Australian Government
Geoscience Australia

SUBMISSION TO THE INQUIRY INTO AUSTRALIA'S ANTARCTIC TERRITORY

Terms of Reference

This submission addresses the Terms of Reference (ToR) as per the Letter of Invitation (29 June 2017; addressed to Dr James Johnson, CEO, Geoscience Australia) to provide a submission to the Joint Standing Committee on the National Capital and External Territories inquiry into the adequacy of Australia's infrastructure assets and capability in Antarctica, with regard to:

- maintaining national interests;
- serving the scientific program into the future;
- international engagement, including collaboration and resource sharing with other countries;
- fostering economic opportunities consistent with the Antarctic Treaty System obligations; and
- environmental considerations.

Key Recommendations

In the context of advancing Australia's interests in Antarctica, the Australian Government should consider:

- Maintaining and expanding its geophysical monitoring observatories in Antarctica; these are key nodes in a global network and are essential for:
  - accurate navigation (maritime, terrestrial and aeronautical),
  - benchmarking geospatial and marine geophysical surveying, and
  - underpinning Australia's international treaty obligations.
- Developing a strategic approach for the new icebreaker to undertake dedicated marine science voyages across the Australian Antarctic marine jurisdiction to provide information essential for:
  - marine environmental management
  - fisheries regulation and management
  - scientific research
  - effective demonstration of sovereignty.
- Developing its digital infrastructure capabilities to enable scientists to store, manage, discover, share and use Antarctic data.
- Developing its Antarctic ground station capabilities to further support the polar orbiting Earth observation satellite missions of key space agency partners, becoming an active contributor to their Antarctic activities.
- Further developing the Digital Earth Australia initiative to include Antarctica and the Southern Ocean.
- Continued support for existing logistics infrastructure including stations, cargo, aviation and communications and further developing these to provide year-round aviation and deep-field overland traverse capabilities to enable greater access to the AAT.

If implemented, these increased capabilities would:

- measurably augment Australia's physical presence and international visibility within the AAT and adjacent marine jurisdiction,
- improve the available geoscience information for informing and advising government on Antarctic policy and issues, including economic opportunities and environmental considerations,
- provide a wealth of data to enable scientists to conduct world-class scientific research,
- enable development of international collaboration and co-operation between nations active within East Antarctica.

Contents

1 Executive Summary

Geoscience Australia (GA) is the national geoscience agency that provides geoscientific advice to the Australian Government to support national priorities and interests for Australia and external territories, including the Australian Antarctic Territory. Underpinning that advice, GA has deep domain knowledge of the science of Australia's lands and waters. GA conducts a diverse range of terrestrial, marine and spatial science research and monitoring activities, provides geoscience products and services that address national and international issues and contributes to the evidence base for informed policy development and decision-making.

GA provides geoscience information and advice on the Australian Antarctic Territory (AAT) and adjacent marine jurisdiction, supporting Australia's Antarctic strategic interests and obligations under the Antarctic Treaty System (ATS). GA also operates geophysical monitoring observatories, including seismic, geomagnetic, infrasound (under construction) and geodetic observatories, in the AAT that form key components of Australia's scientific infrastructure, and contribute to Australia's international treaty obligations.

Against this background, GA presents this submission for the inquiry into Australia's Antarctic Territory by the Joint Standing Committee on the National Capital and External Territories. This submission draws on the integrated and diverse nature of geoscience and spatial activities conducted at GA and the knowledge that outcomes of these activities support Australia's national interests as they relate to the AAT and adjacent marine jurisdiction. This submission focusses on current infrastructure assets that GA operates and utilises and the capability of that infrastructure to support desired outcomes for the nation. In addition, opportunities and benefits for future infrastructure assets and capabilities are identified. GA considers both traditional physical infrastructure as well as digital infrastructure to be critical in the work we do and as such both are included in this submission.

Australia's Antarctic infrastructure assets support a range of geoscience activities and objectives which address Australia's long-term strategic national interests, enable scientists to conduct world-class scientific research, foster economic opportunities, and directly contribute to Australia's capacity for influence, and meeting our environmental obligations, under the Antarctic Treaty System (ATS). The various infrastructure assets range in their capability to support the various activities and objectives. While some future infrastructure capabilities are addressed in the Australian Antarctic 20 Year Action Plan, Geoscience Australia has identified a number of areas where increased infrastructure capability is required to maintain and support Australia's engagement in Antarctica.

Currently, Australia's Antarctic activities, and the infrastructure supporting these activities, are concentrated around the three continental stations (Casey, Davis and Mawson). However, for Australia to maintain its national interests in Antarctica, serve the scientific program into the future (as outlined in the Australian Antarctic Science Strategic Plan 2011-12 to 2020-21), foster economic opportunities such as sustainable fisheries and tourism, and remain influential within the ATS, Australia needs to demonstrate its capability to undertake activities across the entire AAT and adjacent marine jurisdiction. This requires infrastructure capable of supporting these activities.

This submission includes a number of recommendations regarding infrastructure assets and capability in the AAT. In summary, Geoscience Australia recommends the Australian Government consider:

- Maintaining and expanding its geophysical monitoring observatories in Antarctica.
- Developing a strategic, priority-driven approach for the new icebreaker to undertake dedicated marine science voyages across the Australian Antarctic marine jurisdiction.
- Developing a data acquisition and data management plan for the new icebreaker.

- Developing its digital infrastructure capabilities which will enable scientists to store, manage, discover, share and use Antarctic data.
- Developing its Antarctic ground station capabilities to further support the polar orbiting Earth observation satellite missions.
- Investigating the value proposition and viability of an undersea communications cable to Antarctica.
- Further developing the Digital Earth Australia initiative to include Antarctica and the Southern Ocean.
- Continued support for existing logistics infrastructure and further developing these to provide year-round aviation and deep-field overland traverse capabilities.

In order to expand GA's infrastructure assets and capability in Antarctica, additional appropriation funding would need to be allocated to Geoscience Australia specifically to undertake these additional activities.

2 Overview of Geoscience Australia's activities in Antarctica

The Australian Government maintains a policy of effective engagement in the AAT including the adjacent marine jurisdiction (Fig. 1). While Australia strongly supports the Antarctic Treaty, it also carries out activities that support Australia's long term position, i.e. activities that demonstrate a presence and capability to manage the region. Installation of infrastructure and field-based activities such as mapping[1] are the most effective means of demonstrating sovereignty within the AAT and the adjacent marine jurisdiction.

Geoscience Australia supports the Government's engagement in the AAT and adjacent marine jurisdiction by conducting a diverse range of geoscience[2] activities in Antarctica. These activities include:

- geophysical monitoring,
- marine and terrestrial geoscience (research, mapping and advice),
- Earth observations from space,
- geospatial information and advice.

[1] Mapping refers to the graphic representation of real world features (coastlines, rivers, infrastructure, geology, seafloor morphology etc.) on a paper map or computer screen. The process of *mapping* requires collection of field and/or remotely sensed observations and measurements and the subsequent compilation of Geographic Information Systems (GIS) datasets to create digital map products.

[2] Geoscience, for the purposes of this submission, broadly encompasses geology (study of the rocks that comprise the Earth), geomorphology (study of surface landforms), geophysics (study of the physical properties of the Earth) and geospatial (geographic information describing the location and names of features beneath, on or above the Earth's surface).

