marinematters IMOS

issue twenty one June 2015 Integrated Marine Observing System

IMOS News

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Sea level is rising fast – and it seems to be speeding up

This article was originally published in **The Conversation**

Christopher Watson, University of Tasmania, John Church, CSIRO, Matt King, University of Tasmania

Many observations have shown that sea level rose steadily over the 20th century – and at a faster rate than over the previous centuries. It is also clear from both satellite and coastal observations that seas have risen faster over the past two decades than they did for the bulk of the 20th century.

More recently, **several studies** have shown that the flow of ice and water into the oceans from Greenland and West Antarctica has increased since 1993. This raises an interesting question: has the rate of sea-level rise changed since 1993, when satellite observations began to give us a more complete picture of the global oceans?

Our **new research** tackles this question by comparing satellite observations of sea level with those measured at the coast by tide gauges. We use this comparison to determine small biases in the satellite data that have changed over time. Understanding how the land supporting the tide gauges is moving becomes an important part of these comparisons. We found three important results.

First, the seas really have risen faster since 1993, relative to the slower rate over previous decades as evident in the tide gauge data.

Second, comparison of the coastal and satellite measurements reveal small differences in the early part of the satellite record from 1993 to 1999. After allowing for land motion at the tide gauges, the first six years of the satellite record marginally overestimates the sea-level trend. Our revised estimate of global mean sea-level rise for the satellite era (1993 to mid-2014) is about 2.6-2.9 mm per year (the exact value depends on how we estimate land motion) – slightly less than the **previous estimate** of 3.2 mm per year.

Third, previous estimates of the rate of rise from satellite data that didn't incorporate the careful comparison with coastal sea-level measurements, as we have done in our recent study, showed a slower rate of rise over the past decade relative to the one before. Our revised record is clearly different and suggests that the rate of rise has increased, consistent with other observations of the increased contributions of water and ice from Greenland and West Antarctica.

However, sea level varies from year to year, as water is exchanged between the land and oceans (for example during the Australian floods associated with the 2010-11 and 2011-12 La Niña events), and as a result the observed increase in the rate of rise over the short satellite record is not yet statistically significant.

Strikingly, our estimate of the increase in the rate of rise is consistent with the **projections of future sea level** published by the Intergovernmental Panel on Climate Change (IPCC). Currently, these projections forecast a rise of up to 98 cm by 2100 if greenhouse gas emissions are allowed to continue unabated (and even more if parts of the **Antarctic ice sheet** collapse). If the world makes strong cuts to greenhouse gas emissions, the rise by 2100 is projected to be significantly less, somewhere between 28 cm and 61 cm.

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director's corner

Tim Moltmann

Welcome to the 21st issue of Marine Matters. In the previous issue I described this as 'a make or break year for the IMOS national collaboration'. I'm very pleased to report that we've made significant steps in the right direction since then.

The May 12th Federal Budget confirmed $150M funding for the National Collaborative Research Infrastructure Strategy (NCRIS) in 2015-16, and committed to another $150M in 2016-17. This was incredibly important to the long term future of IMOS. It will enable the Research Infrastructure Review chaired by Phil Clark to make its recommendations about long-term planning and funding in the context of a multi-year commitment to NCRIS, and have them considered within the normal 2016-17 budget cycle. And it means we avoid the 'annual funding cliff' that has been so challenging for us in the last few years. Hallelujah!

Shortly after Budget night, we were advised that IMOS had been allocated $13.963M for 2015-16 – see https://www.pyneonline.com.au/media-centre/media-releases/ncris-2015-16-funding-allocations-announced. This was the highest amount allocated to any NCRIS project, and we take it as a strongly positive signal in terms of the performance of IMOS and its value to the nation.

Another, perhaps softer indicator of success is how much easier it's become to prepare Marine Matters each quarter. Not that long ago it was quite a chore to extract interesting stories from the IMOS community. They were out there, but we needed to go looking. Now 'the pipeline' is always full of new deployments, new data, new uses, and new partnerships delivering impact.

With RV *Investigator* coming into commission, it's fantastic to see that its first two official voyages were to redeploy IMOS deepwater moorings in the Southern Ocean, and the East Australian Current. May this productive partnership between IMOS and the Marine National Facility (MNF) continue for many decades to come.

