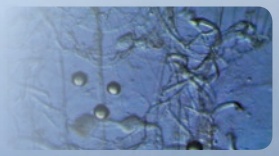
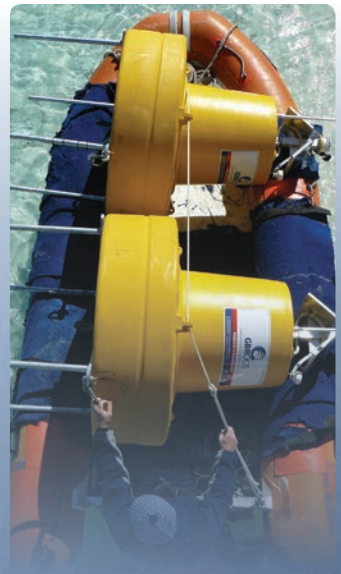
highlights 2012-2013

IMOS Integrated **Marine Observing** System





overview

Tim Moltmann
IMOS Director

This Annual Highlights document covers the sixth full year of IMOS operation, and the final year supported through the Education Investment Fund. It is very pleasing to report that recent allocations of collaborative research infrastructure funding will ensure IMOS continues to operate for at least a further two years.

During 2012-13 we have seen clear and compelling evidence of the benefits generated by sustained investment in IMOS. These benefits manifest through:

- national scale, multi-institutional capability to successfully deploy and recover a wide range of marine observing platforms and sensors,
- a functioning national information infrastructure, enabling marine and ocean data to be discovered, accessed, used and re-used,
- science uptake of IMOS observations and data streams to increase our knowledge and understanding of Australia's marine estate, and
- outputs produced by research providers using IMOS data to address priorities across government portfolios, industry sectors and societal needs.

The vast majority of deployments and recoveries were successfully completed during the year, which is an outstanding achievement by our Operating Institutions. Highlights include the one millionth profile from the global Argo array (10% of which is deployed in the Australian region), the one hundredth IMOS ocean glider mission, and the thirty millionth detection of an acoustically tagged marine animal. These are not just large numbers. They represent tangible evidence that IMOS is actually building national scale time series of essential ocean variables, covering physical, chemical and biological properties.

Strong performance in the field resulted in greater availability of data via the IMOS Ocean Portal. As of June 2013 there were 3,000 metadata records describing IMOS data with 24% growth in data holdings over the last 12 months.

With greater availability of data, science uptake also continued to expand during 2012-13. For the third consecutive year, publications and reports using IMOS data grew by 40% per annum, to over 2,000 in total (cumulative). This includes 160 post graduate projects, and 343 journal publications. It also includes 213 research projects that are producing science outputs addressing priorities across a range of government portfolios, industry sectors and societal needs.

In this report we focus on a selection of science highlights across the five major research themes IMOS has been designed to address. We trust you'll enjoy reading about new knowledge and understanding gained from the ocean that is relevant to all Australians living in our 'marine nation'.

CSIRO

How does it work?

IMOS is designed to be a fully integrated, national system, observing at ocean basin and regional scales and covering physical, chemical and biological variables.

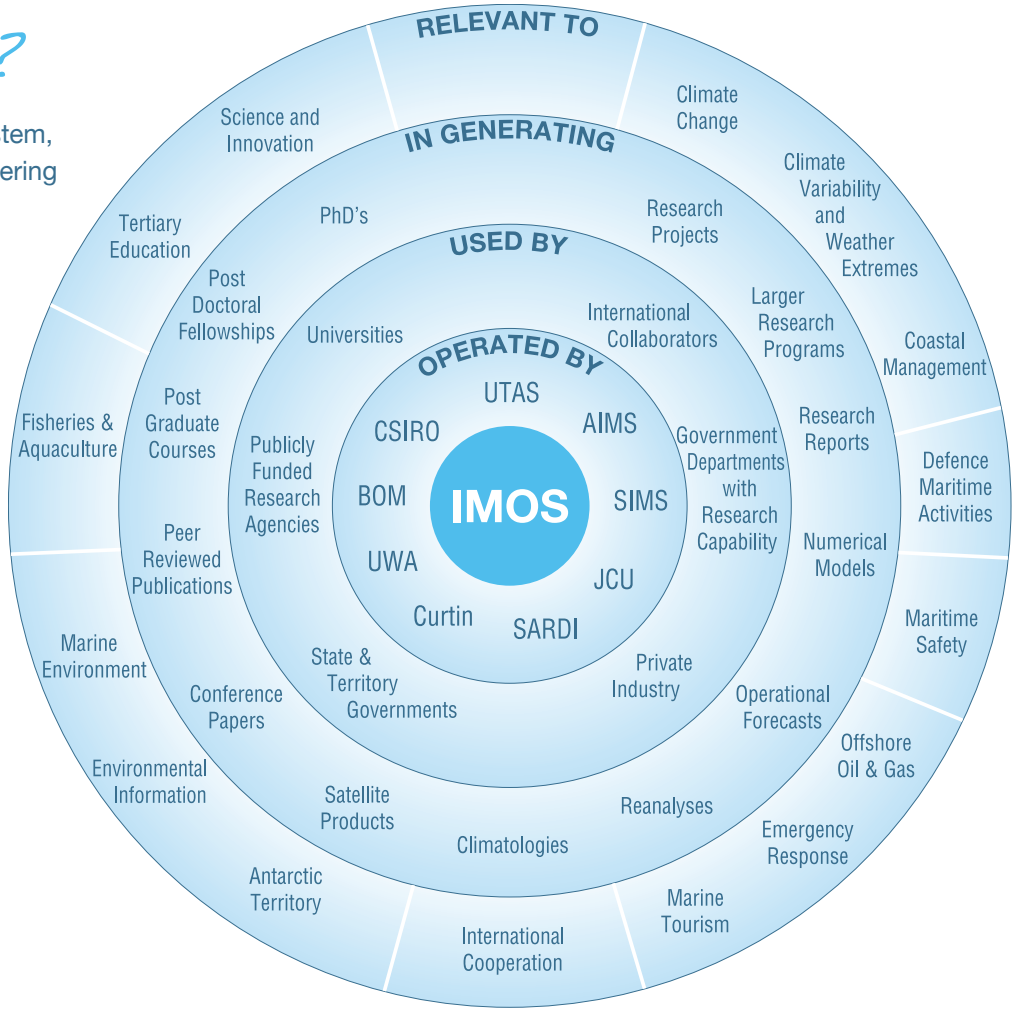
IMOS Facilities, operated by nine different institutions within the National Innovation System, are funded to deploy equipment and deliver data streams for use by the entire Australian marine and climate science community and its international collaborators.