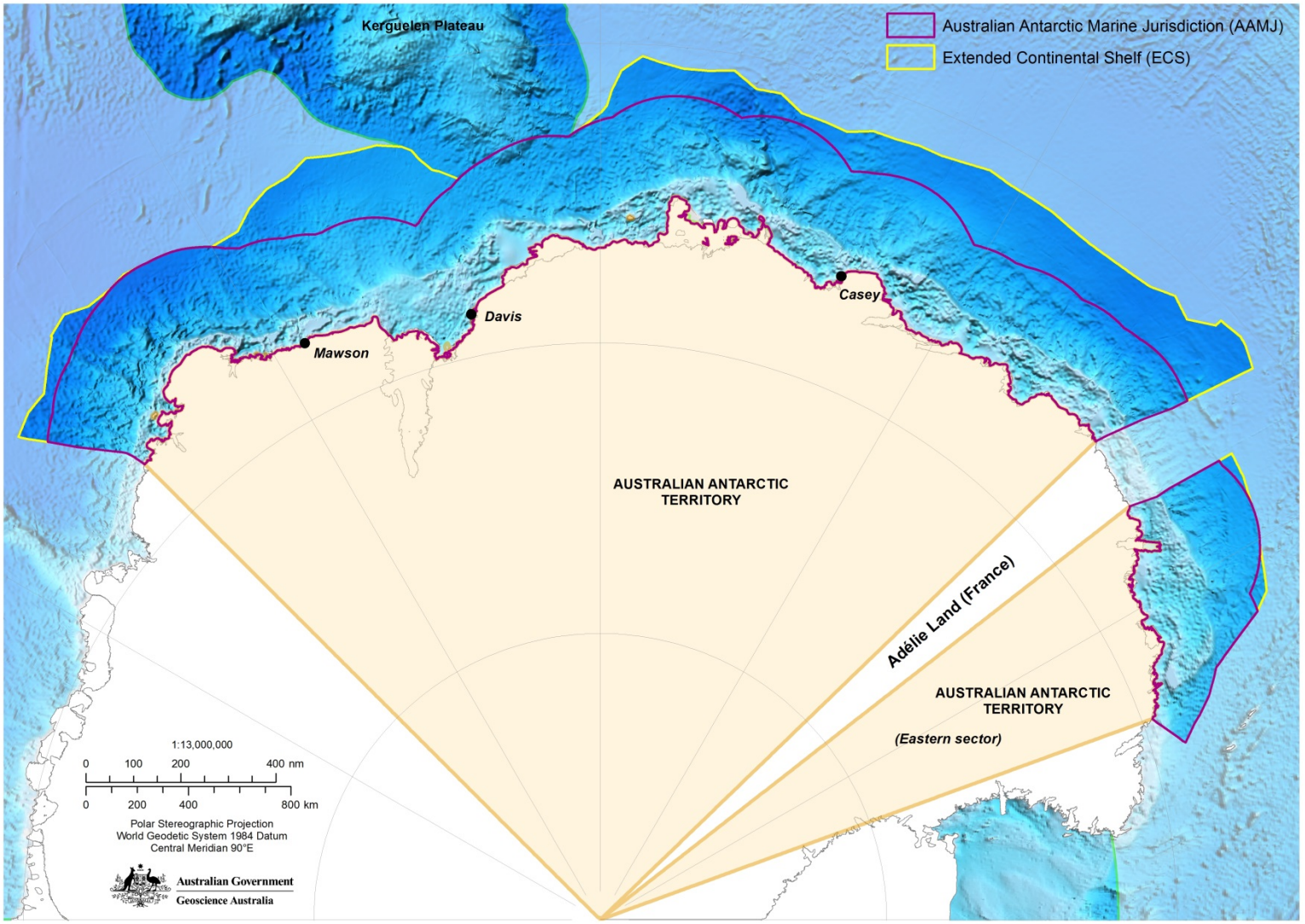

Figure 1: Australia's Antarctic Territory and adjacent marine jurisdiction (the Australian Antarctic Marine Jurisdiction)

It should be noted that the Australian Antarctic Territory and adjacent marine jurisdictions discussed in this submission are substantial geographic areas, as outlined below:

- The Australian Antarctic Territory is **5.9 million km^2** (~42% of Antarctica)
- The Australian Antarctic marine jurisdiction is **2.2 million km^2** (~15% of Australia's total marine jurisdiction). This includes the Territorial Sea (12 nautical mile limit) and Exclusive Economic Zone (200 nautical mile limit). There is an additional 0.68 million km^2 of extended continental shelf (ECS) beyond the EEZ that remains to be resolved and is not included.

2.1 Geophysical Monitoring

Geoscience Australia's geophysical monitoring program (of which the Antarctic observatories are an essential component) is critical for a diverse range of applications such as navigation, national planning and developmental activities, cadastral and engineering surveys, airborne geophysical surveys, topographic mapping, as well as for detecting nuclear explosions and potentially tsunamigenic earthquakes.

Geoscience Australia operates geodetic, seismic, geomagnetic and infrasound (currently under construction) observatories at the three Antarctic stations (Casey, Davis and Mawson) and Macquarie Island. These observatories are key nodes in global networks of similar observatories that monitor various Earth processes and are used to derive a number of fundamental scientific datasets and products, many of which are directly relevant to Australia's Antarctic Territory and adjacent marine jurisdiction.

GA also maintains geodetic and gravimetric survey mark networks across exposed rock areas predominantly in the Prince Charles Mountains, near Casey station and in the Vestfold and Larsemann Hills. These networks are an essential component of the global reference frame which supports scientific understanding of plate tectonics, sea level rise, post-glacial rebound and ice sheet dynamics and geospatial activities such as mapping.

2.2 Marine Geoscience

Geoscience Australia's Antarctic marine geoscience activities produce fundamental information and products, including maps, which support a diverse range of applications, including:

- operational requirements, e.g. nautical charts, infrastructure development and facilitating search, rescue and recovery operations
- scientific research, e.g. oceanography, benthic ecology, paleoclimate studies, ice sheet dynamics and tsunami modelling
- strategic national interests, e.g. fisheries management, definition of maritime boundaries, evidence-based marine environmental management.

Our marine geoscience activities acquire, compile, analyse, integrate and interpret a spectrum of physical, biological and spatial marine datasets across a range of scales (continental, regional, local), including bathymetry, acoustic backscatter, substrate composition, benthic imagery, and sub-bottom profiles. This data is used to produce accurate and high-resolution maps of the seafloor which characterise the seafloor morphology, benthic habitats, sedimentary processes and subsurface geology.

Bathymetry data is a fundamental input to tsunami modelling and, in 2017, data for Antarctica and Macquarie Island has been used for the first time in the national offshore tsunami hazard assessment. This information is used to support tsunami planning.

A comprehensive understanding of the seafloor environment can be used to identify key natural assets, improve maritime safety, inform sustainable fisheries management and inform marine environmental management strategies. An understanding of the physical controls on the distribution of Antarctic marine ecosystems is used to support, in particular, the proposed representative systems of Marine Protected Areas around the east Antarctic continental margin, currently under consideration by CCAMLR[3]. Information on sedimentary processes and subsurface geology is essential for defining maritime boundaries in areas of extended continental shelf.

2.3 Terrestrial Geoscience

Geoscience Australia's terrestrial geoscience activities acquire and produce a range of fundamental geological, geomorphological and geophysical datasets and maps to support onshore environment management practices in the AAT. Geological and geomorphological mapping is essential for landscape vulnerability and geoheritage assessments which identify and characterise fragile landforms in high-use regions near Australia's Antarctic stations and sites of intrinsic geological significance in the Antarctic. These activities inform the development of appropriate environmental management and protection strategies for the AAT under the Committee for Environmental Protection (CEP)[4].

2.4 Earth Observations from Space

Geoscience Australia uses Earth Observations from Space (EOS), i.e. observations of Earth collected from satellites, to observe and monitor the AAT and adjacent marine jurisdiction. Satellites enable routine observation of the land, oceans, atmosphere and sub-surface, and gather information regularly across large and remote areas. Satellite observations can be used for time-series measurements and observations which can aid the understanding of the ice sheet dynamics and enable assessment of change, such as ice mass and coastline position, over time. This information is required for accurate and precise delineation of maritime boundaries and as essential support for regional mapping programs.

Geoscience Australia uses satellite observations to fill data gaps where traditional, ground-based observations are not possible, e.g. satellite-derived bathymetry in waters too shallow for workboats or where seasonal sea-ice prevents access. GA has also used satellite observations to assist in search and rescue operations, e.g. to locate the 2010 French helicopter crash. In addition, Geoscience Australia acquires archives of the Landsat satellite series over Antarctica and is a member of the Copernicus Data Hub which acquires the Sentinel satellite constellation over Antarctica. The potential for using EOS in Antarctica, particularly for environmental monitoring, is significant.

[3] The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) is a convention under the Antarctic Treaty System (ATS). Australia is a signatory to of both CCAMLR and the ATS.

[4] The CEP was established within the Antarctic Treaty System to advise on the development and implementation of the Protocol on Environmental Protection to the Antarctic Treaty (The Madrid Protocol)

2.5 Geospatial Information and Advice

Geoscience Australia is the Australian Government's national mapping agency and provides authoritative location information and geographic services, spatial analysis and advice.

Geoscience Australia is responsible for topographic map products and underlying geographic digital datasets. These are a fundamental requirement supporting a wide range of field-based activities within the AAT and enable more efficient logistics planning. Topographic information (including elevation and obstacles) provide the essential baseline data for aeronautical charts. Accurate aeronautical charts are essential for safe air travel in Antarctica, and improve efficiency of planning, logistics and field operations for research activities, including minimising ecological effects from noise and landing planes.

Geoscience Australia is responsible for defining Australia's maritime boundaries and providing geospatial advice on Australia's maritime jurisdictional limits, including the United Nations Convention on the Law of the Sea (UNCLOS). The delineation of these boundaries has strategic, economic and environmental implications.