The new look for IMOS *OceanCurrent* is getting excellent reviews, and is encouraging us to think about creative ways to make IMOS data more useful, and usable.

The Watson *et al Nature Climate Change* paper on sea level rise shows how systematic and sustained in situ observing in our region can make a fundamental contribution to international satellite missions, which in turn deliver massive benefits to Australia through open access to data.

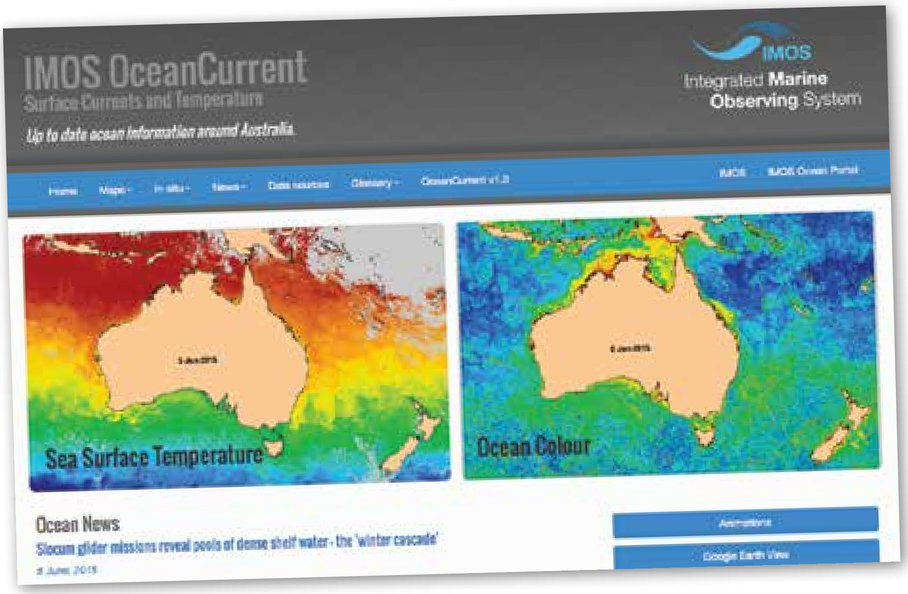
Partnering for impact is also prominent. Our animal tracking and monitoring network is supporting a new marine research partnership between CSIRO and BHP Billiton Petroleum at Ningaloo Reef. The IMOS National Reference Station in Darwin Harbour is underpinning an excellent collaboration with Darwin Port Corporation that is enabling safer shipping through improved ability to predict local conditions.

All this, and more. I hope you enjoy reading Marine Matters #21.

Tim Moltmann

A fresh new look for the IMOS *OceanCurrent* website

We are excited to announce the newly designed IMOS *OceanCurrent* website.



Our IMOS *OceanCurrent* (http://oceancurrent.imos.org.au/) website's fresh new look and user-friendly navigation provides ready access to up to date ocean information around Australia, including geostrophic current, sea surface temperature and chlorophyll-a.

It is now easy to navigate to maps of sea surface temperature and ocean colour by simply clicking on the two big maps on the home page. Lower down, you can read ocean news, and a series of tabs allows access to animations of the maps and in-situ observational data.

For help, information and to provide feedback about IMOS *OceanCurrent* please contact info@emii.org.au

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Coping with the impacts

The increasing rate of sea-level rise is not good news for our coastal population, nor for the natural and built environment in the coastal zone. The world is currently not on track to achieve the lower range of projected sea-level rise. And of course, sea-level rise will not stop in 2100 – as in the current century, the magnitude of future sea-level rise will be linked to our greenhouse gas emissions.

Increasing rates of sea-level rise will place increasing stress on the coastal margin. Extreme sea level events will become more frequent. Inundation and erosion will affect our infrastructure, affect ecosystems and, in some regions, displace populations. Adaption in the coastal zone will occur – this adaption can be either planned or forced upon us by the natural environment. Information on regional sea level changes and their projections are needed to underpin adaptation and mitigation strategies.

It is important that agencies in Australia and worldwide consider the impact of accelerating sea levels and provide communities with advice and planning directions that are commensurate with the magnitude of the problem. Failure to consider these issues will mean painful and costly impacts, particularly during extreme events.