IMOS observations are guided by science planning undertaken collaboratively across Nodes of the Australian marine and climate science community. There are five major research themes that unify IMOS science plans and related observations: Multi-decadal ocean change; Climate variability and weather extremes; Major boundary currents and interbasin flows; Continental shelf and coastal processes; and Ecosystem responses. This annual highlights document is arranged by these major research themes to provide a clear focus on relevance and impact.

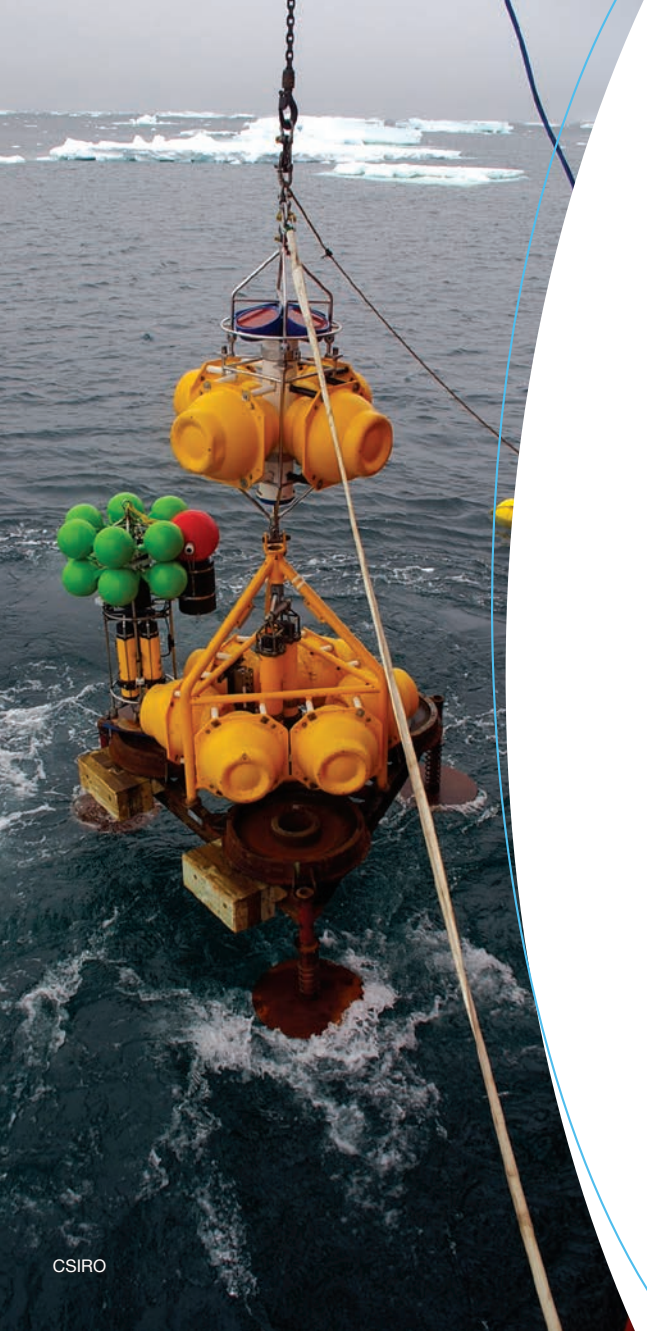
The observations and data streams are collected via ten technology platforms, or Facilities:

- Argo floats
- Ships of opportunity
- Deep water moorings
- Ocean gliders
- Autonomous underwater vehicles
- National mooring network
- Ocean radar
- Animal Tagging and Monitoring
- Wireless sensor networks
- Satellite remote sensing

The IMOS Ocean Portal (imos.aodn.org.au) allows marine and climate scientists and other users to discover and explore data streams coming from all of these Facilities.



In the diagram above, we show how IMOS is being implemented through the Operating Institutions, and used by the entire sector to generate a wide range of science-based outputs that are relevant across multiple societal drivers.

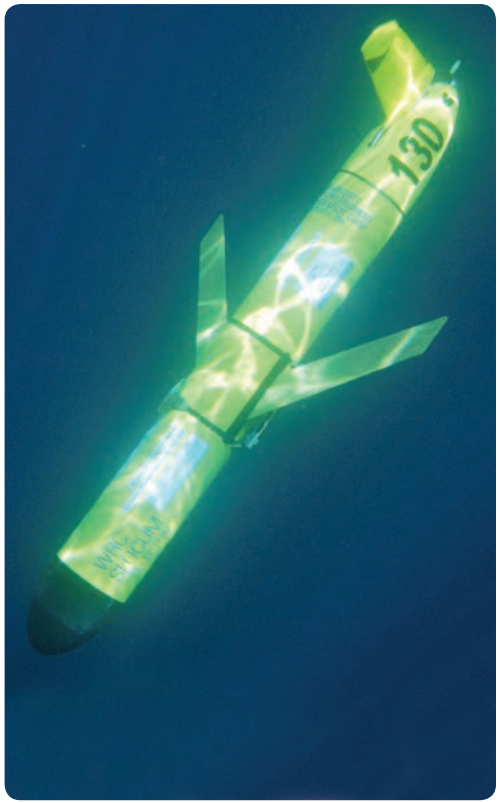


CSIRO

Multi-decadal ocean change

Tracking and understanding the processes by which heat and carbon are sequestered into the global oceans is essential for monitoring rates of global change, and for informing Earth system models that are being used to project future climate. Tracking and understanding ocean salinity is also essential for monitoring changes in the global hydrological cycle, as most precipitation and evaporation occurs over the ocean surface where few historical observations are available. To complete the picture, observations of the global ocean circulation determine the distribution of these properties in the ocean.

Within IMOS, estimates of multi-decadal change are drawn from observations of temperature, salinity, carbon and general ocean circulation delivered by Argo Floats (to 2000m depth), Ships of Opportunity (expendable bathythermographs or XBTs in the upper 700m, and surface carbon fluxes), Moorings (deepwater and continental shelf), Ocean Gliders (to 1000m depth), Animal Tagging and Monitoring (in high latitudes), and Satellite Remote Sensing of sea surface temperature, ocean colour and altimetry.