2.6 Digital Infrastructure

Geoscience Australia is expanding the capability of its digital infrastructure in support of the National Collaborative Research Infrastructure Strategy and the Government's National Innovation and Science Agenda and Digital Transformation Agenda. The Science First program is building GA's scientific data and computing capability and capacity. It will deliver fit-for-purpose technology platforms and processes which will enable scientists to store, manage, discover, share and use data.

Programs such Science First rely upon collections of Analysis Ready Data (ARD) which is stored in a super computer or cloud environment so that scientists can conduct analysis over any data in the archive at any time and of any scale of computation.

The recently funded Digital Earth Australia initiative is an exemplar of these digital infrastructure capabilities. The DEA platform stores petabytes of satellite data over continental Australia for rapid answers to environmental policy issues such as water quality, biomass, and habitat mapping.

3 Current infrastructure overview and future requirements

Geoscience Australia operates and utilises a range infrastructure assets in the AAT and adjacent marine jurisdiction. These assets directly support Australia's national interests in Antarctica and, in some instances, form part of global infrastructure networks.

Historically, the infrastructure Geoscience Australia operates and utilises has been solely traditional, physical infrastructure, however, new technologies and the Government's digital agenda will see considerable advancement in digital infrastructure over coming years.

Geoscience Australia operates infrastructure in Antarctica and also utilises the infrastructure operated by other organisations, as outlined in Table 1.

Table 1: Infrastructure operated or used by GA

Infrastructure Type	Locations	Operator	Purpose
Geodetic network (GPS stations and survey marks)	Antarctic stations Remote field sites	GA	Geophysical monitoring (see section 3.1)
Gravimetric network (Absolute gravity stations and gravity marks)	Antarctic stations Remote field sites	GA	Geophysical monitoring (see section 3.1)
Geomagnetic observatories	Antarctic stations	GA	Geophysical monitoring (see section 3.1)
Seismic observatories	Antarctic stations	GA	Geophysical monitoring (see section 3.1)
Infrasound station	Antarctic station (Davis)	GA	Geophysical monitoring (see section 3.1)
Meteorological satellite ground stations	Antarctic stations	Bureau of Meteorology	Earth Observations from Space (see section 3.3)
Icebreaker (RV *Aurora Australis*)	Antarctic stations Australian Antarctic marine jurisdiction	Australian Antarctic Division	Logistical support (personnel and cargo transport) Marine geoscience research (see section 3.2)
Workboats	Antarctic stations	Australian Antarctic Division Royal Australian Navy	Marine geoscience research (see section 3.2)
MNF RV *Investigator*	Australian Antarctic marine jurisdiction	CSIRO	Marine geoscience research (see section 3.2)
International ships	Australian Antarctic marine jurisdiction	Various	Marine geoscience research (see section 3.2)
Aviation (includes aircraft and helicopters)	Wilkes runway Australian stations Remote field sites	Australian Antarctic Division Various international collaborators	Logistical support (personnel and cargo transport) (see section 3.4)
Permanent stations	Australian stations	Australian Antarctic Division	Logistical support (accommodation, field operations) (see section 3.4)
Seasonal (summer only) stations	Bunger Hills (Edgeworth David) Larsemann Hills (Law Base)	Australian Antarctic Division	Support for field operations (see section 3.4)
Field camps	Remote field sites	Australian Antarctic Division	Support for field operations (short-term) (see section 3.4)
Copernicus Data Hub	Virtual	GA, CSIRO, NSW/WA/QLD governments	Earth Observations from Space (see section 3.3)

To maintain and enhance Australia's national interests in Antarctica and to serve the scientific program into the future, GA envisages the following infrastructure opportunities:

- New icebreaker – for continued logistical support and enhanced marine geoscience capability
- Expanded aviation capability – to provide greater access and flexibility for field programs
- New satellite ground stations – to support polar orbiting satellite missions for both scientific and commercial purposes
- New geophysical observatories – to expand the globally distributed networks of sensors
- New autonomous underwater vehicles – to increase marine geoscience capabilities
- Expanded digital infrastructure – to enable access to large volumes of data relevant for Antarctic science, policy, management and logistics and to support the Government's digital agenda.
- New deep-field overland traverse capability – to improve science leadership and provide access for field programs across the AAT.

3.1 Geophysical Monitoring (Observatories)

Geoscience Australia operates an integrated geophysical observing system, of which the Antarctic observatories are an essential component. The observing system consists of four key elements:

- Geodetic: maintains and develops a precise geodetic infrastructure that supports research and global geospatial activity
- Geomagnetic: monitors geomagnetic-field changes
- Seismic: monitors global earthquake activity and nuclear tests
- Infrasound: monitors nuclear tests.

The geophysical observing system is comprised of a network of physical monitoring and observing stations at various locations (Table 2). Geoscience Australia installs, operates and maintains the network of stations and sophisticated instrumentation that monitors natural and anthropogenic hazards in Australia and around the globe.

Table 2: Observatories in Antarctica currently operated by GA

Infrastructure Type	Number and locations	Purpose
Geodetic network (GPS stations and survey marks)	4 - Continuous Operating Reference Stations (CORS) (Casey, Davis, Mawson, Macquarie Island) 6-7 – 'Campaign' GPS stations (various remote locations) 403 - survey marks (rocky outcrops across AAT)	• Form part of the Australian Antarctic GNSS Network and Australian Regional GNSS Network • Improving and extending the International Terrestrial Reference Frame (ITRF) • Monitoring deformations of the solid Earth • Variations in sea level and in earth rotation • Determining orbits of scientific satellites • Monitoring the troposphere and ionosphere
Gravimetric network	3 – absolute gravity base stations (Davis, Mawson, Casey) 2 – gravity reference marks (Wilkes, Casey)[5]	• Benchmark for gravity surveys, including the international collaborative airborne gravity program (ICECAPII)
Geomagnetic observatories	3 – Casey, Mawson, Macquarie Island	• Forms part of the Geoscience Australia geomagnetic observatory network • Geomagnetic reference field modelling • Compass navigation • Space weather monitoring • Airborne geophysical surveys and research
Seismic observatories	3 – Casey, Mawson, Macquarie Island	• Form part of the Australian National Seismograph Network (ANSN) • Earthquake monitoring • Tsunami warning • Nuclear test monitoring • Part of the CTBTO global verification system
Infrasound array	1 – Davis station (under construction)	• Nuclear test monitoring • Forms part of the International Monitoring System (IMS) Infrasound network • Part of the CTBTO global verification system • Supports Comprehensive Nuclear Test Ban Treaty

[5] There are additional historic gravity reference marks in the AAT; however these have been infrequently visited in recent years and are unlikely to be used now technology has advanced to focus on absolute gravity stations and airborne gravity surveys.

Geodesy: Geodesy provides the fundamental reference frame that enables accurate positioning, navigation and mapping on the Earth's surface. The Australian geodetic program, including its field work and computations carried out in Antarctica, contributes to the development of the International Terrestrial Reference Frame (ITRF), within which all positioning activities in Antarctica are undertaken. The geodetic program therefore supports, directly or indirectly, navigation of aircraft and ships, and the monitoring of the atmosphere, oceans and coastal zones.

Geodetic networks are a continually evolving infrastructure. The Australian Antarctic Geodetic Network (AAGN) commenced in the mid-1960s and consists of over 400 permanent survey marks on stable rock across the AAT. In the mid-1990s, GA increased its geodetic capability on the Antarctic continent with the installation of new infrastructure using Global Positioning Systems (GPS). Four Continuously Operating Reference Stations (CORS) were installed at Casey, Davis, Mawson and Macquarie Island. These four stations provide Global Navigation Satellite System (GNSS) data in support of three dimensional positioning, meteorology, space weather, and geophysical applications and form the Australian Antarctic GNSS Network. In recent years, GA and the Australian National University have augmented the CORS stations with part-time, 'campaign' GPS sites in remote rocky locations across the AAT, including the Prince Charles Mountains, Grove Mountains, Bunger Hills, and Enderby Land. To date, these sites operate predominantly over the Australia summer period using solar power. These 'campaign' GPS stations typically only last 2-3 years.

As user requirements change and new techniques become available the design and functionality of the network needs to change as well. Increasingly, users of the AAGN are expecting it to be an active network rather than a passive network consisting of unoccupied survey marks. The demand for active Global Navigational Satellite System (GNSS) stations whose data is available to the broader research community is increasing and there is an emerging interest in the use of gravimetry as an independent constraint on height variation. Effort needs to be placed in developing autonomous remotely operating systems that operate reliably over both summer and winter periods. This will also allow the study of the seasonal effects on tectonic motion not to mention a large variety of glaciological topics. Finally, the integration of all ground- based techniques with satellite-based observations will result in a better understanding of the dynamics of Antarctica at local, regional and continental scales.