Continued monitoring of sea level is essential

Despite progress, our understanding of sea-level change is incomplete, particularly when it comes to forecasting contributions from the ice sheets. Currently, observed sea-level rise is consistent with the most recent projections. Continuing to know where sea level is tracking relative to projections is important for planning and early warning of any rate of rise that differs from current projections is vital.

Australia relies on other countries for launching and maintaining satellite missions such as those used in our study. We provide an important contribution to the long-term monitoring of altimeter data that spans several different missions and space agencies – this is why long-term government support via Australia's Integrated Marine Observing System is so valued.

THE CONVERSATION

The Nature Climate Change paper discussed in this Conversation article, 'Unabated global mean sea-level rise over the satellite altimeter era' can be viewed here: http://dx.doi.org/10.1038/nclimate2635.

Jack Beardsley, University of Tasmania

GPS buoy deployed over the Bass Strait moored oceanographic sensors in order to derive an absolute datum for the derived sea level time series. For scale, the white antenna is approximately 0.5 m from the water surface.

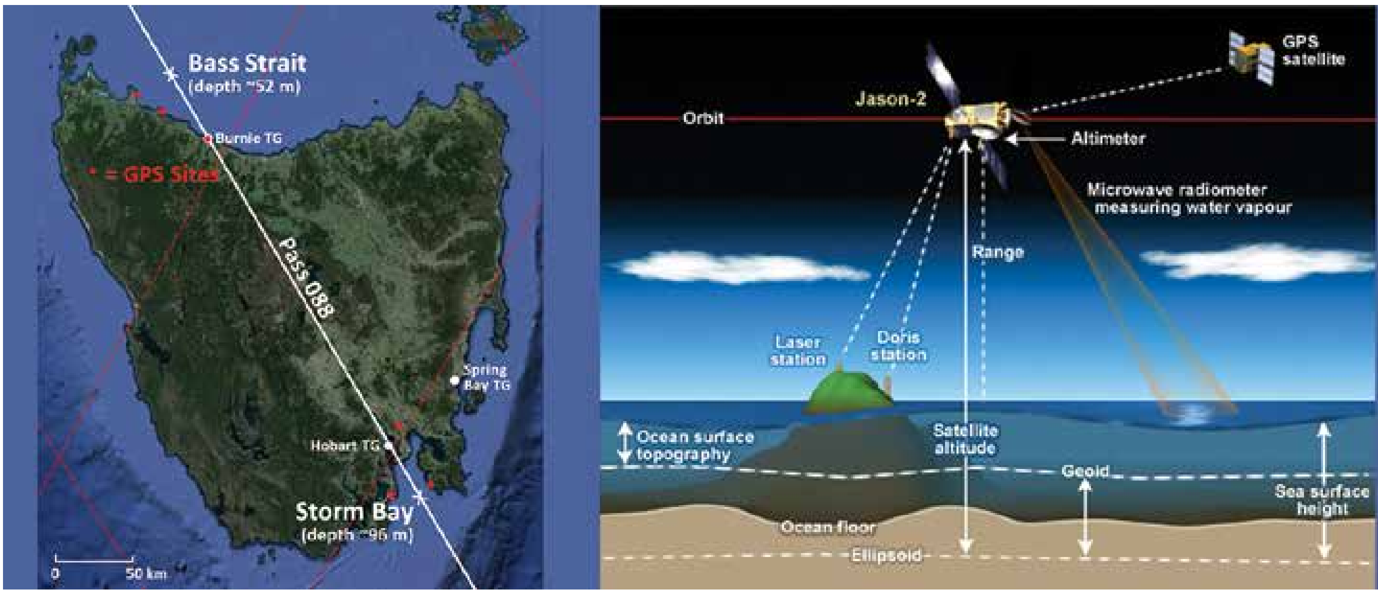


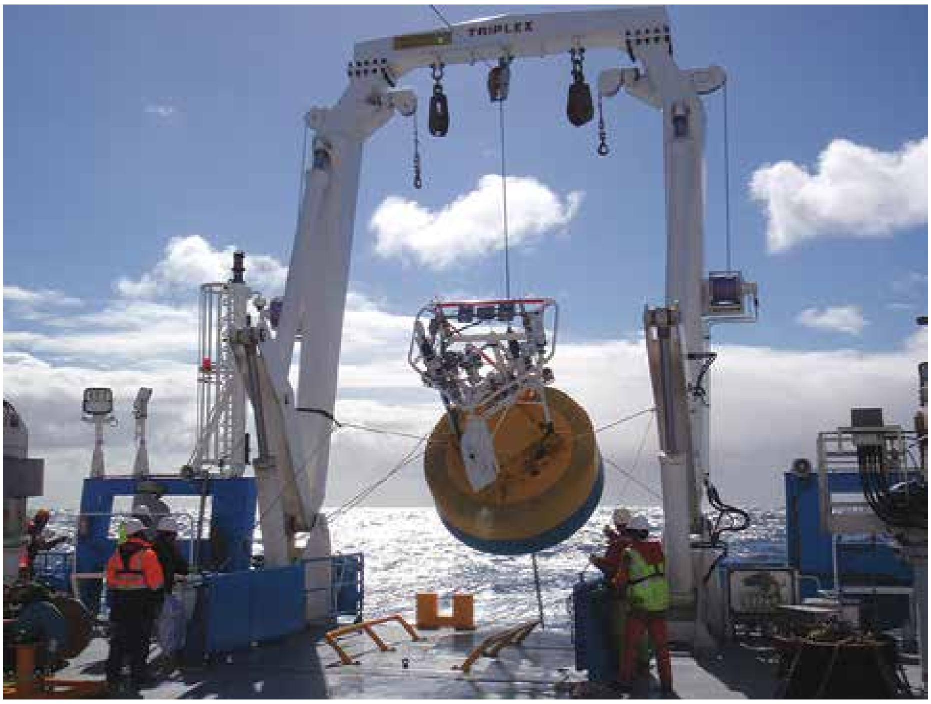
Image courtesy NOAA/STAR

Left: The IMOS satellite altimetry calibration/validation sites at Bass Strait and Storm Bay. IMOS provides the only calibration data stream for satellite altimeter data in the southern hemisphere. Right: Altimeters measure sea level by measuring the time it takes a radar pulse to make a round-trip from the satellite to the sea surface and back. They orbit approximately ~1330 km above the Earth, and their ground track repeats every ~9.9 days.

Surprising results as RV *Investigator's* first scientific voyage builds on IMOS long-term monitoring of the Southern Ocean

WRITTEN BY DAVID REILLY

