should collaborate with the Department of Defence, other Commonwealth and state EOS agencies and universities in the progressive development of a more integrated national EOS service and research framework for Australia.

APPENDIX 1: **TERMS OF REFERENCE**

The terms of reference for the AAS (Australian Academy of Science)-ATSE (Australian Academy of Technological Sciences and Engineering) study of Australian needs for Earth observations from space over the next 10 to15 years and of the working group to prepare a National Strategic Plan for Earth Observations from Space, were set down in a joint letter of 23 December 2008 from the Presidents of AAS and ATSE to the invited members of the working group, as follows:

a) Review Australia's current activities in Earth observations from space in the context of space science, Earth observation and Australia's international role in Earth observations from space, including involvement in the Global Earth Observation System of Systems (GEOSS);

b) Identify Australia's likely needs and potential capabilities for research, operations and applications of space-based Earth observation for the next 10 to 15 years;

c) Formulate the essential elements of a national strategy for meeting the identified needs for space-based Earth observation over the next decade, including the effective use of existing Earth observation data;

d) Suggest the appropriate institutional responsibilities and coordination arrangements needed for implementation of the proposed strategy;

e) Provide appropriate recommendations for follow-up action by the Academies, research community, industry and government; and

f) Deliver the plan to the Presidents of AAS and ATSE by July 2009.

APPENDIX 2: **COMPOSITION OF THE WORKING GROUP**

Professor John Zillman AO FAA FTSE (Chair) is a Vice Chancellor's Fellow at the University of Melbourne and Chair of the international Steering Committee for the Global Climate Observing System. He is a former President of ATSE (2003–06) and of the National Academies Forum (2005–06). He was Director of the Bureau of Meteorology (1978–2003), President of the World Meteorological Organization (1995–2003) and President of the International Council of Academies of Engineering and Technological Sciences (2005).

Professor Iver Cairns of the School of Physics, University of Sydney, is an expert in the theory and observation of waves, radio emissions, shocks, and accelerated particles in space. He has published about 200 refereed papers in journals and books. He is an official co-Investigator on the S/Waves instrument on NASA's STEREO mission (launched 2006). He is Chair of the Academy of Science's National Committee for Space Science and chairs the Steering Committee for the first Decadal Plan for Australian Space Science.

Dr John Church FTSE is an oceanographer with the Centre for Australian Weather and Climate Research and the Antarctic Climate and Ecosystems Cooperative Research Centre. He is an expert in the role of the ocean in climate, particularly in climate change. He has been a Principal Investigator with NASA and CNES since 1987 and was a co-convening lead author for the IPCC Third Assessment Report. He chaired the Joint Scientific Committee of the World Climate Research Programme (2006–08).

Professor Richard Coleman is the Director of the Centre for Marine Science at the University of Tasmania. He is an expert in use of satellite and *in situ* data for oceanographic and climate research especially related to global change in sea level and cryosphere studies. He has been a Principal Investigator with NASA, CNES and ESA on satellite altimeter missions since 1987 and is a current member of the Science Working Teams of the Jason-1 and -2, ERS-2 and Envisat satellite missions and the Cryosat-2 mission.

Dr Roger M. Gifford is a Chief Research Scientist at CSIRO Plant Industry and Chair of the Australian Academy of Science's National Committee for Earth System Science. He is an experimental plant physiologist who has focused since 1970 on the relationships between the increasing atmospheric CO_2 concentration and its associated climate change and the terrestrial carbon cycle, agriculture and other ecosystems.

Dr Alex Held is the Terrestrial Remote Sensing Group Team Leader at the CSIRO Division of Marine and Atmospheric Research and at the Centre for Australian Weather and Climate Research. He was Head of the CSIRO Office of Space Science and Applications 2004–07. He represents CSIRO on the international Committee on Earth Observation Satellites (CEOS), and is a member of the Australian Academy of Science's National Committee on Space Science. He is an expert in plant physiology and the linking of remote sensing and vegetation mapping, and is a special technical advisor to the Department of Climate Change's global carbon monitoring program.

Professor John Le Marshall is a scientist at the Centre for Australian Weather and Climate Research. He is an expert in remote sensing and in meteorological satellite data assimilation into numerical weather prediction models and has been a Principal Investigator, co-Investigator or Science Team Member in relation to a number of space missions. He was the Director of the NASA, NOAA and DoD Joint Centre for Satellite Data Assimilation 2003–07 and was awarded the NASA Exceptional Scientific Achievement Medal in 2007.