University of Western Australia

Argo floats	Ships of opportunity	Deep water moorings	Ocean gliders	Autonomous underwater vehicles	National mooring network	Ocean radar	Animal tagging & monitoring	Wireless sensor networks	Satellite remote sensing	IMOS *OceanCurrent*
✔	✔	✔	✔		✔		✔		✔	

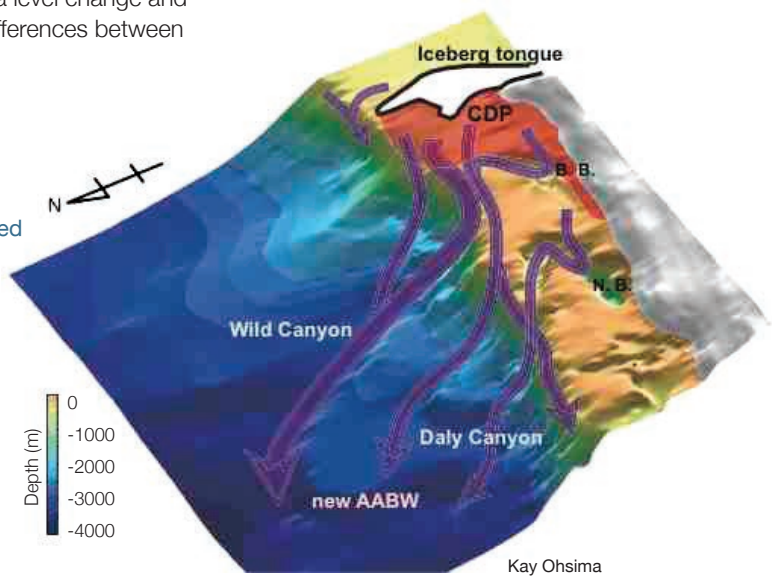
2012-13 Highlights

Seals equipped with current, temperature and pressure sensors have been responsible for the significant discovery of a previously unconfirmed source of Antarctic Bottom Water in the Cape Darnley Polynya, northwest of the Amery Ice Shelf. Antarctic Bottom Water is a key source of cold, dense water that helps regulate the Earth's climate. Winter foraging by the seals in this area provided very rare and valuable measurements of temperature and salinity in a region that otherwise would have remained unsampled by conventional methods.

The International Argo program has continued to grow, reaching a milestone one-millionth ocean profile this past year. Around 10% of the global array is now deployed in the Australian region supported by strong international collaboration. These profiling floats have provided unprecedented coverage of deeper waters between 700–2000m, revealing a significant but elusive heat sink for part of the Earth's energy budget that had been previously unaccounted for in some climate models. The profile data revealed that the 'missing' energy was in fact being absorbed by this deeper 700–2000m layer, illustrating the importance of the deeper ocean in setting rates of global warming and highlighting our need to gather data to better understand the ocean-Earth-atmosphere system.

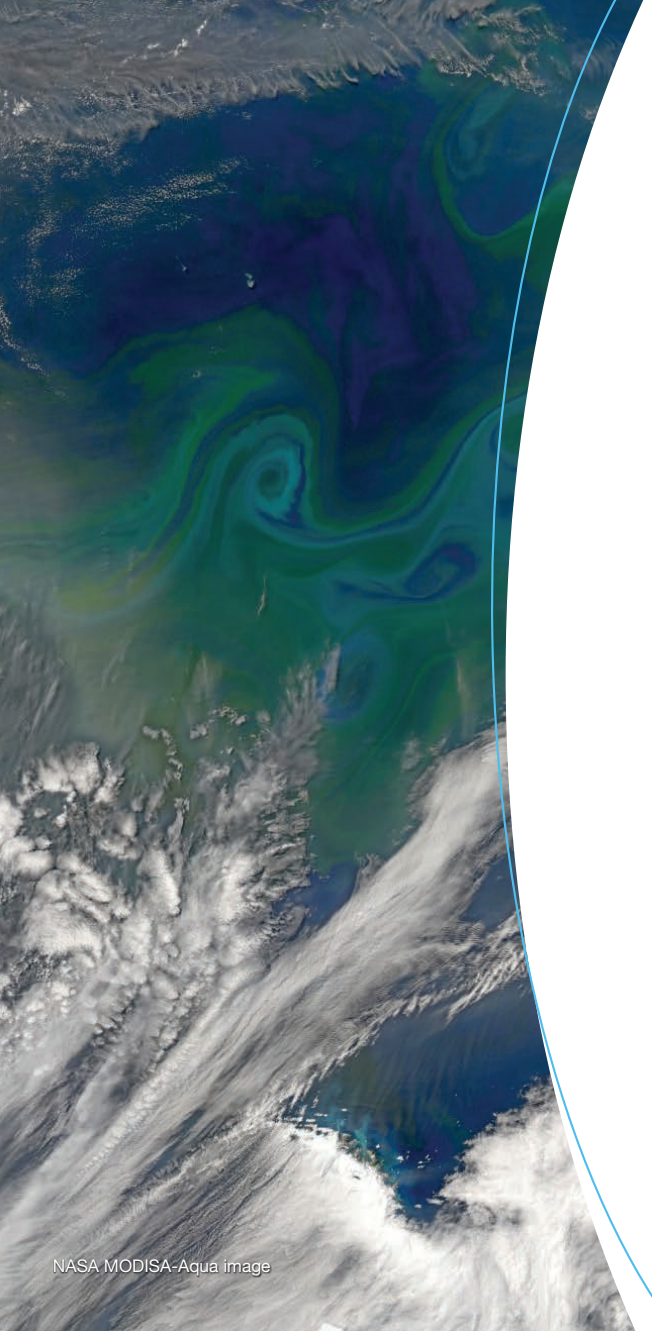
In satellite altimetry calibration and validation, IMOS has refined data in the evolving altimeter sea level climate data record, by analysing the altimeter and tide gauge sea level differences around the globe. The system now allows for the subtle drift in altimeter measurements, which has important implications for measuring global mean sea level change and understanding the small differences between observations and models.

International cooperation has continued to grow as IMOS plays an increasingly important role in global carbon, salinity, and hydrological observations. Acidification moorings at the Maria Island, Yongala and Kangaroo Island National Reference Station sites are now part of a network of critical international moorings monitoring changes in ocean acidification.



Schematic of Antarctic Bottom Water cascading over Cape Darnley, Published in *Nature Geoscience*, Vol 6, March 2013.

Kay Ohsima



NASA MODISA-Aqua image

Climate variability and weather extremes

There are three major, coupled ocean–atmospheric modes which account for a significant portion of Australian seasonal climate variability – El Nino/Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) and Southern Annular Mode (SAM). Upper ocean thermal distribution is the largest source of predictability at seasonal timescales for all coupled modes, due to the large thermal inertia of the ocean and its predictable dynamics. Observations needed to understand upper ocean thermal distribution and inform seasonal and climate models include:

> broad scale upper ocean temperature and salinity structure,

> well-resolved time series in the equatorial oceans, and

> global wind, air-sea exchange (fluxes) and sea level measurements.