Australia's new National Marine Facility, the RV *Investigator*, successfully deployed IMOS moorings to monitor indicators of climate variability and long-term change in March. Upon their return from the voyage in the Southern Ocean, scientists have reported findings that impact how we develop climate models.


Marine National Facility

Deployment of the Southern Ocean Flux Station mooring from the RV *Investigator's* A-Frame.

The key task for the voyage to the Southern Ocean was the redeployment of three high-precision deep-water moorings that form part of IMOS. These moorings are capable of measuring a large array of ocean properties including temperature, salinity, currents, waves, and biological activity, as well as atmospheric conditions.

The largest mooring, the Southern Ocean Flux Station, measures the air-sea heat flux: the rate at which the ocean absorbs heat from solar radiation and the surrounding atmosphere. IMOS has committed to a long-term investment in this infrastructure since 2008, in order to build time series data, which are important in climate research.

Data on heat transfer are relayed back via satellite, where they can be viewed in near real time on the IMOS data portal.

Professor Tom Trull from the Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC) and Dr Eric Shulz from the Bureau of Meteorology (BoM) led the voyage and will analyse data from the moorings as well as data collected via the vessel's new radar equipment. The data is expected to provide unprecedented insights into the ways that climate change is affecting the physical, chemical and biological properties of the Southern Ocean.

Cloud formations are an important factor in climate predictions yet they remain the single greatest source of uncertainty in current models used in forecasting. The RV *Investigator* carries highly specialised weather radar for measuring clouds.

In addition, an upward looking radar was installed specifically for this voyage by the BoM, under the leadership of Dr Alain Protat. The BoM radar is able to send 800 microwave pulses every second and collect data within a 150 km radius of the ship and 20 km into the atmosphere.