Dr Adam Lewis has led Geoscience Australia's National Earth Observation Group, formerly known as ACRES, since 2005. He has over 25 years of experience in the use of spatial information and remotely sensed data to support environmental science and natural resource management. One of his major achievements was to re-map the Great Barrier Reef Marine Park using images from Landsat-7, allowing reefs to be located with sufficient accuracy to be consistent with modern GPS-based navigation techniques.

Professor Michael Manton FTSE (alternate Chair) was Chief of the Bureau of Meteorology Research Centre before his retirement in 2006. He now consults on climate matters, and has a part-time position in the School of Mathematical Sciences at Monash University. He is a member of the Board of ATSE. He was a member of the Joint Scientific Committee for the World Climate Research Programme (1987–98) and was chair of the Atmospheric Observation Panel for Climate of the Global Climate Observing System (1997–2006).

Professor Anthony Milne is a visiting Professor of Geography and Remote Sensing at the University of New South Wales, the Science Program Manager at the Cooperative Research Centre for Spatial Information, and a co-Director of Horizon Geoscience Consulting Pty Ltd. He has been President of the IEEE Geoscience and Remote Sensing Society since 2008. He is an expert in environmental assessment using remote sensing and geographic information systems. He was formerly a member of the Japanese Space Agency's Global Rainforest Mapping Experiment, and has been an ongoing member of the ALOS Kyoto and Carbon Science Advisory Panel since 2002.

Professor Dietmar Muller is Head of the School of Geosciences at the University of Sydney and a member of the Australian Academy of Science's National Committee for Earth Science. He is an expert in Earth sciences with special interests in marine geophysics, tectonic plate motions, geodynamics, continental margin tectonics, petroleum exploration, paleoclimate and seafloor imaging.

Professor Stuart Phinn directs the University of Queensland's Centre for Remote Sensing and Spatial Information Science and the Joint Remote Sensing Research Program for Queensland and New South Wales Government Agencies. He is responsible for remote sensing courses at the university, and serves on the National Commission of the Remote Sensing and Photogrammetry components of the Spatial Sciences Institute of Australia, of which he is an elected Fellow. He is an expert in developing remote sensing applications for resource science and management agencies.

Dr Chris Pigram is Deputy CEO and Chief of the Geospatial and Earth Monitoring Division in Geoscience Australia. He is a geologist with more than 35 years experience in a wide range of geological research and mapping. He has been a senior research manager at Geoscience Australia since 1993 and has led the marine and petroleum geoscience and minerals geoscience programs.

Dr Paul Tregoning leads the geodetic research at the Research School of Earth Sciences at the Australian National University. He is the national delegate to the International Association for Geodesy, a member of the Steering Committee of AuScope Geospatial and Chair of the AuScope Gravity sub-committee. He is an expert in the use of satellite geodesy techniques to study geophysical properties of the Earth (including crustal deformation, sea level studies, mass balance of polar regions, and water resources).

Mr Stephen Ward is a Director of Symbios Communications, a space systems consulting firm. He has worked in the area of international coordination of space programmes, global environment and climate change since 1990. He is the author of the *Earth Observation Handbook* which is a major global reference publication on current and planned international satellite missions to obtain Earth observations from space.

Mr Antony Wheeler operates his own company, Akuna Consulting, which is currently managing a project for the Department of Climate Change to assess the coastal vulnerability of Australia's most populated mainland centres. He was a Senior Principal at Sinclair Knight Merz (SKM) for the past 11 years. He was the inaugural Chairman of the Australian Spatial Information Business Association and is a member of the NSW Board of Surveying and Spatial Information. He is an experienced consultant in fields such as surveying, remote sensing and environmental projects, space-based Earth observation systems, and strategy development.