These observations come from Argo Floats, Ships of Opportunity (XBT, SST and air-sea fluxes), Deep Water Moorings (Southern Ocean flux station) and Satellite Remote Sensing SST and altimetry.

CSIRO

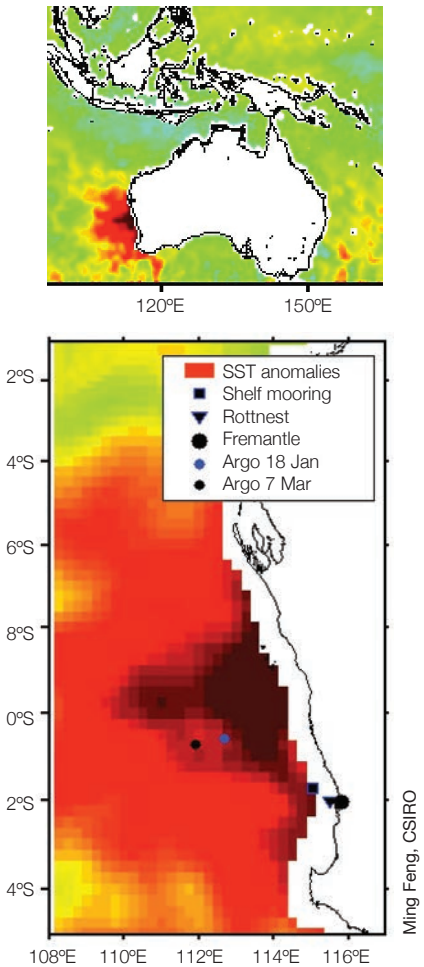
Argo floats	Ships of opportunity	Deep water moorings	Ocean gliders	Autonomous underwater vehicles	National mooring network	Ocean radar	Animal tagging & monitoring	Wireless sensor networks	Satellite remote sensing	IMOS *OceanCurrent*
✔	✔	✔							✔	✔

2012-13 Highlights

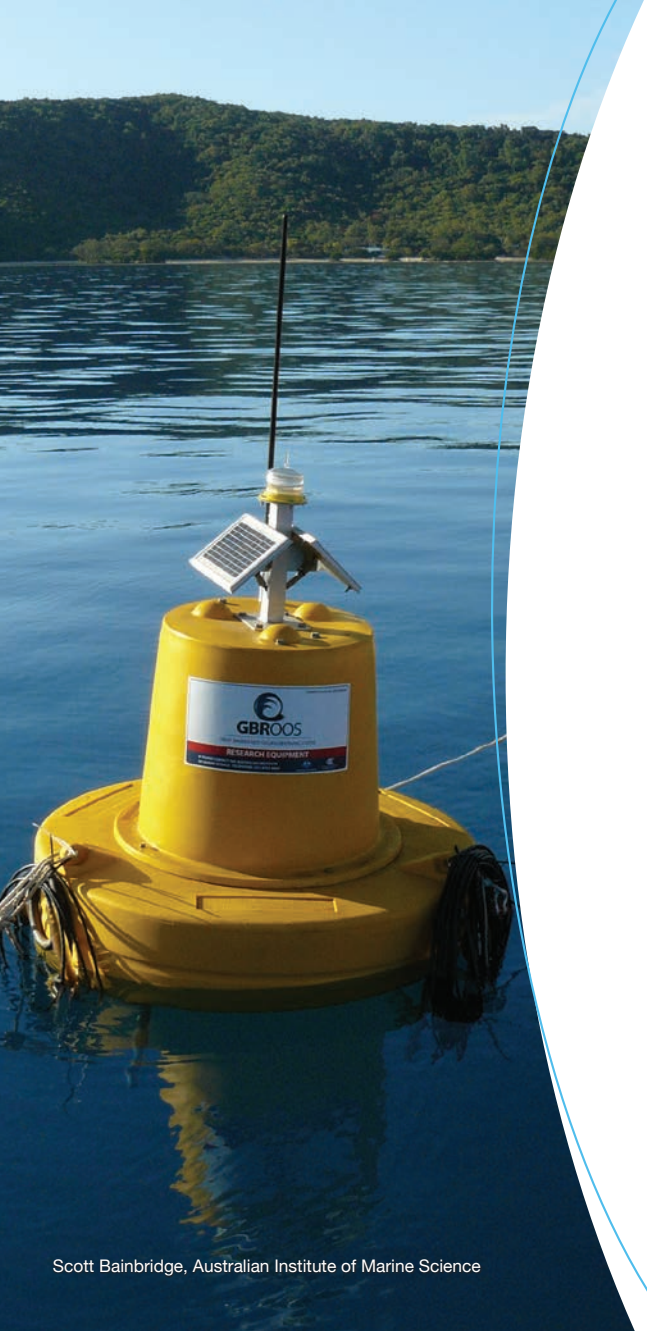
Shelf moorings, Argo floats and satellite temperature observations are providing detailed insight into climate and weather events, such as marine heat waves on the west coast of Australia. Record easterly wind in the eastern Pacific and record northerly wind in the southeast Indian Ocean combined to produce a large unseasonable ocean surge of the Leeuwin Current and extreme ocean warming. At its peak this caused a two-week period of 5ºC warmer water than normal. This had a profound impact on the local marine ecosystem with massive fish and invertebrate kills and coral bleaching along the coast. Understanding the factors that influence such events as marine heat waves is vital for us to predict and prepare for these extreme warming events in the future.

Last summer was the latest of several characterised by extreme weather in north eastern Australian, including major flooding. Such events have significant impacts along the Great Barrier Reef, affecting coastal marine environments and the marine tourism industry. Imagery processed by the Satellite Remote Sensing Facility provided graphic evidence of the spatial overlap between flood plumes, plankton blooms and outbreak populations of crown-of-thorns starfish on coral reefs between Lizard Island and Cairns. This ability to access and use a combination of satellite and in-situ observations from the marine environment is crucial to better understanding, managing and predicting the impacts of climate variability and weather extremes.

Data from Argo floats and sea surface temperature observations in the Indian Ocean have contributed to a greater understanding of Indian Ocean Dipole (IOD) variability. The IOD is an irregular oscillation of sea surface temperature in the western Indian Ocean that is a major pathway for ENSO impacts in our region. Recently there have been an unprecedented number of positive IOD occurrences corresponding to cooling waters in the eastern Indian Ocean, which tends to cause drought in Indonesia and Australia (as opposed to flood in east Africa), and increased risk of major summer wildfires in south eastern Australia. Observation-based assessments, in this case undertaken with Chinese collaborators, are necessary to reduce uncertainties in climate models and reanalyses.