One of the most surprising and interesting early findings came when the research team pointed the BoM radar into the Southern Ocean sky. Information from the radar, combined with data from the IMOS air-sea flux mooring and images from a satellite passing overhead revealed something previously unknown.

"We were able to get readings from all these systems at the same time, which in turn allowed us to get a very precise understanding of the radiative impact of these clouds," said Dr Protat. "What we found was that the satellite simply was not seeing the lower level clouds that sit in the bottom kilometre and a half of the atmosphere," he said.

Low altitude clouds are more common in the Southern Ocean than elsewhere in the world. This is potentially very important to our understanding of the rate of heat uptake by the ocean.

"If we want to quantify that and understand how and why that is happening, we need to understand what the clouds are doing in the lower atmosphere," said Dr Protat.

The implication, according to Dr Protat, is that if satellites are not picking up low-level cloud over the Southern Ocean that's something that climate models will need to account for.

The World Heritage listed Ningaloo Reef in Western Australia will be the focus of a new marine research partnership between CSIRO and BHP Billiton Petroleum

The five-year, jointly-funded $5 million research program will include both deep and shallow reef research, turtle and shark tagging, and three PhD scholarships. In addition, there will be opportunities for the local community to be involved in some aspects of the research.

The program will use existing IMOS infrastructure at Ningaloo Reef. IMOS and CSIRO deployed the Ningaloo Reef Ecosystem Tracking Array in 2007: this is an array of acoustic receivers that detect tagged fish and animals, which aims to understand species' movements and habitat use on the unique coral reef ecosystem. There have been 2,960,481 detections since 2007, with the data stored in a database accessed via the IMOS Ocean Portal, https://imos.aodn.org.au.

"It is exciting to see new research projects spin up and build on the data collected by IMOS," says IMOS Director, Tim Moltmann. "This research program is a great example of the expanding use and value of our national Integrated Marine Observing System to Australian science and industry."

The new investment in marine science at Ningaloo Reef will help all stakeholders to better understand the reef and help target management efforts. The research program will provide baseline data on the condition of the ecological values of the reef, which will allow assessments over time to determine any changes. The project aims to translate the results that come from this new scientific research into improved management practices, so that Ningaloo can be used safely and responsibly for generations to come.

Project leader Mat Vanderklift from CSIRO Oceans & Atmosphere Flagship says "In our tagging and tracking research we will focus on sharks and turtles – iconic fauna that are key ecological values in the marine park. We will identify where and how far they move, allowing us to draw inferences about how they use various habitats within the park, and how they interact with activities that occur outside the park."

The program builds on CSIRO's extensive decade-long shallow coral reef and fauna research and turtle tracking using satellite and acoustic technology and follows the successful BHP Billiton Petroleum investment in the Ningaloo Atlas Research program.

> *"It is exciting to see new research projects spin up and build on the data collected by IMOS"*

Mick Haywood, CSIRO

CSIRO researcher Richard Pillans services an acoustic receiver in Mangrove Bay.

Russ Babcock, CSIRO

CSIRO researcher Mat Vanderklift releases a juvenile green turtle at Ningaloo Reef.

news

Darwin Harbour safer for shipping with improved ability to predict conditions

The ability to monitor and predict ocean conditions in Darwin Harbour is crucial for maritime safety. Building on existing observation infrastructure, a new monitoring station in the Beagle Gulf is set to provide detailed information to assist decisions affecting commercial shipping and recreational boating in the Harbour.

A partnership between IMOS, the Australian Institute of Marine Science (AIMS) and the Darwin Port Corporation (DPC) has enabled a better understanding of factors affecting the harbor such as tides, currents, wave height and movement of sediment.

The Darwin **National Reference Station (NRS)**, is one of only seven such facilities in Australia. Deployed on a channel marker at the start of the fairway, it has been providing valuable information to the Darwin Port Corporation since 2009. Sensors on the reference station provide data on over 30 parameters every 30 minutes. These include wind direction and speed, wave height and water velocity.

"IMOS and AIMS have collaborated to collect, analyse and disseminate data for many years now. The information we receive from devices anchored out in the shipping channel is of great benefit to the operations and future of the port of Darwin and in fact anyone who uses the harbour," says Tim Moltmann, IMOS Director.