APPENDIX 3: **WORKING ARRANGEMENTS**

This strategic plan was prepared in accordance with its terms of reference (Appendix 1) by a working group of experts (Appendix 2). The chair of the working group was advised by an informal steering committee whose membership comprised:

Professor John W Zillman AO, FAA, FTSE, Vice Chancellor's Fellow at the University of Melbourne *(Chair)*

Professor John Richards AM, FTSE, Professor of Electrical Engineering, Australian National University; formerly the Deputy Chair of the Australian Space Council. *(Deputy Chair)*

Dr Miriam Baltuck, Director, Canberra Deep Space Communications Complex and NASA Operations, CSIRO Information and Communication Technology

Mr Howard Bamsey, Deputy Secretary, Department of Climate Change; and Australia's Special Envoy on Climate Change[1]

Professor Robert Clark FAA, Chief Defence Scientist of Australia; and Chief Executive Officer, Defence Science and Technology Organisation, Department of Defence

Dr Michael Green, General Manager, Manufacturing Innovation Branch, Department of Innovation, Industry, Science and Research

Professor Michael Manton FTSE, a Board member of the Australian Academy of Technological Sciences and Engineering

Dr Neville Smith FTSE, Deputy Director (Research & Systems) Bureau of Meteorology[2]

Dr Neil Williams PSM, FTSE, Chief Executive Officer, Geoscience Australia.

The preparation of the plan was facilitated by a secretariat comprising the project officer (Mr Bruce Neal), the AAS science policy coordinator (Dr Michael Agostino), and the AAS events coordinator (Ms Savita Khiani). In preparing the plan, members of the working group drew on their personal and collective expertise and sought information on an ad hoc basis from colleagues, representatives of Commonwealth and state government organisations, universities, Cooperative Research Centres, and private sector representatives (see Appendix 4). The working group also drew heavily on material in various related reports and scientific publications (see Appendix 5).

The development of the plan was reviewed at key stages via the following series of meetings and web-based stakeholder involvement:

- initial meetings of the steering committee and the working group on 27 January 2009;
- working group progress review meetings on 15 April, 22 May, 23 June and 3 July 2009;
- steering committee progress review meetings on 23 June and 3 July 2009;
- the posting of drafts of the plan on the AAS and ATSE websites inviting stakeholder comments during the period 18 June to 20 July 2009;
- a stakeholder review meeting in Canberra on 3 July; and
- finalisation of the plan by the working group over the period 21 to 31 July 2009.

Notes

1 Mr Ian Carruthers (First Assistant Secretary, Adaptation and Land Management Branch, Department of Climate Change) served as alternate for Mr Bamsey, with support from Dr Gary Richards (Principal Scientist, Land Management Branch, Department of Climate Change).

2 Dr Susan Barrell, Assistant Director (Observations & Engineering) Bureau of Meteorology served as alternate for Dr Smith, with support from Dr Tom Keenan (Deputy Director, Centre for Australian Weather and Climate Research).

APPENDIX 4: **CONSULTATION AND REVIEW**

The working group was greatly assisted by the following people who provided advice, information and critical review during the development of the plan.

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Roger Atkinson^	Bureau of Meteorology
Damian Barrett^	Centre for Water in the Minerals Industry (Uni of Qld)
Ian Barton^	CSIRO
Imans Berzins^	Bureau of Meteorology
Gypsy Bhalla*	Remote Sensing Commission, Surveying & Spatial Sciences Institute
Brett Biddington*	Cisco Systems, and Australian Space Industry Chamber of Commerce
David Bruce^	University of South Australia
Max Bye*	GEOIMAGE Pty Ltd
Peter Caccetta*	CSIRO
Ken Campbell#	Australian National University
Graziella Caprarelli^	University of Technology Sydney
Jon Clarke^	Geoscience Australia
Kimberley Clayfield*	CSIRO Space Sciences and Technology
Tim Danaher#	NSW Department of Environment and Climate Change
John Dawson^	Geoscience Australia
Arnold Decker^#	CSIRO
Graham Ezzy^	Bureau of Meteorology
Brian Fraser^	University of Newcastle
Clive Fraser^	University of Melbourne
Will Featherstone^	Curtin University of Technology
Mark Fenotti*^	Department of Innovation, Industry, Science and Research
Kevin Fleming^	Curtin University of Technology
Bruce Forgan^	Bureau of Meteorology
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Glen Gould^	Bureau of Meteorology
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Douglas Gray#	University of Adelaide
David Griffin^	CSIRO
David Griffith^	University of Wollongong
Brian Griffiths^	CSIRO
John Gunn+#	Australian Antarctic Division
Jorg Hacker^#	Flinders University
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Geoff Horn^	Department of Environment and Climate Change (NSW)
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Janette Lindesay^	Australian National University
Leo Lymburner^	Geoscience Australia
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John Nairn^	Bureau of Meteorology
Zoran Ninkov^	Centre for Imaging Technology (Curtin University)
Rocco Panseria#	University of Melbourne
John Parslow^	CSIRO
Svetlana Petelina^	Latrobe University
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Trevor Powell*	Integrated Marine Observing Systems
Anthony Rea*^	Bureau of Meteorology
Shanti Reddy^	Geoscience Australia
Kim Ritman^	Bureau of Rural Sciences
Chris Rizos*#	University of NSW
Chris Rudiger#	University of Melbourne
Martin Rutherford*^	Directorate of Oceanography and Meteorology (Defence)
Chris Ryan^	Bureau of Meteorology
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Michael Willmott^	Bureau of Meteorology
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Christian Witte#	Queensland Department of Environment and Resource Management
Peter Woodgate*^	CRC for Spatial Information
Neal Young*^	Australian Antarctic Division and ACE CRC
Kefei Zhang^	RMIT University