Ocean temperature at the peak of the 2011 warming event off Western Australia. Published in *Nature Scientific Reports* February 2013.



Scott Bainbridge, Australian Institute of Marine Science

Major boundary currents and interbasin flows

The waters around Australia form a complex intersection of the Pacific and Indian Oceans. There are two major boundary current systems; the East Australian Current (EAC) on the east coast and the Leeuwin Current on the west coast. There are also two major interbasin flows connecting these ocean regions; the Indonesian Throughflow, between the western Pacific and the northeast Indian Ocean, and the Tasman Outflow by which the EAC penetrates into the Indian Ocean. These current systems have a central role in transferring heat, salt and nutrients into the coastal region. They vary on interannual and longer time scales, influenced by the major modes of climate variability (e.g. ENSO). The boundary current systems are therefore crucial to understanding local manifestations of global ocean processes and their influence on regional marine ecosystems.

Monitoring boundary currents demands multiple observational techniques within IMOS. Shelf and Deep Water Moorings are being deployed in the narrowest and most coherent sections of the Indonesian Throughflow and EAC to monitor fluxes of heat, mass and salt. Ocean Gliders, Ocean Radars and National Reference Station Moorings are being used to look at boundary current dynamics and their interaction with circulation on the continental shelf. Argo Floats and Ships of Opportunity are providing broad scale context and drivers, with Satellite Remote Sensing altimetry and SST providing broad spatial and temporal resolution.

Teledyne Webb Research

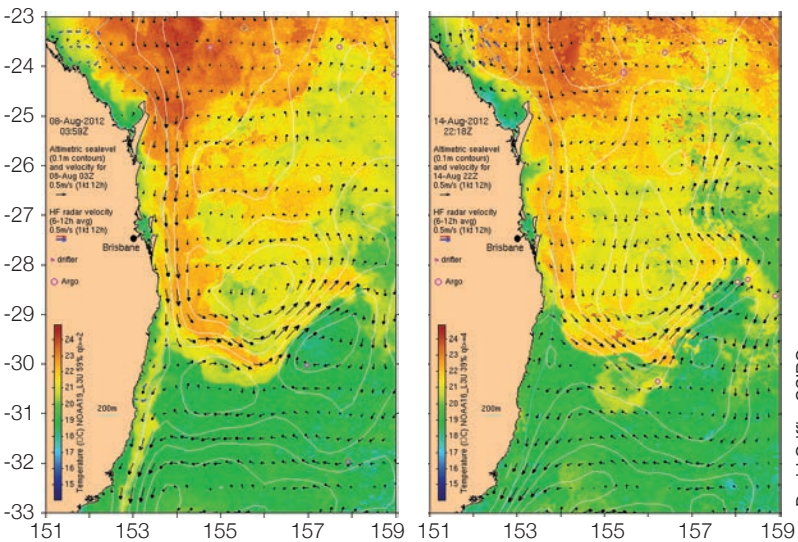
Argo floats	Ships of opportunity	Deep water moorings	Ocean gliders	Autonomous underwater vehicles	National mooring network	Ocean radar	Animal tagging & monitoring	Wireless sensor networks	Satellite remote sensing	IMOS *OceanCurrent*
✔	✔	✔	✔		✔	✔			✔	✔

2012-13 Highlights

The Indonesian Throughflow mooring array in the Timor Sea, north of Australia, has produced its first annual temperature, salinity and current time series at two points in these deep ocean channels. Initial analysis of the data showed that in the Ombai Strait the Indonesian Throughflow is stronger at the surface and weaker at depth compared to earlier (2003–06) data, and that in the Timor Passage the Throughflow is more intense at the southern side of the Passage. These observations have significantly improved deepwater monitoring and modelling in this region.

The EAC moorings were retrieved after measuring to a full depth of 5.5km for the first time. The EAC is a major component of the world ocean and has been poorly measured to date. While it is understood to be getting warmer and moving south, this newest data will be integrated with other observations from regional moorings, gliders, HF radar, and Argo floats along the current from the Great Barrier Reef to Tasmania, to build a clearer picture of the implications and potential effects of this large scale change.

The daily IMOS *OceanCurrent* data stream continues to publish maps of surface currents and temperature using Argo, satellite altimetry, satellite ocean colour, satellite sea surface temperature, ships of opportunity and ocean radars. Over the past year it continued to expand incorporating near real time data from gliders and updated time series for acoustic doppler current profilers from regional moorings. The *OceanCurrent* daily maps have been able to demonstrate changes in Australia's major boundary currents, including identifying a period when the East Australian Current 'vanished' south of Coffs Harbour in August 2012 – caused by a cold core eddy restricting southward flow and an atmospheric low pressure system off New South Wales. The ability of *OceanCurrent* to provide detailed 'nowcasting' – information about ocean conditions on demand – will be invaluable for a broad range of applications important to Australia, from engineering designs for ocean structures to assessing the public health risk of water borne substances.



The 'vanishing' East Australian Current. Note the yellow streak on the 8 August 2012 (left) does not appear on the 14 August 2012 (right).

David Griffin, CSIRO

Australian Institute of Marine Science

Continental shelf processes

Australia has a large and varied continental shelf environment; broad and shallow in the tropical north and narrow on the subtropical east and west coasts. There are key processes occurring across this environment that provide a focus for observing connections between global ocean processes, boundary currents and biological responses on the continental shelf. These include encroachment of warm and cold core eddies, upwelling and downwelling systems, coastal currents, and wave climates.

IMOS is providing an extensive, national backbone around the continental shelf, as well as more intensive observations in regions of socio-economic and ecological significance e.g. coral reefs, biodiversity hotspots, population centres, and regional development hubs. The backbone comprises a network of National Reference Station Moorings, and national access to Satellite Remote Sensing products, along with the IMOS national information infrastructure. The more intensive, region specific observations include a combination of Shelf Moorings, coastal Ocean Gliders, Ocean Radar (for currents and waves), and Wireless Sensor Networks (on the Great Barrier Reef).