Gravity: The gravimetric network consists of a number of permanent reference marks including three absolute gravity base stations (Davis, Mawson and Casey). These are co-located with GNSS Continually Operating Reference Stations and provide information on vertical movements of the Earth's crust. The absolute gravity station at Casey will also provide a valuable benchmark for the multi-year multi-national airborne geophysics program (ICECAPII). There are numerous historical gravimetric reference marks across exposed rock areas in the AAT, but these have been infrequently visited in recent years.

Seismic monitoring: Geoscience Australia operates and maintains three seismological stations in the AAT at Casey, Mawson and Macquarie Island. These form part of the Australian National Seismograph Network (ANSN), a state-of-the-art network of stations and sophisticated instrumentation that monitors natural and anthropogenic hazards in Australia and around the globe. Data from these ground stations are a key component of the regional tsunami warning network (Australian Tsunami Warning System), and support studies of continental plate motions. The stations are operated jointly by Geoscience Australia and the United States Geological Survey.

Geomagnetic monitoring: Australia's three geomagnetic observatories in Antarctica – at Macquarie Island (established in 1952), Mawson (1955) and Casey (1999) – monitor the Earth's continuously changing magnetic field and form part of wider Australian and international observatory networks. These observatories provide continuous, time-series data which is used in regional and global

mathematical models of the geomagnetic field, space weather monitoring and scientific research. The data and information provided by geomagnetic observatories are required by international treaties to support maritime and aviation compass navigation and by airborne geophysical surveys to study the nature of the Antarctic continent below the ice cover. Other applications include magnetic direction-finding, space weather monitoring, magnetic detection, and the mitigation of geomagnetic hazards.

Nuclear monitoring: Stations in Antarctica, notably the seismological station at Mawson and infrasound array at Davis (under construction) contribute to the global monitoring of nuclear tests. These stations are listed as part of the International Monitoring System of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) which Australia has signed and ratified. Australia's obligations under the Treaty include the establishment, operation, maintenance and upgrade of these Antarctic stations, and the provision of uninterrupted data.

GA commenced construction of an infrasound array near Davis station in the 2016-17 summer. Data from this array will form part of the verification regime for the enforcement of the CTBT by detecting low frequency acoustic waves that are generated by atmospheric explosions. The arrays are used to determine the direction of the arriving pressure wave and locate the sources of the potential explosion. Natural sources of infrasound waves are from volcanic eruptions, meteorites and storms. The data from the arrays are sent directly to the Comprehensive Nuclear-Test-Ban Treaty Organisation (CTBTO) for analysis and directly to GA for data quality monitoring.

Geophysical data from the observatory network is acquired, quality controlled and delivered 24 hours a day, 7 days a week in near real-time and distributed for magnetic field monitoring, tsunami monitoring, national and international earthquake detection. In addition, weekly geomagnetic observations are recorded year-round by over-wintering staff at the three locations.

Australia has no permanent geophysical observatories in the eastern sector of the Australian Antarctic Territory (AAT), inland away from exposed rock outcrops, or west of Mawson in Enderby Land. Expansion of observatory, geodetic and gravity infrastructure is important for two reasons. Firstly, Antarctica is a geographically important location for elements of the globally distributed networks of sensors. Secondly, the same sensors assist Antarctic science activities.

Recommendations:

- Australia continues to maintain and support its geophysical monitoring observatories in the Antarctic.
- Australia considers expanding the geophysical monitoring network to include areas such as the eastern sector, Enderby Land and inland.

3.2 Marine Geoscience

Marine geoscience information within the Australian Antarctic Marine Jurisdiction (AAMJ) is acquired by dedicated and targeted marine surveys utilising the marine geoscience capabilities of Australia's icebreaker (RV *Aurora Australis*), the Marine National Facility (RV *Investigator*) and foreign icebreaker vessels. Smaller vessels owned and operated by the AAD (*RV Howard Burton*) and Royal Australian Navy (ASV *Wyatt Earp*) are used to conduct near-shore surveys in the high-use, shallow water regions around the three Australian Antarctic stations.

Comprehensive seabed mapping requires vessels equipped with suitable marine geoscience equipment. Multibeam echosounders acquire high-resolution bathymetry data that are used to produce accurate, full-bottom coverage maps of seafloor topography. In addition, acoustic backscatter

data acquired concurrently can be used to determine seafloor composition and texture. These datasets form the physical framework for understanding the seafloor environment. Sediment samples and underwater images are used to ground-truth multibeam data and improve the broad-scale physical interpretation, and are also used for understanding marine biodiversity. Seismic reflection systems provide information on the sub-surface and are used to understand the structure of the continental shelf and for identifying sedimentary deposits.

The RV *Aurora Australia* has limited capacity to undertake comprehensive seabed mapping activities, largely due to lack of suitable equipment. Most notably, the *RV Aurora Australis* in only equipped with a single beam echosounder, rather than a multibeam echosounder. Coverage of single-beam sonar data in the AAMJ is quite variable with good coverage limited to the areas immediately adjacent to the three Australian stations. However, even in areas of good data coverage, the minimum track spacing is several kilometres apart and these data are not very useful for the purpose of seafloor mapping. Collection of sediment samples and underwater imagery is possible on the RV *Aurora Australis*; however, there is limited ship time available for marine science surveys. The RV *Aurora Australis* sails for 180 Government-funded days per year but in the last 10 years, only two surveys have acquired marine geoscience information (samples and seafloor imagery) and both of these surveys were in the same general location (George V Shelf near the Mertz Glacier).

The new Australian Marine National Facility (MNF) research vessel, the RV *Investigator*, supports marine research in the Southern Ocean, including within the Australian Antarctic marine jurisdiction. This ship is equipped with the latest, state-of-the-art marine geoscience equipment, including two multibeam echosounders, allowing mapping across all ocean depths. It also has seismic capability with the final parts of the seismic acquisition systems currently being procured by the MNF and GA. In addition, sediment coring technology allows the collection of long climate records for the first time from an Australian vessel. The vessel is ice-strengthened and can conduct research activities as far south as the Antarctic sea-ice edge. Therefore, this new research vessel represents a significant shift in marine geoscience capability in the AAMJ. The RV *Investigator* conducted its maiden voyage to Antarctica in early 2017 and collected more detailed multibeam bathymetry in the AAMJ during this one survey than all previous detailed mapping surveys combined[6]. However, it is worth noting that the RV *Investigator* has had its research expedition time cut from 300 days to 180 days per year, limiting opportunities available to scientist to utilise its facilities in the AAMJ.

The Australian Antarctic Division's workboat *Howard Burton* and the Royal Australian Navy's ASV *Wyatt Earp* are available annually during the austral summer (November-April) to conduct hydrographic surveying and seabed mapping surveys. The *Howard Burton* does not have any specialised marine geoscience equipment but has a moonpool and davit which is used to deploy Geoscience Australia's multibeam echosounder, sediment grabs, underwater cameras and sub-bottom profiler during shallow-water seabed mapping surveys. The ASV *Wyatt Earp* is equipped with a shallow-water multibeam echosounder.

The *Howard Burton* and *Wyatt Earp* must be deployed to Antarctica by ship (future deployment by air on board the C17 is currently being investigated). Therefore, their use is dependent on cargo availability and shipping schedules. The *Wyatt Earp* is scheduled to be decommissioned in 2020. The multibeam systems on the *Howard Burton* and *Wyatt Earp* are only suitable for mapping shallow waters (<300 m). Further, the search and rescue (SAR) requirements for these vessels limit their geographic range and surveys are largely limited to working near-shore, adjacent to the stations.

[6] Based on coverage of multibeam bathymetry data and only including detailed mapping, i.e. areas covered by more than a single swath track.

Surveys on the *Howard Burton* and *Wyatt Earp* are also only possible through the availability of additional infrastructure in the form of cargo and personnel transport to Antarctica (via ship or aviation) and on-ground logistical support at the stations, e.g. wharves, plant equipment, workshops, communications and accommodation.

Geoscience Australia currently operates some digital infrastructure to store, manage and share marine geoscience datasets. This includes the MARS (MARine Sediments) database and Australian Marine Spatial Information System (AMSIS). The MARS database contains detailed information on seabed sediment characteristics for samples collected from Australia's marine jurisdiction, including Antarctica. It is an important scientific resource that includes survey and sample information such as locations, water depths and sample descriptions. AMSIS is a web-based interactive mapping and decision support system that improves access to integrated government and non-government information in the Australian Marine Jurisdiction, including Antarctica. AMSIS contains many layers of information including maritime boundaries, fisheries, regulatory data, and environmental attributes.