* *indicates those who attended the stakeholder review meeting on 3 July 2009.*

indicates those who provided written comments on the draft of the plan released on 25 June 2009.

+ *indicates signatory of review comments submitted on behalf of a group or institution.*

^ *indicates those who provided information or assisted in other ways.*

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APPENDIX 6: **EXAMPLES OF STATE PROGRAMS RELIANT ON EOS**

(**Note:** No information available from the ACT or Tasmania. The CRC for Tropical Savannas Management cooperates with Bushfires NT and the Cape York Peninsula Development Association in the use of EOS for twice-weekly fire mapping over the northern one third of the continent.)

AGENCY	SATELLITE DEPENDENCY	MAJOR DEPENDENT PROGRAMS
QUEENSLAND: Department of Environment and Resource Management	LANDSAT TM/ETM	• QLD land-use mapping program • QLD regional ecosystem mapping • QLD remnant vegetation mapping • QLD State-wide Landcover and Tree Study • QLD wetland classification and mapping
NEW SOUTH WALES: Department of Environment and Climate Change	LANDSAT TM/ETM+ SPOT-5 MODIS ALOS LiDAR	• NSW vegetation monitoring program • NSW evapotranspiration of groundwater dependent ecosystems (GDE) • NSW groundwater quality and coastal GDE mapping • NSW dust plume and bare ground mapping • NSW elevation and vegetation structural mapping • NSW land cover mapping • NSW inland wetland inventory and monitoring
VICTORIA: Department of Sustainability and the Environment	LANDSAT TM/ETM+ SPOT-4, -5 MODIS	• VIC Land Use Information System • VIC measurement, monitoring and management for regional water resources from farm to national scale • VIC native vegetation extent and condition • VIC monitoring of bushfire areas and tree cover

AGENCY	SATELLITE DEPENDENCY	MAJOR DEPENDENT PROGRAMS
SOUTH AUSTRALIA: Department of Water, Land and Biodiversity Conservation	LANDSAT TM/ETM ALOS	• SA Imagery Baseline Data Project • SA Statewide Native Vegetation Detection
WESTERN AUSTRALIA: Landgate	LANDSAT TM/ETM SPOT ASTER MODIS NOAA AVHRR MTSAT QuikBird	• WA Land Monitor Project • WA Southwest Vegetation Monitoring • WA Southwest Agimage • WA Carbon Watch • WA Pastures from Space Program • WA Ocean Watch Program • WA Firewatch Program • WA Vegetation Watch Program • WA Floodmap Program • WA Land Clearing and Compliance Program
WESTERN AUSTRALIA: Department of Environment and Conservation	LANDSAT TM/ETM ALOS	• WA vegetation monitoring • WA current and historical fire boundaries • WA marine mapping and monitoring
WESTERN AUSTRALIA: Department of Water	ALOS	• WA monitoring groundwater decline
NORTHERN TERRITORY: Department of Natural Resources, Environment and the Arts	MODIS	• NT rangeland monitoring
NORTHERN TERRITORY: Bushfires NT	LANDSAT TM/ETM	• NT fire mapping: National Parks, and Arnhem Land Fire Management Area