Lucy Wyatt, James Cook University

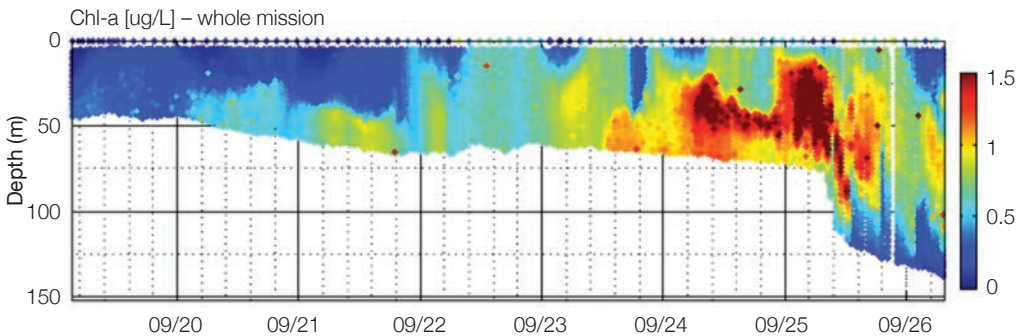
Argo floats	Ships of opportunity	Deep water moorings	Ocean gliders	Autonomous underwater vehicles	National mooring network	Ocean radar	Animal tagging & monitoring	Wireless sensor networks	Satellite remote sensing	IMOS *OceanCurrent*
			✔		✔	✔		✔	✔	✔

2012-13 Highlights

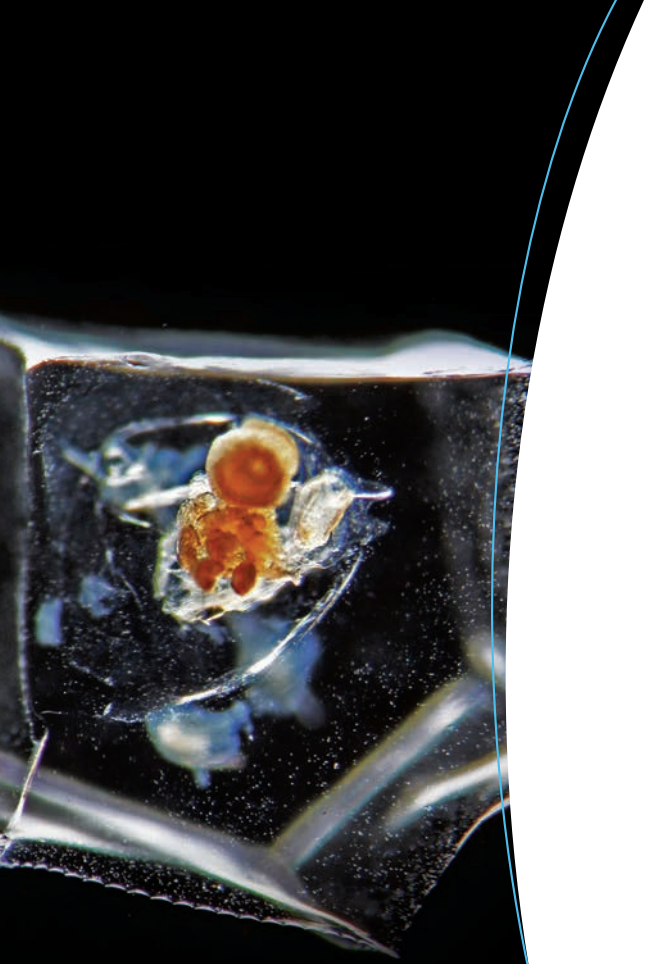
Targeted expansion of the regional mooring network across Northern Australia began to return science dividends during the past year. First data from the Pilbara, Kimberley and Bonaparte Gulf moorings have confirmed the existence and structure of the Holloway Current on the outer North West Shelf and slope. A second near real time mooring in Beagle Gulf, along with the Darwin National Reference Station, also significantly improved coastal and offshore monitoring and modelling in this rapidly developing region.

The Coffs Harbour coastal radar, the last of the scheduled radar site installations, was established this year to monitor the East Australian Current separation zone (together with the East Australian Current deep water and South East Queensland moorings). The radar provides maps of real time sea surface current of Coffs Harbour inshore waters, which have direct application to the *Bluelink* ocean forecast model and the IMOS *OceanCurrent* daily maps. The Ocean Radar Facility began to contribute to the Global Earth Observation System of Systems (GEOSS) as part of a Global HF Radar Network for data sharing and promoting using HF radar surface current velocity measurements internationally.

Gliders continued to observe dense shelf water cascades – slow moving 'rivers' that transport water, heat, salt, phytoplankton, nutrients and pollutants from the Australian coastal regions to the deep ocean. Until recently, these cascades were most commonly found in high latitudes as a result of ice formation, but observations collected by gliders in West Australia found them at low latitudes, on the Rottnest and Pilbara shelves. An additional site was discovered in the southern Great Barrier Reef, north of Rockhampton, after the Australian Defence Science & Technology Organisation made additional glider data available to IMOS. These results indicate that dense shelf water cascades are more widespread around Australia than previously thought.



A chlorophyll-a profile from the Pilbara glider deployment in September 2013.



Anita Slotwinski, CSIRO

Ecosystem responses

Australia's large ocean territory, from the tropics to the Antarctic, encompasses a diverse range of marine ecosystems. IMOS is seeking to take an integrated approach, whereby measurements ranging from biogeochemistry through lower to higher trophic levels are undertaken across particular systems.

At basin scale, our initial focus is in the highly dynamic Southern Ocean. Seasonal changes in circulation, stratification and ice cover boost ecosystem production making this one of Australia's richest ecosystems, supporting the greatest density and biomass of apex predators to be found in Australian waters.

At regional and local scales, major boundary currents and continental shelf processes around Australia play a vital role in regulating the productivity, abundance, and distribution of marine ecosystems, both in the water column and on the sea floor. The warm boundary currents are generally nutrient poor, leading to marine systems of relatively low productivity. However, continental shelf processes, including cold core eddies and upwelling systems, cause localised peaks in productivity. These 'hotspots' are critical to supporting highly diverse fish, seabird, marine mammal and sea turtle populations within regions.

Ecosystem responses to variability and change need to be considered at all levels of the food web (trophic levels), from primary producers to apex predators. IMOS is observing ecosystem responses through an extensive, national backbone comprised of Ships of Opportunity (continuous plankton recorders, and echo sounders to estimate biomass), a network of National Reference Station Moorings, and national access to Satellite Remote Sensing ocean colour, along with the IMOS national information infrastructure. More intensive, region specific observations include a combination of Animal Tagging and Monitoring (acoustic arrays and satellite tagging), Autonomous Underwater Vehicles (undertaking benthic surveys), deep water and shelf Moorings (Southern Ocean Time Series, acidification moorings, noise loggers), Ocean Gliders, and Wireless Sensor Networks.