The maritime safety and ecological conservation of Darwin Harbour depend on a range of factors. An understanding of these ensures the best use of resources to facilitate the growing industrial and recreational use of the harbour, while protecting its significant marine biodiversity.

The addition of a second mooring in the Beagle Gulf in May will expand our understanding of the factors influencing coastal systems and serve as an early warning system. It will provide alerts of approaching weather and allow forecasting of waves and current at key sites along the shipping channel.

CEO of Darwin Port Corporation, Terry O'Connor, said "Our investment in the national reference station with IMOS and AIMS as partners has resulted in significant value for the Darwin Port Corporation."

"Investing in a second mooring will increase our ability to monitor and predict conditions in the harbor, helping us to manage safe and efficient shipping," he says

AIMS scientists based in Darwin and Townsville interpret the data and make it available for a variety of users, including for oceanographic and climate research.

"Accurate, real-time data about harbour and ocean conditions allows us to create models to predict the weather in shipping channels. These models inform decisions on ways to improve harbour safety and to conserve the rich biodiversity in this area," says John Gunn, CEO of AIMS.

As well as providing crucial information for the DPC to operate the shipping channels effectively, local recreational boaties, yachties and fishers benefit from the data.

A real-time stream of weather data from the Darwin NRS can be accessed in various formats:

1. > **Configured for DPC**
2. > **General parameters**
3. > **For mobile devices**

All the data from the NRS and Beagle Gulf moorings will be made freely available via the **IMOS Ocean Portal**.

Deployment of the Darwin NRS Buoy. The pole on the far right side of the buoy contains instruments to measure water quality, and is lowered after deployment.

Paul Rigby, AIMS

Latest news from IMOS OceanCurrent

NSW floodwaters seen from space and by an IMOS glider

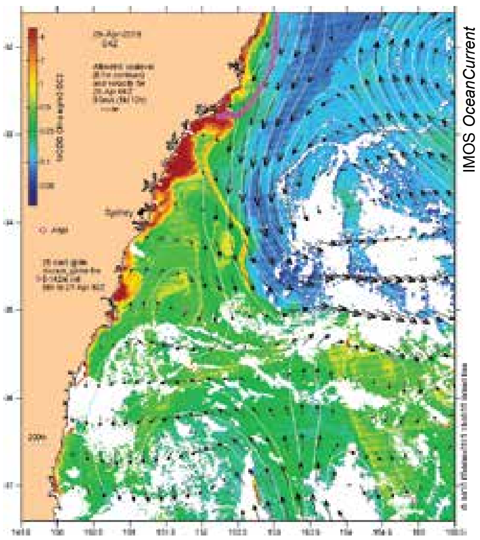
The storms that hit the Hunter Valley region of NSW on 21-22 April 2015 caused flooding as well as damage from winds and huge waves. River discharge mixes with seawater to form a buoyant mixture that can take some time to disperse, depending on the influence of winds and ocean currents.

The MODIS satellite image for 25 April says much about the way dispersal works in the ocean. A thin tendril of floodwater, coded yellow-orange in this image, can be seen stretched out along the boundary that already existed between the low-chlorophyll waters of the East Australian Current (coded blue) and the Tasman Sea waters shown in green. Most of the buoyant plume was still close to the coast on 25 April, its seaward edge marked by a sharp but irregular boundary.

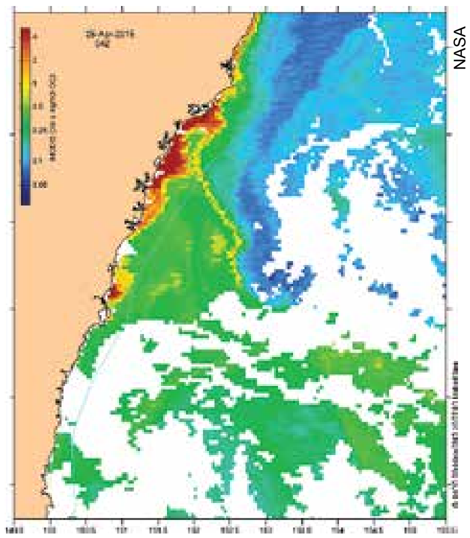
The satellite is not our only way of investigating this significant event. An IMOS Slocum glider was also on the job. Its track is shown in magenta overlain on the MODIS images. Its sensors very clearly distinguish the floodwaters from the ocean waters, especially through the impact on the water's salinity and fluorescence.