ABBREVIATIONS

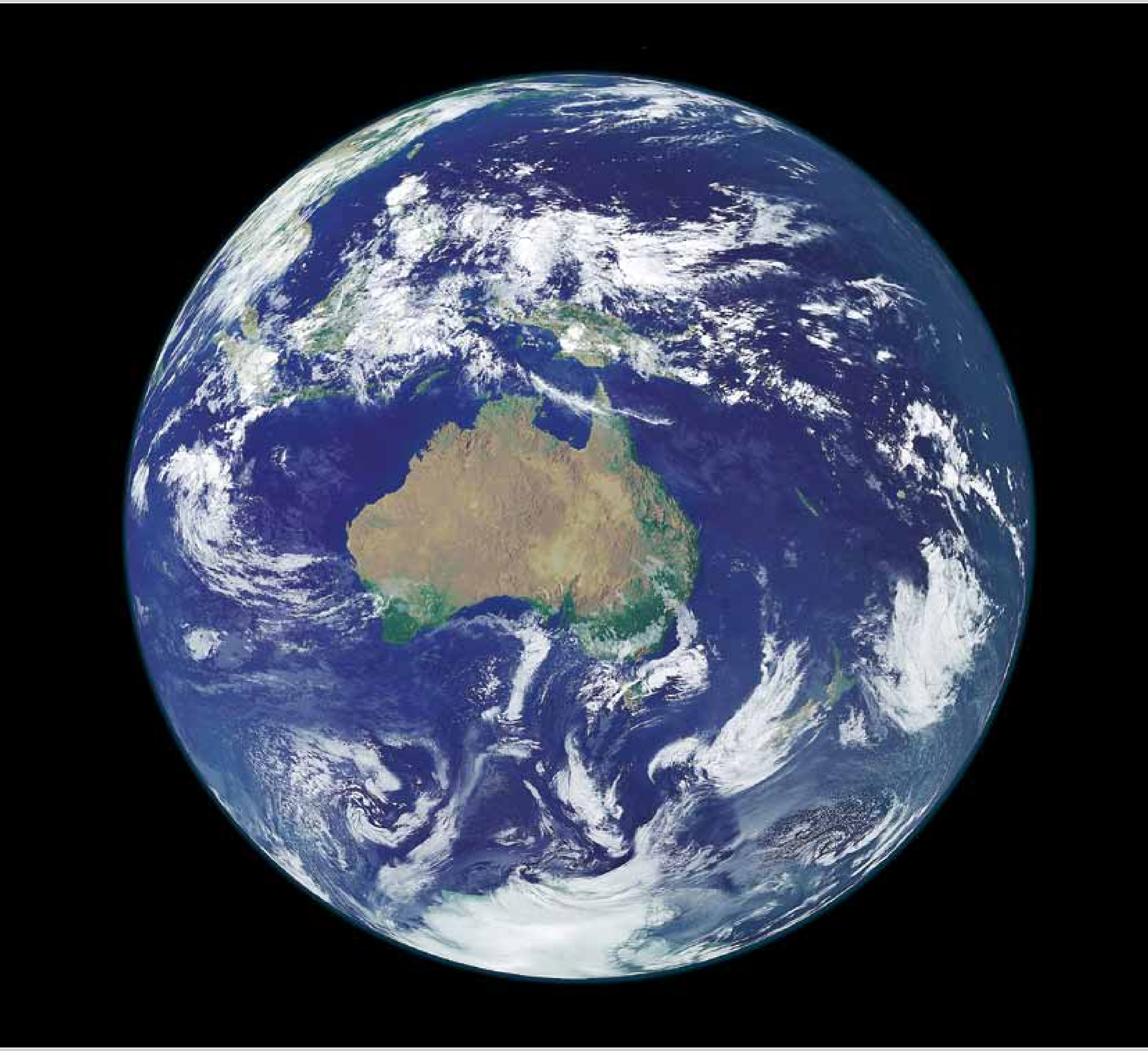
AAD	Australian Antarctic Division
AARNet	Australian Academic and Research Network
AATSR	Advanced Along Track Scanning Radiometer
AAS	Australian Academy of Science
ACCESS	Australian Community Climate and Earth System Simulator
ACE CRC	Antarctic Climate and Ecosystems Cooperative Research Centre
ACERTS	Australian Committee for the Earth Resources Technology Satellite
ACLUMP	Australian Collaborative Land Use Mapping Programme
ACMA	Australian Communications and Media Authority
ACRES	Australian Centre for Remote Sensing (Geoscience Australia)
ADF	Australian Defence Force
AFAC	Australasian Fire and Emergency Service Authorities Council
AGSF	Australian Government Space Forum
AIMS	Australian Institute of Marine Science
AIRS	Atmospheric Infrared Sounder
ALOS	Advanced Land Observing Satellite (Japan)
AMS	American Meteorological Society
AMSA	Australian Maritime Safety Authority
ANARE	Australian National Antarctic Research Expeditions
APRGP	Asia Pacific Regional Geodetic Project
APRSAF	Asia Pacific Regional Space Agencies Forum
ARC	Australian Research Council
ARCS	Australian Research Collaboration Service
ARGN	Australian Regional GPS Network
ASI	Agenzia Spaziale Italiana (Italy)
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATS	Australian Academy of Technological Sciences
ATSE	Australian Academy of Technological Sciences and Engineering
AVHRR	Advanced Very High Resolution Radiometer
AVNIR	Advanced Visible and Infrared Radiometer
AWAP	Australian Water Availability Project
BMR	Bureau of Mineral Resources
BMTC	Bureau of Meteorology Training Centre
BoM	Bureau of Meteorology
BPC	Border Protection Command
BRS	Bureau of Rural Sciences
CALIPSO	Cloud-Aerosol Lidar & Infrared Pathfinder Satellite Observations
CAWCR	Centre for Australian Weather and Climate Research
CBERS	China Brazil Earth Resources Satellite
CEOS	Committee on Earth Observation Satellites
CGMS	Coordination Group for Meteorological Satellites