The current digital infrastructure for marine geoscience data is limited in scope. National digital infrastructure initiatives such as the Integrated Marine Observing System (IMOS) and the Australian Ocean Data Network (AODN) are largely focussed on oceanographic data and hold little marine geoscience data.

The Australian Antarctic Division (AAD; Department of the Environment and Energy) is in the process of delivering a new icebreaker to the replace the Australia's ageing Antarctic research and supply vessel (RV *Aurora Australis*). This new vessel will have the capability, equipment and technology needed to map and sample the seafloor primarily along the Australian Antarctic Territory continental shelf and slope as well as the adjacent deep ocean abyssal basins. The new icebreaker is scheduled to be operating from the 2020–2021 summer.

Increased seabed mapping capabilities will also be provided by a tender vessel that is part of the new icebreaker specifications. This vessel will be useful for nearshore mapping close to the ship and in areas away from stations, overcoming the current limitations on workboats.

Marine geoscience capabilities of both the replacement icebreaker and the RV *Investigator* are intended to be 'seamless', in that, subject to the specialised design requirements necessary for an icebreaker, both vessels will be equipped with similar state-of-the-art equipment and instrumentation. Together, these vessels will provide Australia with a modern marine research capability that can support marine geoscience objectives over the next 20 to 30 years.

The Australian Antarctic marine jurisdiction is large (>2.2 million km^2) and remains largely unmapped. The new icebreaker offers the opportunity for Australia to collect unprecedented amounts of multibeam data, both during dedicated marine science voyages but importantly, also during transit whilst on resupply voyages to the three Australian stations. Only by collecting multibeam data on each and every voyage will Australia begin to fill the gaps in seafloor bathymetry data around the AAMJ. It is important to note, however, that with this new equipment also comes the need for additional expertise and data management capacity. The new data streams also require enhanced storage and management systems to avoid loss of data or timely access.

In particular, multibeam sonar equipment requires skilled staff to operate the system. It cannot simply be switched on and left unattended. Skilled staff need to be at sea to operate the systems, oversee the data collection process and manage the data. Further, processing the data in real time maximises the value of the equipment. Experience with multibeam sonar systems to date shows that the processing of data after the survey requires 10 times as long as during acquisition. Therefore, the new icebreaker needs to include staffing costs to operate and manage the new scientific equipment.

Acquisition of marine geoscience data in Antarctica is currently limited by sea ice and ice shelves which prevent access. In the future, new infrastructure, e.g. the Antarctic Gateway Partnership-funded Polar Automated Underwater Vehicle (AUV), will enable scientists to acquire high-resolution marine geoscience data in these previously inaccessible areas. AUV's will also overcome the limitations of shallow water surveys using the *Howard Burton* and *Wyatt Earp* by having a greater operational range beyond current SAR requirements.

Demonstration of Australian engagement in the AAT will be enhanced by collection of data and samples that contribute to consistent national data sets so that Australia collects, maintains and distributes data that are consistent right across the Australian marine jurisdiction. Use of the equipment on the new icebreaker vessel and its data management systems should therefore be developed in coordination with the Marine National Facility, the Integrated Marine Observing System and national data custodians such as the Australian Antarctic Division, Geoscience Australia and the Australian Hydrographic Service. Discussions have already commenced but an agreement on data management will need to be in place before the icebreaker commences sailing.

Development of digital infrastructure to store, manage, discover, share and use marine geoscience data is a current priority within Geoscience Australia. GA is pursuing the development of a system to store, manage and subset large volumes of spatial data. The information will be delivered using server-oriented architecture and web services. Flexibility in the ability to query and deliver data will be key in maximising uptake of the information by different stakeholders.

Recommendations:

- Australia develops a strategic, priority-driven approach for the new icebreaker to undertake dedicated marine science voyages across the Australian Antarctic marine jurisdiction
- Australia develops a data acquisition and data management plan for the new icebreaker to ensure:
  - multibeam data is collected on every voyage (including during transit)
  - skilled staff operate the new equipment and manage the data
  - there is coordination between relevant agencies
- Australia develops its digital infrastructure to store, manage, discover, share and use marine geoscience data.

3.3 Earth Observations from Space

Earth Observations from Space (EOS) are observations collected from satellites. Individual satellite observations can be used for a myriad of different applications, including weather and climate forecasting, ocean monitoring and identifying coastline position. Polar orbiting satellites are one of the most common types of Earth observation satellites and pass over Antarctica every 100 minutes. The data captured from these satellites is down-linked and commands from Earth are up-linked via satellite ground stations.

The Bureau of Meteorology operates two meteorological satellite ground stations in the AAT (Davis and Casey) but these can only receive a fraction of the EOS satellites currently imaging the world. Australia's only full capability satellite ground station is at Alice Springs which means Australia can currently only receive data captured from satellites which include Australia in their orbit.

A full capability satellite ground station (capable of both up-link and down-link) either in Tasmania, Macquarie Island or even Antarctica would be capable of seeing every polar orbiting satellite on Earth

every 100 minutes. The key to a full capability site would be high speed optical fibre communications to mainland Australia.

Geoscience Australia operates and maintains digital infrastructure to enable Earth observations from space, including over Antarctica and the Southern Ocean. This includes an archive of the Landsat satellite series and the Copernicus Australia data hub. Copernicus Australia is a regional data hub providing access to satellite observations from Europe's Sentinel satellite missions over the region, including East Antarctica and the Southern Ocean. The hub is operated by a consortium of GA, CSIRO and the NSW, WA and Queensland governments. The National Computational Infrastructure (NCI) operates the master data repository for the hub. This virtual observatory brings petabytes of data from the Antarctic region to Australia for scientific analysis and forms a consolidated approach to enhance access to satellite Earth observation data for scientific research.

The recently announced Digital Earth Australia (DEA) initiative is a digital infrastructure platform which translating almost 30 years of data into readily accessible information and insights about Australia's changing landscape and coastline. DEA will build on the globally recognised innovation, the Australian Geoscience Data Cube; which was the winner of the 2016 Content Platform of the Year at the Geospatial World Leadership Awards and was developed as a partnership between GA, CSIRO and the National Collaborative Research Infrastructure Strategy (NCRIS) supported National Computational Infrastructure (NCI).

While Digital Earth Australia will make it quicker and easier to access Earth observation satellite data, the current DEA initiative only covers continental Australia. However, the source data for Antarctica already exists within Australia. Australia should extend DEA to cover either Australia's Antarctic Territory, all of Antarctica, or all of Antarctic and the Southern Ocean, including Macquarie, Heard and McDonald Islands. This extension of DEA would organise all EOS data for Antarctica in a high-performance-computing domain. It would allow close monitoring of Antarctic through time-series' of radar and optical images to track glaciers, ice sheet dynamics, environmental change, human impact and other phenomena, and would provide a common high –performance computing environment for data management and modelling. The DEA would provide a common science resource for all Antarctic nations.

Recommendations:

- Australia develops its Antarctic ground station capabilities to further support the polar orbiting Earth observation satellite missions.
- Australia investigates the value proposition and viability of an undersea communications cable to Antarctica
- Australia further develops the Digital Earth Australia initiative to include Antarctica and the Southern Ocean.

3.4 General logistical support

Geoscience Australia's activities in the AAT require dedicated and targeted field surveys to install and maintain observatories and ground stations, gather data and samples and ground-truth remotely-sensed information (e.g. aerial photography, satellite imagery). Field activities require significant on-ground support in the form of cargo and personnel transfer to and from Antarctic stations (either by ship or aviation) and support at the stations, including accommodation and other facilities, logistics and communications.

The geophysical observatories require year-round communication infrastructure to enable the necessary real-time monitoring for geophysical observatory data. Station infrastructure and over-wintering staff are necessary for year-round, weekly geomagnetic observations.

Aviation infrastructure is used to transport Geoscience Australia personnel and some cargo to and from Hobart on the A319 aircraft. Fixed wing aircraft are utilised for intra-continental personnel and cargo transfers, and to support remote field operations. Helicopters are also used to support field operations. While the current aviation infrastructure is adequate to support Geoscience Australia's field activities, the limited number of inter- and intra-continental flights allows little flexibility for the timing and duration of field surveys.

Geoscience Australia supports the expansion of Australia's aviation capabilities in Antarctica, in particular a year-round runway at Davis station. This increased capability will improve access to Antarctica for field activities and provide greater flexibility in terms of timing and duration of field surveys.