Click forward from 26 April to see the glider encounter, then depart from, the buoyant pool of floodwaters. The observations during the latter half of 30 April show how the seaward edge of the plume is over-ridden by the EAC water because the temperature effect on density is winning against the freshness effect. High estimates of Coloured Dissolved Organic Matter (CDOM) in the low-salinity water suggest that the MODIS estimates of Chlorophyll are probably being 'tricked' by high levels of CDOM as well as by the suspended sediments, but nevertheless, can be used to monitor the dispersal of floodwaters.

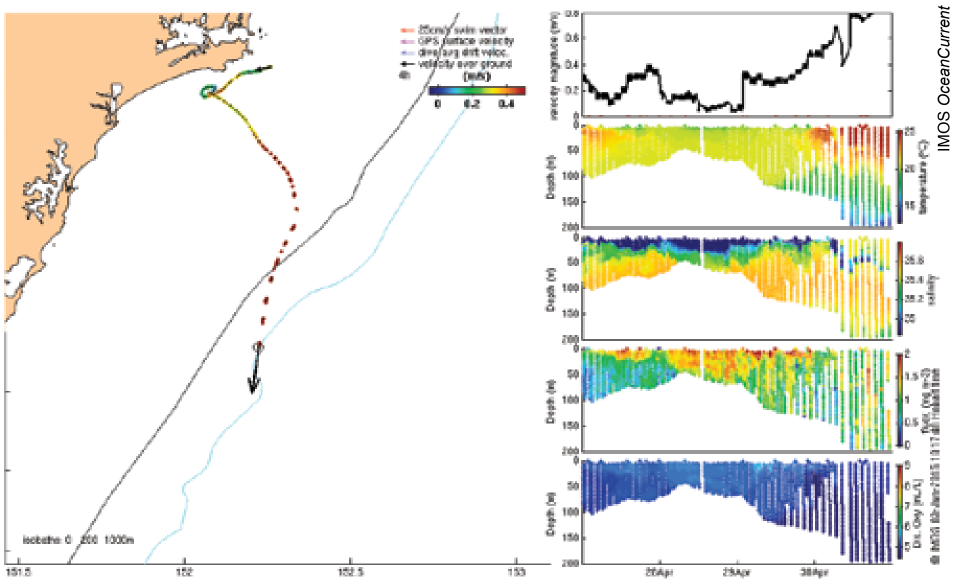
The satellite image (top left) from IMOS *OceanCurrent* provides an excellent example of the extra value provided by IMOS through ocean colour processing to 1km resolution (which underpins the OceanCurrent image). Australian scientists and other users derive massive benefit from global satellite data made available by NASA. The additional processing undertaken by IMOS makes this resource even more useful in the Australian region (when compared to the NASA image top right). In this case it has provided the detail necessary to observe interaction of floodwater with the East Australian Current.



MODIS satellite image for 25 April (1km resolution) of the floodwater plume showing interaction of floodwater with the East Australian Current.



The comparable MODIS satellite image for 25 April (4km resolution) from NASA.



The glider observations during the latter half of 30 April show how the seaward edge of the plume is over-ridden by the EAC water.

Bluewater and Climate Node: Moorings crucial for understanding the East Australian Current

In May the Marine National Facility RV *Investigator* redeployed the IMOS deep water moorings in the East Australian Current (EAC). The mooring data is applied by researchers in the IMOS Bluewater and Climate science node to help answer questions about one of Australia's major boundary currents.

"The East Australian Current sets the whole structure of the Tasman Sea," CSIRO scientist and voyage leader Dr Bernadette Sloyan said. "It influences our climate, the ecosystem, commercial and recreational fishing, much of what we see on the coast. If the current wasn't there, we'd have a very different Tasman Sea."

The current is also a key component of global ocean circulation, moving heat, freshwater and nutrients around the South Pacific. It moves massive amounts of water – each second transporting more than 25 million cubic metres of water, or 10,000 Olympic swimming pools, southwards.