CHAMP	Challenging Mini-sat Payload for Geophysical Research & Application
CNES	Centre National d'Etude Spatiale
COPUOS	Committee on the Peaceful Uses of Outer Space (United Nations)
COSMIC	Constellation of Observing Systems Meteorology Ionosphere Climate
COSMO	Constellation of Small Satellites for Mediterranean basin Operations
COSSA	CSIRO Office of Space Science and Applications
CRC	Cooperative Research Centre
CRC-SI	Cooperative Research Centre for Spatial Information
CRCSS	Cooperative Research Centre for Satellite Systems
CSA	Canadian Space Agency
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSP	Concentrating Solar Power
CSST	CSIRO Space Science and Technology
DAFF	Department of Agriculture Fisheries and Forestry
DCC	Department of Climate Change
DEWHA	Department of the Environment, Water, Heritage and the Arts
DIGO	Defence Imagery and Geospatial Organisation
DIISR	Department of Innovation, Industry, Science and Research
DITRDLA	Deptartment of Infrastructure Transport Regional Development and Local Government
DLR	Deutches Zentrum fur Luft-und Raumfart
DMSP	Defense Meteorological Satellite Program (USA)
DoD	Department of Defence
DOM	Directorate of Oceanography and Meteorology
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DSTO	Defence Science and Technology Organisation
EC	Exceptional Circumstances (in the context of drought)
ECV	Essential Climate Variables
EEZ	Exclusive Economic Zone
EMA	Emergency Management Australia
EMSINA	Emergency Managers Spatial Information Network for Australia
Envisat	Environmental Satellite (ESA)
EOS	Earth Observations from Space
ERIN	Environmental Resources Information Network
ERSDAC	Earth Remote Sensing Data Analysis Center
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellite
FAO	Food and Agriculture Organization of the United Nations
G8	Group of Eight leading industrialised countries
G20	Group of Twenty leading industrialised countries
GA	Geoscience Australia
GAW	Global Atmosphere Watch
GBRMPA	Great Barrier Reef Marine Park Authority
GCMS	Global Carbon Monitoring System