Geoscience Australia has used the three Antarctic stations, Macquarie Island station as well as seasonal stations and remote field camps while conducting activities in Antarctica. These stations and camps are all adequate for Geoscience Australia's purposes.

Accurate geological, geophysical and topographic maps and accompanying digital datasets for the entire AAT are required to serve the needs of modern scientific research, environmental management, and Antarctic logistics and operations. Accurate Geographic Information System (GIS) datasets only exist in high-use areas (e.g. around stations). In other regions, GIS datasets are either non-existent or of poor spatial accuracy by modern standards. Currently, little or nothing is known of the ice-free area between Casey and the eastern limit of the AAT (eastern sector) and, in some regions, Australian field operations utilise Soviet-era topographic map products.

Access to remote parts of the AAT is required to gather essential baseline data for a range of mapping purposes. The proposed development of a deep-field overland science traverse capability will provide unprecedented access across East Antarctica. Geoscience Australia supports the development of Australia's overland traverse capabilities in Antarctica. This increased capability will improve access and enable mapping activities in parts of the AAT that Australia has never visited and cannot currently access.

Recommendations:

- Australia continues to support existing logistics infrastructure including stations, cargo, aviation and communications and further develops these to provide year-round aviation and deep-field overland traverse capabilities to enable greater access to the AAT.

4 Maintaining National Interests

The operation of infrastructure in the AAT and adjacent marine jurisdiction to produce geoscience information and products support Australia's Antarctic long-term strategic national interests, directly contributes to Australia's capacity for influence under the Antarctic Treaty System (ATS), enables scientists to conduct world-class research, fosters economic opportunities and facilities decision-making to ensure Australia meets its environmental obligations. Perhaps most importantly, installation of permanent infrastructure (e.g. observatories) and activities which utilise infrastructure (e.g. field

surveys) to produce tangible, up-to-date products such as maps and charts, are an effective means to preserve Australia's sovereignty over the Australian Antarctic Territory and adjacent marine jurisdiction.

4.1 Geophysical Monitoring

GA maintains critical infrastructure and delivers standards-compliant observed and derived data for Earth monitoring in Antarctica and links to similar organisations worldwide to add to global coverage. The geophysical monitoring network detects seismic and geomagnetic activity (and infrasound in the near future) in Antarctica and contributes to the foundation upon which the earthquake, tsunami, nuclear test, and geomagnetic monitoring functions of GA and the Department of Foreign Affairs and Trade are built. The network is also utilised by the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO).

Ground-based geophysical observatories provide:

- essential benchmarks for all geophysical activities,
- the geospatial framework that underpins Australia's GPS system
- information to enhance our understanding of the basic structure and behaviour of the Earth.

Perhaps most importantly, installation, operation and maintenance of physical observatory infrastructure provides tangible evidence of Australia's presence in Antarctica and are an effective means to preserve Australia's sovereignty over the Australian Antarctic Territory.

4.2 Marine Geoscience

High-resolution bathymetric maps of the seafloor, based on multibeam sonar data, are increasingly recognised within the Antarctic science, operations and environmental management communities as fundamentally important datasets. Coverage of high-resolution multibeam bathymetry of the Australian Antarctic marine jurisdiction is extremely limited (approximately 7%), yet much of this data has been collected as single swaths along ship tracks. Only 3% of Australia's Antarctic marine jurisdiction is considered "adequately mapped", i.e. multibeam data density is adequate for mapping seafloor features for scientific purposes (e.g. geomorphic features indicative of Antarctic ice sheet retreat), development of evidence–based marine environmental management, reducing risk for maritime operations and reinforcing sovereign interests. Further, with the exception of several shallow water surveys adjacent to Australia's stations in recent years, and the recent RV *Investigator* survey, high-resolution bathymetry data in the AAMJ has been collected by other nations (Germany, France, USA, and Italy).

Coverage of other marine geoscience datasets is variable. The Australian Antarctic and Southern Ocean Profiling Project (AASOPP) acquired seismic, magnetic and gravity data approximately every 90 km around East Antarctica. Sediment samples, underwater video and sub-bottom profiles which are important for seafloor geomorphology and benthic habitat mapping are mostly limited to a few focussed study areas.

Marine geoscience information is critical for supporting Australia's national interests, including:

- effective demonstration of sovereignty in the Antarctic region
- the maintenance and reaffirmation of maritime jurisdictional boundaries

- contributing to our knowledge of marine environmental assets and stewardship of the marine environment
- conducting world-class scientific research utilising state-of-the-art research vessels
- ongoing assessment of marine ecosystems to monitor changing environmental stresses and conditions associated with human activities on local, regional and global scales
- contributing to international fisheries industry management under CCAMLR
- enhancing Australia's capacity for influence under the Antarctic Treaty System and associated marine environmental protection protocols (CCAMLR)
- Minimising risks to maritime activities and facilitating search and rescue operations.

4.3 Earth Observations from Space

Earth observations from space are a powerful tool to support Australia's interests in Antarctica. Satellites enable routine observation of the land, oceans, atmosphere and sub-surface, and gather information regularly across large and remote areas. Time-series measurements and observations are particularly useful, for example, they can aid the understanding of the ice sheet dynamics and enable assessment of change, such as ice mass and coastline position, over time. This information is required for accurate modelling of sea level change, for accurate and precise delineation of maritime boundaries and as essential support for regional mapping programs.

Australia is well positioned to harness the potential of EOS without joining a very expensive race to space. Australia is highly regarded in the international community for:

- Applying EOS data to produce information of value to end users
- Expertise in managing large volumes of satellite data and making it available for analysis using high performance computing and other modern techniques (as demonstrated by the Digital Earth Australia initiative)
- Ability to operate the ground infrastructure, including antennas and communication links required to download data and upload essential command and control information.

In other words, Australia is internationally respected for its ability to translate what are often billion-dollar investments in space hardware into practical, on the ground results that provide the ultimate return on investment to the foreign governments who fund them. Satellite operators respect this contribution highly because it is an area they have found highly challenging.

Australia can build on these internationally recognised niche strengths to make targeted investments that enable access to the data that other nations can already collect. By investing in these areas, Australia has the very real potential to secure access to a comprehensive suite of information about the AAT at a fraction of the cost, and without the practical limitations of surface, sea or air-based observations. Investment in Earth observation data acquisition over the AAT would also reinforce Australia's sovereign interests.

These steps would also progress Australia's domestic space policy (the Satellite Utilisation Policy) and government planning to maintain space capabilities (Australia's National Earth Observations from Space Infrastructure Plan). These plans already identify the need to engage more actively with and as a contributor to international remote sensing efforts, to develop high performance computing systems that can extract information from data volumes that would otherwise be overwhelming, and to increase the geographic reach of Australia's ground station network to provide greater coverage of Australian territories and the region.

4.4 Geospatial Information

The Australian Government has proclaimed an Exclusive Economic Zone (EEZ) around the AAT and has prepared a claim[7] for an area of extended continental shelf (ECS) beyond the EEZ from the AAT (see Fig. 1). While the Australian Government does not enforce the Exclusive Economic Zone around the AAT and it has requested the UNCLOS not to assess the AAT ECS claim, it is imperative to demonstrate activity in these areas to support the claim should it be activated in the future. Activities to support the maritime boundaries claim include dedicated marine geophysical surveys and determining accurate positional information on the coastline utilising high-resolution satellite imagery.

The AAT coastline was defined by GA for the purposes of delineating maritime boundaries over 10 years ago. The baseline for delineating maritime boundaries in Antarctica is defined in many places by the edge of the permanent ice; however the dynamic nature of the Antarctic ice-sheet causes ongoing changes to the mostly ice-fringed Antarctic coastline. This has direct implications for the position of Australia's Antarctic maritime boundaries. High-resolution satellite images are required to provide spatially accurate and precise positional information of the AAT coastline. These changes need to be monitored via Earth observation techniques and Australia's Antarctic maritime boundaries modified accordingly.

The recent increase in air transport and air rescue within the AAT and neighbouring regions, as well as recent aircraft operational incidents, has highlighted the need for Australia to develop and maintain comprehensive, accurate and up-to-date aeronautical charts for the AAT. The coastline is also an important visual navigation aid; therefore, updates of the AAT coastline are needed. Most existing aeronautical charts of the AAT are in excess of 40 years old, pre-dating GPS and satellite elevation data, with some charts known to have vertical elevation errors exceeding 300 m. Up-to-date aeronautical charts would provide information for more efficient logistics and planning for AAT research activities and importantly, would ensure the placement of an Australian flagged product on the lap of all pilots working within the AAT, a useful demonstration of sovereignty.