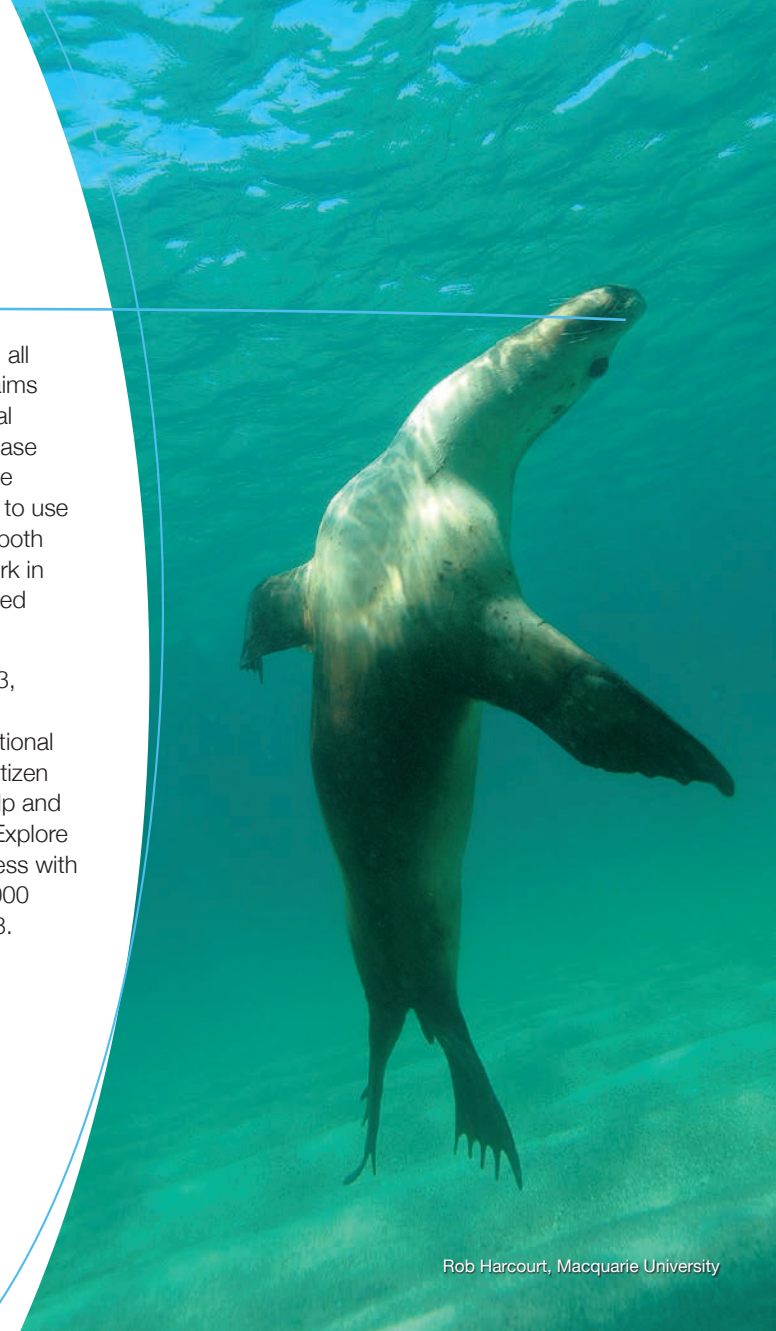
Argo floats	Ships of opportunity	Deep water moorings	Ocean gliders	Autonomous underwater vehicles	National mooring network	Ocean radar	Animal tagging & monitoring	Wireless sensor networks	Satellite remote sensing	IMOS *OceanCurrent*
	✔	✔	✔	✔	✔		✔	✔	✔	✔

2012-13 Highlights

In collaboration with Australian and Canadian scientists, IMOS extended the global Ocean Tracking Network of acoustic receivers to detect tags on marine animals in Australian waters. These acoustic receivers have been strategically deployed to improve our understating of animal movements along Australia's continental shelf. The two most recent lines were deployed in Tasmania, with a 50km line running from the Tasmanian east coast to the eastern edge of the continental shelf and a second 50km line running east from Flinders Island into Bass Strait. Tag detections from these receivers started to provide information about species distribution, migration patterns, and swimming direction and depth. The IMOS animal tagging and monitoring database now has over 30 million detections, providing an entirely new resource for national level analysis.

During the past year a national zooplankton database was created with 90,000 records from around Australia, including 55,000 records from historical information back to the 1960s. This valuable resource has aggregated all the available plankton data, and now aims to expand to include all biogeochemical data into a single database. The database was published as The Australian Marine Zooplankton Guide and Atlas, an easy to use guide of zooplankton identification for both novices and experts. The Atlas is a work in progress and will continue to be updated building on feedback from scientists.

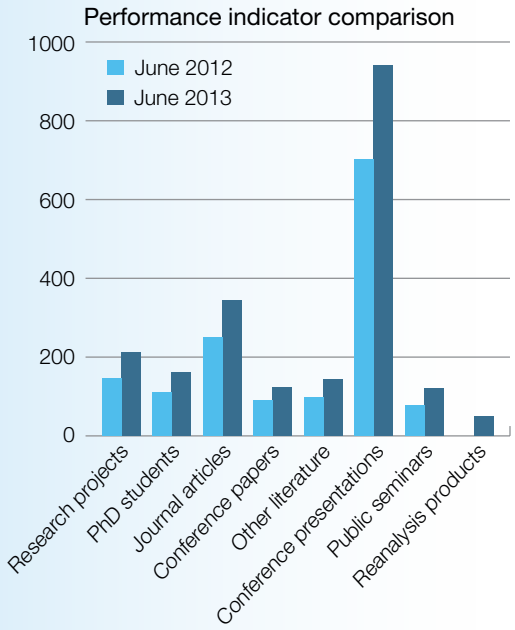
As part of National Science Week 2013, the Autonomous Underwater Vehicle Facility collaborated with Australia's national broadcaster, the ABC, to establish a citizen science project aimed at identifying kelp and sea urchins in images of the seafloor. Explore the Seafloor was an outstanding success with 220,000 photos being analysed by 8,000 plus people by the end of August 2013.