GCOS	Global Climate Observing System
GDP	Gross Domestic Product
GEO	Geostationary Earth Orbiting (satellite system context)
GEO	Group on Earth Observations (organisational context)
GEOSS	Global Earth Observation System of Systems
GGOS	Global Geodetic Observing System
GIS	Geographic Information Systems
GLONASS	Global Navigation Satellite System (Russia)
GMES	Global Monitoring for Environment and Security
GNSS	Global Navigation Satellite Systems
GOCE	Gravity field and steady-state Ocean Circulation Explorer (ESA)
GOOS	Global Ocean Observing System
GOS	Global Observing System (of the World Weather Watch)
GOSAT	Greenhouse Gases Observing Satellite (Japan)
GPM	Global Precipitation Mission
GPS	Global Positioning Satellites
GRACE	Gravity Recovery and Climate Experiment
GTOS	Global Terrestrial Observing System
HOMA	Heads of Marine Agencies
IASI	Infrared Atmospheric Sounding Interferometer
ICAO	International Civil Aviation Organization
ICESAT	Ice, Cloud and land Elevation Satellite (NASA mission))
ICSU	International Council for Science
IDC	Inter Departmental Committee
IFCI	International Forest Carbon Initiative
ICSU	International Council for Science
IGBP	International Geosphere-Biosphere Programme
IGOS-P	Integrated Global Observing Strategy Partnership
ILRS	International Laser Ranging Service
IMOS	Integrated Marine Observing System
INAE	Indian National Academy of Engineering
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
IPS	Ionospheric Prediction Service
IRSS	Indian Remote Sensing Satellite
ISRO	Indian Space Research Organisation
ITRF	International Terrestrial Reference Frame
ITU	International Telecommunications Union
JAXA	Japan Aerospace Exploration Agency
JCSDA	Joint Center for Satellite Data Assimilation (USA)
JMA	Japan Meteorological Agency
LAI	Leaf Area Index
LEO	Low Earth Orbiting (satellites)

MEO	Medium Earth Orbiting (satellites)
MERIS	Medium Resolution Imaging Spectrometer
METOC	Meteorological and Oceanographic Centre
MODIS	Moderate Resolution Imaging Spectroradiometer
MOU	Memorandum of Understanding
MRV	Monitoring Reporting Verification
MSR-MS	Moderate Scale Resolution-Multispectral
MTSAT	Multi-functional Transport Satellite
NAFI	North Australia Fire Information
NAMS	National Agricultural Monitoring Systems
NASA	National Aeronautics and Space Administration (of the USA)
NCAS	National Carbon Accounting System
NCES	National Committee for Earth Sciences (AAS)
NCESS	National Committee for Earth System Science (AAS)
NCRIS	National Collaborative Research Infrastructure Strategy
NCSS	National Committee for Space Science
NDVI	Normalised Difference Vegetation Index
NES	National Environmental Significance
NEXIS	National Exposure Information System
NGRS	National Geospatial Reference System
NLWRA	National Land and Water Resources Audit
NMHS	National Meteorological and Hydrological Services
NOAA	National Oceanic and Atmospheric Administration (of the USA)
NPOESS	National Polar Orbiting Operational Environmental Satellite System
NWP	Numerical Weather Prediction
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PARASOL	Polarization Anisotropy Reflectances Atmospheric Science Obs Lidar
PARNet	Perth Academic Regional Network
PCGIAP	Permanent Committee for GIS Infrastructure in the Asia Pacific
PI	Principal Investigators
PMW	Passive Microwave (radiometer)
PV	Photo Voltaic
RADASAT	Radar Satellite (Canada)
RPD	Rapid Prototyping & Development
SAC-C	Satellite de Aplicaciones Cientificas-C
SAR	Synthetic Aperture Radar
SBA	Societal Benefit Area
SDLT	Super Digital Linear Tape
SKA	Square Kilometre Array
SLATS	State Land Cover and Tree Survey (Queensland)
SMAP	Soil Moisture Active Passive (NASA mission)
SME	Small and Medium Enterprises
SMOS	Soil Moisture Ocean Salinity (NASA mission)

SOE	State of the Environment
SOPAC	South Pacific Islands Applied Geoscience Commission
SPAG	Space Policy Advisory Group
SPOT	Satellite Pour l'Observation de la Terre
SPSLCMP	South Pacific Sea Level and Climate Monitoring Program
SSMIS	Special Sensor Microwave Imager/Sounder
TARS	Turn Around Ranging Station
TDRS	Tracking and Data Relay Satellite
TEC	Total Electron Content
TIROS	Television and Infrared Observation Satellite
TERN	Terrestrial Ecosystem Research Network
TERSS	Tasmanian Earth Resources Satellite Station
TM	Thematic Mapper
ToR	Term(s) of Reference
TRMM	Tropical Rainfall Mapping Mission
UN	United Nations
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNSW	University of NSW
UTAS	University of Tasmania
VLBI	Very Long Baseline Interferometry
VSAT	Very Small Aperture Terminal
WASTAC	Western Australian Satellite Applications Consortium
WCRP	World Climate Research Programme
WIRADA	Water Information Research and Development Alliance
WMO	World Meteorological Organization
WRON	Water Resource Observation Network
WWC	World Water Council



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