5 Serving the scientific program into the future

5.1 Geophysical Monitoring

The Australian Antarctic Science Strategic Plan (2011-12 to 2020-21)[8] recognises geophysical observatories in Antarctica for their role in underpinning the diverse science portfolio and for being critically important to Australia's understanding of Antarctica.

The recently installed absolute gravity station at Casey will provide a valuable benchmark for the multi-year multi-national airborne geophysics program (ICECAPII). The ICECAPII program is collecting a range of airborne geophysical datasets, including ice-penetrating radar, LiDAR, gravity and magnetics, across large areas of east Antarctica. This information is being collected to better understand the volume and dynamic behaviour of the vast East Antarctic Ice Sheet, as well as the underlying bedrock topography and geological characteristics. The absolute gravity benchmark is essential to improving

[7] The Extended Continental Shelf claim is underpinned by information gathered by the Australian Antarctic and Southern Ocean Profiling Project (ASOPP) which involved the acquisition and interpretation of seismic, magnetic and gravity data approximately every 90 km around East Antarctica.

[8] p10, p16.

the utility and value of airborne gravity data for further use by Geoscience Australia and other science end-users.

Data from geomagnetic monitoring contribute to research into the nature of geomagnetic phenomena (particularly in auroral zones), Earth structures and processes, and solar-terrestrial physics. Geomagnetic data from Australian observatories in Antarctica are provided in near real-time to the Bureau of Meteorology Space Weather Services for space weather forecasting and research.

The geodetic infrastructure in Antarctica enables geophysical studies or the ice, ocean, atmosphere, ocean circulation and is used as a reference and calibration for Australian and international research programs that use geodetic and satellite-derived gravity data to study ice mass balance in Antarctica, such as Project POLENET, undertaken in the International Polar Year. Real-time positioning systems are also used by other science programs.

The Australian Antarctic GNSS Network aims to establish a reference framework for understanding the horizontal and vertical motion of Antarctica. It provides the geodetic infrastructure for all science programs using geospatial data. Improvements to these fundamental geospatial datasets would significantly enhance the capability of scientists to monitor and understand:

- Deformations of the solid Earth (e.g., Glacial Isostatic Adjustment),
- Determine the long-term movement of the Antarctic plate
- Variations in hydrosphere and cryosphere (e.g., sea level change, ice sheet dynamics),
- Earth rotation to better determine orbits of scientific satellites and monitoring the troposphere (i.e. atmospheric water vapour) and ionosphere

Furthermore, densification of the geodetic infrastructure (particularly in regions of the AAT for which there are no Australian geophysical monitoring capability) in collaboration with international collaborators (e.g. Geodetic Infrastructure of Antarctica (GIANT) Expert Group within the Scientific Committee on Antarctic Research) would:

- Enhance the common geospatial reference surface used by all scientists and operators,
- Provide fundamental positioning, navigation and timing data used to better map, monitor and model the AAT

5.2 Marine Geoscience

Together, the marine geoscience capabilities of both the replacement icebreaker and the RV *Investigator* will provide Australia with a modern marine research capability that can support marine geoscience objectives over the next 20-30 years and address the present paucity of seabed mapping.

Accurate and high-resolution mapping of the seafloor can be used to characterise the seafloor morphology and subsurface geological framework offshore from the AAT, thereby supporting a number of scientific objectives. This information would:

- Improve understanding of ice sheet dynamics and paleoclimate,
- Improve regional and global ocean circulation models,
- Improve our understanding of marine ecosystem dynamics and benthic habitats,
- Improve our understanding of tsunami hazard in the AAT.

Geoscience Australia has previously recommended a priority-driven, ongoing and systematic program of marine geoscience surveying, involving collection of datasets (geological, geophysical, and

bathymetric), expert analysis and interpretation of these datasets, and delivery of map products, critical for supporting Australia's Antarctic objectives. The long term goal of this mapping effort is to produce high-resolution seafloor maps and accompanying digital datasets that will serve the needs of modern scientific research, environmental management, and Antarctic logistics and operations. We reiterate the need for this marine geoscience program for this inquiry, noting that a recent Senate Inquiry into the Southern Ocean and Antarctic Waters[9] also recommended such a program:

> *Recommendation 12*
>
> *4.74 The committee recommends that resources be dedicated to the development and implementation of a Southern Ocean mapping program, as a whole-of-government initiative under the guidance and coordination of Geoscience Australia, and that such a strategy be included in future decisions about the allocation of funding and vessel time.*
>
> To ensure the full capabilities of the new icebreaker are fulfilled, it is imperative that a strategy be developed to ensure it undertakes priority-driven surveys.

5.3 Earth Observations from Space

The number of satellites is growing rapidly with new countries entering space, and new types of infrastructure being launched almost every year. The volume of Earth observation data continues to grow, offering opportunities to improve the understanding of our physical environment. Therefore, the potential for using EOS in Antarctica, particularly for environmental monitoring, is significant.

Inclusion of Antarctica in an expanded Digital Earth Australia (DEA) program (i.e. and Antarctic Geoscience Data Cube) will provide new opportunities for scientific research and will deliver a unique capability to process, interrogate, and present Earth observation satellite data in response to a range of issues. It will track changes in unprecedented detail, identifying human impacts, ecological changes, water quality, and changes to ice shelves and coastlines.

An Antarctic Geoscience Data Cube would be a focal point for international science cooperation for remote sensing and modelling, including linking improved observations of the Antarctic land mass to regional and global climate models.

The information within an Antarctic Geoscience Data Cube would also allow improved mapping of Antarctic topography and surface features (through higher resolution and increased availability of imagery), improved measurement of glacial movement through time-series analysis of optical data, improved mapping and monitoring of surface uplift and subsidence through inferometric analysis of satellite radar images.

[9] Senate Standing Committee on Foreign Affairs, Defence and Trade Inquiry into Australia's future activities and responsibilities in the Southern Ocean and Antarctic Waters (2014)

6 Fostering economic opportunities consistent with ATS opportunities

6.1 Marine Geoscience

Marine geoscience information is useful for fostering economic opportunities arising from Antarctic-related activities, including from well-managed Antarctic tourism and sustainable, well-regulated Southern Ocean fisheries.

Geoscience Australia provides marine datasets that support fisheries management and regulation in Antarctic waters. Essential datasets such as seafloor morphology, substrate type, bathymetry, and benthic ecosystem assessments are provided to the Australian Antarctic Division. This information is, in turn, utilised and considered by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR)[10] to enable effective and evidence-based decisions on regulating the fishing industry, marine environmental management and monitoring the state of Antarctic marine ecosystems.

The application of high-resolution multibeam sonar seafloor mapping provides detailed information on the morphology or 'submarine topography' on the seafloor. Such seafloor information is invaluable for informed assessment of likely habitats for benthic and pelagic biological communities and for understanding the influence of submarine topography on ocean currents, especially nutrient-rich currents. This information is fundamental to robust assessments of the spatial distribution of fish stocks and for the monitoring and surveillance of illegal fishing activities.

Paucity of adequate bathymetry data also limits the effectiveness of current fisheries management practise. For example, CCAMLR declared that a 2009 fishing conservation measure[11] (22-08) prohibits fishing (using any technique) of certain species (*Dissostichus* ssp., or Toothfish) in waters shallower than 550m in all CCAMLR management zones[12]. Currently, due to poor bathymetric data, the exact location of the 550 m contour is unknown, making planning by legal fishers and enforcement by CCAMLR nations difficult. Improved seafloor mapping coverage can precisely locate the 550m bathymetric contour and enable better fisheries management within Australia's Antarctic marine jurisdiction, contributing to Australia's marine environmental management commitments under CCAMLR. Other activities have suffered from poorly-defined bathymetry with experimental fishing surveys having difficulty finding sea floor of the right depth using existing charts and bathymetry compilations.