Rob Harcourt, Macquarie University

Performance indicators

The uptake and use of IMOS data is measured by performance indicators related to research projects, postgraduate students, publications and presentations. They are fully listed on the IMOS website at **www.imos.org.au/imospublications.html**. Cumulative totals of the IMOS performance indicators at June 2012 and June 2013 are provided below:



Financial summary

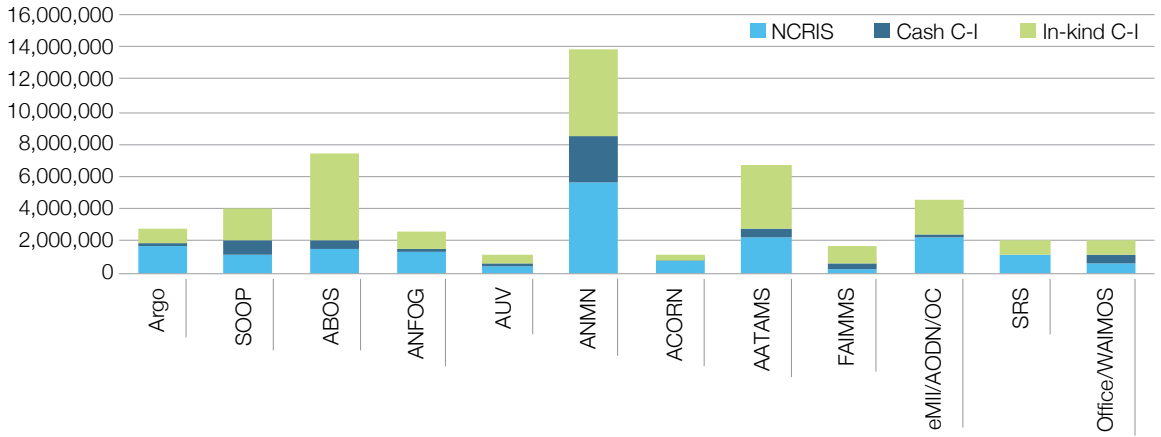
Details of IMOS finances for 2012–13 are provided in the Annual Progress Report which is available for download at **www.imos.org.au/reports1.html**. A summary is provided below:

FINANCIAL OVERVIEW	NCRIS	EIF	CRIS	Total
Balance at 1 July 2012	**4,708,933**	**6,349,200**	**0**	**11,058,133**
Department of Innovation, Industry, Science and Research	0	18,000,000	2,401,544	20,401,544
Interest earnings	126,908	370,885	5,428	503,221
Income sub-total	**126,908**	**18,370,885**	**2,406,972**	**20,904,765**
Cash Co-investments	287,811	6,418,174	0	6,705,985
In-kind Co-investments	952,708	23,143,393	0	24,096,101
Total – Resources received	**1,367,427**	**47,932,452**	**2,406,972**	**51,706,851**
Capital / equipment purchases	209,131	3,767,532	0	3,976,663
Personnel	1,292,749	8,382,996	0	9,675,745
Other	200,589	5,085,760	0	5,286,349
Expenditure sub-total	**1,702,469**	**17,236,288**	**0**	**18,938,757**
Cash Co-investments	326,560	6,481,473	0	6,808,033
In-kind Co-investments	952,708	23,143,393	0	24,096,101
Total – Resources utilised	**2,981,737**	**46,861,154**	**0**	**49,842,891**
Balance at 30 June 2013	**3,094,623**	**7,420,498**	**2,406,972**	**12,922,093**

Operators

- Australian Institute of Marine Science
- Bureau of Meteorology
- Commonwealth Scientific and Industrial Research Organisation
- Curtin University
- James Cook University
- South Australian Research and Development Institute
- Sydney Institute of Marine Science (University of New South Wales, University of Sydney, Macquarie University, University of Technology Sydney)
- University of Tasmania
- University of Western Australia

2012–13 investment by Facility



Co-investors

- Antarctic Climate and Ecosystems Collaborative Research Centre
- Austral Fisheries
- Australian Antarctic Division
- Australian Climate Change Science Program
- Australian National Data Service (ANDS)
- Australian Ocean Data Centre Joint Facility
- Charles Darwin University
- Darwin Ports Corporation
- Defence Science and Technology Organisation
- Department of Aquaculture Fisheries and Forestry (Queensland)
- Department of Commerce (WA)
- Department of Economic Development Tourism and the Arts (Tasmania)
- Department of Environment and Heritage Protection (Queensland)
- Department of Environment and Natural Resources (SA)
- Department of Environment and Primary Industries (Victoria)
- Department of Fisheries (WA)
- Department of Further Education Employment Science and Technology (SA)
- Department of Primary Industries (NSW)
- Department of Science, Information Technology, Innovation and the Arts (Queensland)
- Environmental Protection Authority Victoria
- First Institute of Oceanography (China)
- Flinders University
- French National Centre for Scientific Research (Centre National de la Recherche Scientifique, CNRS)
- French Polar Institute (Institut Polaire Français Paul Emile Victor, IPEV)
- Geoscience Australia
- Griffith University
- Marine National Facility
- Murdoch University
- National Computational Infrastructure (NCI)
- National eResearch Collaboration Tools and Resources (NeCTAR)
- National Institute of Water and Atmospheric Research (NIWA, NZ)
- National Oceanic and Atmospheric Administration (NOAA, USA)
- Ocean Tracking Network/ Dalhousie University (Canada)
- Oceanographic Field Services
- Office for Science and Medical Research (NSW)
- Office of Environment and Heritage (NSW)
- Research Data Storage Infrastructure (RDSI)
- Royal Australian Navy
- Scripps Institute of Oceanography (USA)
- Sea Mammal Research Unit/ University of St Andrews (UK)
- Sealord (NZ)
- Southern Cross University
- Sydney Water Corporation
- Tasmanian Partnership for Advanced Computing
- Tropical Marine Network
- University of Melbourne
- University of Queensland

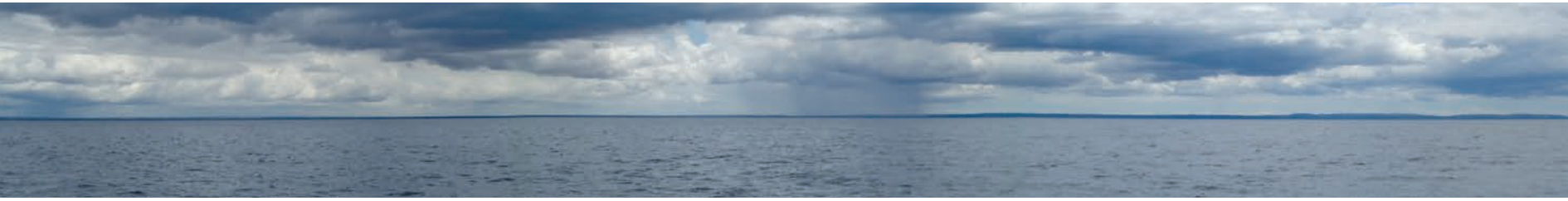
UTAS

An Australian Government Initiative

National Collaborative Research Infrastructure Strategy

IMOS is a national collaborative research infrastructure, supported by Australian Government. It is led by University of Tasmania in partnership with the Australian marine & climate science community.

www.imos.org.au



The Operators of the IMOS infrastructure are:

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SARDI South Australian Research and Development Institute

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