Safe navigation is fundamental to achieving the Australian Government's goal of a well-managed Antarctic tourism industry. Ship-based tourism requires access to coastal areas of the continent however, the coastal waters of the AAT are notorious for steep-sided pinnacles and reefs that are very difficult to detect with single beam echo sounders found on most vessels. Experience shows that they may lie undetected next to established shipping routes until a vessel strays marginally off course. Thus, access to coastal areas of interest to tourists is risky without good quality charts produced using high spatial resolution multibeam sonar equipment. Multibeam echo sounders are essential because of their ability to cover wide swaths of the sea floor, detecting steep-sided obstacles without having to

[10] CCAMLR is a convention within the Antarctic Treaty System (ATS). Australia is a signatory of both CCAMLR and the ATS

[11] http://www.ccamlr.org/sites/drupal.ccamlr.org/files//22-08.pdf

[12] CCAMLR management zones include all of the Australian Antarctic Marine Jurisdiction adjacent to the AAT, the EEZ around Heard and McDonald Islands, and the ECS of Kerguelen Plateau. CCAMLR management zones do not cover the EEZ around Macquarie Island or the associated ECS of Macquarie Ridge.

pass directly over them. Expanding Antarctic tourism in the AAT will require an increase in the number of locations tourist vessels will want to visit in competition with the mountain scenery of the Ross Sea and Antarctic Peninsula. At present, Cape Denison attracts visitors because of its historical significance associated with Mawson's Huts, but other coastal locations like Scullin Monolith could become attractive. Therefore, the ability to survey safe access routes and anchorages using the new icebreaker and its tender vessel will become important to achieving this goal.

6.2 Earth Observations from Space

There are currently four types of Earth Observation from Space missions: meteorological, defence, public good and private sector. A satellite ground station in Hobart, Macquarie Island, or Antarctica could support both Government and private satellite operators, and increase availability of services to the Antarctic and Southern Ocean. Australia could allow private sector missions to use excess down-link capacity of the site on a cost-recovery basis. Commercial usage of a satellite ground station would gain revenue, thereby subsidising the costs of the site.

Increasing the availability of satellite-based observations available through Government digital infrastructure portals (e.g. IMOS) will enhance economic opportunities of the Australian fishing industry, in line with CCAMLR fisheries management regulations. Satellite-remote sensing products describing ocean dynamics enable the fishing industry to more efficiently determine when and where to focus fishing efforts, thereby increasing the efficiency and value of their catch.

7 International engagement

7.1 Geophysical Monitoring

Antarctica is a geographically important location for elements of the globally distributed networks of sensors. Data from the geophysical observatory network in Antarctica contributes to improvement of a broad range of pivotal Earth and space-based datasets and products such as:

- The International Terrestrial Reference Frame (ITRF) which provides a coordinate foundation for all survey, mapping and Earth monitoring applications including absolute sea level rise monitoring. Additional geodetic observatories (i.e. Global Navigation Satellite System tracking stations) distributed throughout the AAT would improve satellite positioning in Antarctica, Australia and globally as well as supporting broader Antarctic science programs reliant on satellite positioning.
- The International Geomagnetic Reference Field (IGRF) which provides the geomagnetic vector, including the angular offset between True North and Magnetic North anywhere on Earth. This is used extensively for land, air and sea navigation, as well as a number of science programs.
- The global seismic datasets are gathered by a number of groups including the Incorporated Research Institution for Seismology (IRIS). These datasets are used for monitoring the tectonic state of the Earth and issuing alerts for large earthquake events that, depending on location, can cause tsunamis, earthquake damage and / or loss of life. These data also contribute, as part of a global network, to GA's Australian Tsunami Warning System facilitating our role of alerting the Australian Government and regional neighbours of potentially damaging tsunamigenic earthquake events.

- A nuclear monitoring capability based on seismic data acquisition (e.g. *Mawson* station) and infrasound observations (*Davis* station, in development) in support of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) of which Australia is a signatory.
- The international INTERMAGNET program of which the three Antarctic geomagnetic observatories are contributing members. The program develops geomagnetic data exchange and related products in near real-time.

7.2 Marine Geoscience

With increasing activity from other nations, such as Russia, China, India, and Italy (for example) within the Australian Antarctic Territory and adjacent waters, opportunities for bilateral and multilateral marine programs are possible. The availability of a state-of-the-art, scientifically capable vessel will act as an incentive for collaborative activities with other Antarctic nations. It also provides a cornerstone for Australian leadership of any collaborative marine programs.

As such, Australia should engage in, and make available suitable resources and logistics, for developing mutually beneficial, equitable, collaborative programs with nations currently active within the Australian Antarctic Maritime Jurisdiction.

7.3 Earth Observations from Space

Polar orbiting Earth observation satellites pass over Antarctica every 100 minutes and collect a myriad of information about Antarctica. A southern ground station, either in Antarctica, Macquarie Island or Tasmania, with optical fibre links to the mainland would be a strategic location for a command and control operations centre and make Australia the focus of attention for southern hemisphere remote sensing, a sought-after co-operator in international agreements, and provide new economic opportunities. The ability to up-link data to satellites as they pass over Antarctica (command and control) would be the basis for an Australian-based satellite operations centre that might well be based in Tasmania. Normal business hours for an operations centre in Australia would 'fill the gap' between time-zones for Europe and North America.

Several countries, including Germany and Italy, already have full capability satellite ground stations in Antarctica, but use satellite communications. An undersea communications cable would not only dramatically upgrade the ability to communicate and exchange information from the site, but would also dramatically decrease the operating costs of a satellite ground station making it highly competitive and valued by many international satellite operators.

An Antarctic Geoscience Data Cube would be globally recognised and would take Australian science agencies to the forefront of Antarctic science. It would attract scientists from around the globe and be a focal point for international Antarctic science using remote sensing dataThe ability to store and analyse satellite remote sensing observations of Antarctica within a single scientific framework would be welcomed by international satellite operators such as the European Space Agency and NASA who face growing difficulties in managing increasing data volumes.

8 Environmental considerations

The Australian Government pursues its goal of protecting the Antarctic marine environment through the Committee for Environmental Protection (CEP) and the Commission for the Conservation of Antarctic Living Marine Resources (CCAMLR). The Antarctic and Southern Ocean are important regions, sensitive and vulnerable to the impact of global-scale human activities. Apart from the importance of monitoring the state of the polar environment and protecting these regions in their own right, the environmental indicators from these regions can act as a 'canary in the cage', pre-empting the effects of climate change *within Australia*, to enable timely and effective domestic mitigation and management strategies and inform domestic environmental policy development.

8.1 Marine Geoscience

Seafloor morphology information, provided by Geoscience Australia to the AAD, has been used to support a joint submission by Australia, France and the European Union for the nomination of Marine Protected Areas (MPAs) along the Australian Antarctic Territory coastline. The provision of these datasets represents a key element of Australia's contribution to the ATS and CCAMLR. The three nominated Marine Protected Areas are still under consideration by CCAMLR.

In anticipation of an MPA network being established in East Antarctica in the near future, focus has now shifted to designing a cost-effective monitoring program. Effective monitoring requires repeat observations of a particular area to detect change. Automated underwater vehicles (AUVs) offer a suitable platform to undertake repeat observations as they are programmable and utilise the accurate positioning technology meaning they can complete identical repeat surveys of an area.

Seabed mapping is used to better understand areas of high conservation value on the Antarctic margin such as Vulnerable Marine Ecosystems (VMEs). CCAMLR has measures aimed at protecting VMEs from bottom fishing. It lists benthic communities on seamounts, hydrothermal vents, cold water coral communities and sponge fields as requiring protection (CM 22-06, 2015). Protecting such communities relies on protocols in place so that vessels cease fishing when they encounter a VME or on detecting VMEs before disturbance. This latter approach requires a range of capabilities for sea bed mapping and imagery.

The presence of VMEs needs to be determined with a combination of sonar and seafloor imagery. High resolution bathymetry is needed as a starting point to identify potential habitats. Confirmation of the presence of VMEs requires sea floor imagery as well as sampling.

A better knowledge of past climate regimes helps scientists understand and predict future climatic changes. The acquisition of high quality climate records from sea floor sediments is an important part of this research. This requires the ability to identify thick undisturbed accumulations of suitable sediments. These sediment accumulations can only be identified through marine geoscience surveys.

The largest risk of oil spills in the Antarctic environment comes from vessel groundings. Also, a vessel grounding far from a station represents a serious search and rescue problem. The International Hydrographic Organisation has made repeated calls for Antarctic nations to improve nautical charts in the Antarctic but progress has been slow. The Australian Antarctic Division, Geoscience Australia and the Royal Australian Navy have conducted multi-purpose surveys of the nearshore waters adjacent to Casey and Davis stations in recent years. These surveys have utilised multibeam echosounders with the primary aim of acquiring data to update nautical charts in these high-use areas. However, progress will continue to be very slow while the main platform (i.e. the RV *Aurora Australis*) only has a

single beam echo sounder. Safe tourism means charting areas tourist vessels wish to visit. Nearshore surveys using AAD and RAN workboats are currently restricted to small areas around existing stations due to SAR requirements and vessel capability.

9 Funding

In order to expand GA's infrastructure assets and capability in Antarctica, we stress that additional appropriation funding would need to be allocated to Geoscience Australia specifically to undertake these additional activities.