The voyage deployed six large moorings, from the continental slope to the deep ocean off Brisbane. This is where the East Australian Current approaches its maximum strength and its flow is relatively uniform so we can measure the current's average flow and how it varies over time.

The collaboration between IMOS, CSIRO and the Marine National Facility will enable the maintenance of multi-year monitoring of the current.

"The East Australian Current shows variations over a range of timescales from seasonal to decadal," IMOS Director Tim Moltmann said.

"Much of what we know about the current has come from irregularly distributed observations collected over many decades. What is lacking is a sustained time-series of observations of the East Australian Current across its entire extent and of sufficient duration to understand seasonal, interannnual and decadal signals.

The IMOS observations will provide significant new insights into the variable nature of the East Australian Current."

The EAC has important implications for Australia's weather and climate. It is the dominant mechanism for the redistribution of tropical Pacific Ocean heat between the ocean and atmosphere in the Australian region. The waters in the Tasman Sea have warmed by more than 2ºC, faster than other parts of the world's oceans. Western boundary current regions, such as the EAC system, are highly variable and linked to large-scale ocean changes. Monitoring the EAC therefore, provides information of the large-scale drivers of regional ocean change. These changes may result in subtropical marine species moving into temperate waters, altering the habitat of many species.

> *"The East Australian Current sets the whole structure of the Tasman Sea"*

Dr Bernadette Sloyan in front of the orange mooring floats aboard the RV *Investigator*.

Facility 5: Autonomous Underwater Vehicle (AUV)

AUV deployed in a coordinated robotics voyage aboard the RV *Falkor* on the Scott Reef

The international research team on board the Schmidt Ocean Institute's research vessel *Falkor* has recently completed a data gathering expedition using coordinated groups of underwater robotics.

Schmidt Ocean Institute's research vessel *Falkor* completed her third expedition in Australian waters in April this year. The voyage was a first of its kind study, using coordinated groups of seven different underwater robotic vehicles. The team, led by Dr. Oscar Pizarro from the University of Sydney's Australian Centre for Field Robotics, had a successful voyage. The remote Scott Reef site was used for experiments aimed at expanding the electronic view of the seafloor and overlying waters.

Scott Reef is extremely remote—some 400 kilometers north from Broome in the Timor Sea and about halfway to Indonesia. But it offers expansive coral habitats, and its south end includes a large lagoon that offers partial protection from surrounding seas.

In total, over 40 dives with various Autonomous Underwater Vehicles (AUV) were completed collecting more than 400,000 seafloor images as well as oceanographic information and multibeam bathymetry data from around the lagoon. In total, the science team was able to achieve 19 dives with the IMOS AUV Sirius, totaling 200 hours of bottom time.

Some of this imagery was collected over sites visited in 2009 and 2011, forming part of a time series observed as part of IMOS. This imagery will provide insights into change in these sensitive coral habitats.

"Having multiple robots that can operate simultaneously is a great outcome. This allowed us to explore different aspects of the reef simultaneously from a single ship, something we haven't done before", said Professor Stefan Williams, IMOS AUV Facility Leader.

SOI/Logan Mock Bunting

Professor Stefan Williams and Deckhand Erik Suits watch from a zodiac as AUV Sirius is recovered to the aft deck.

The science party also developed a flexible visualization tool for tracking the multiple vehicles relative to each other and to the ship in real time. This allowed anyone to see what was happening on the ship using a computer, TV, or even a smart phone. Capitalizing on public interest in the robots, post-doctoral research engineer Ariell Friedman was able to create a citizen science website, Squidle, using images collected from the AUVs. The site allows participants to label images that will be used to train classification algorithms to help analyze the collected imagery. The team hopes that this can be a fun educational tool that gives students a chance to engage in real science while providing valuable data to the science party.

"We believe this voyage was a big step in pushing oceanographic technology forward," said chief engineer, Dr. Pizarro. The work will bring engineers closer to being able to leave groups of robotic vehicles unattended for long periods of time to accomplish tasks like seafloor mapping.

RV *Falkor* is silhouetted as the sun sets over the Timor Sea.

SOI/Logan Mock Bunting

Facility 6: National Mooring Network

Rare tropical diatom discovered for the first time at the Moreton Bay National Reference Station

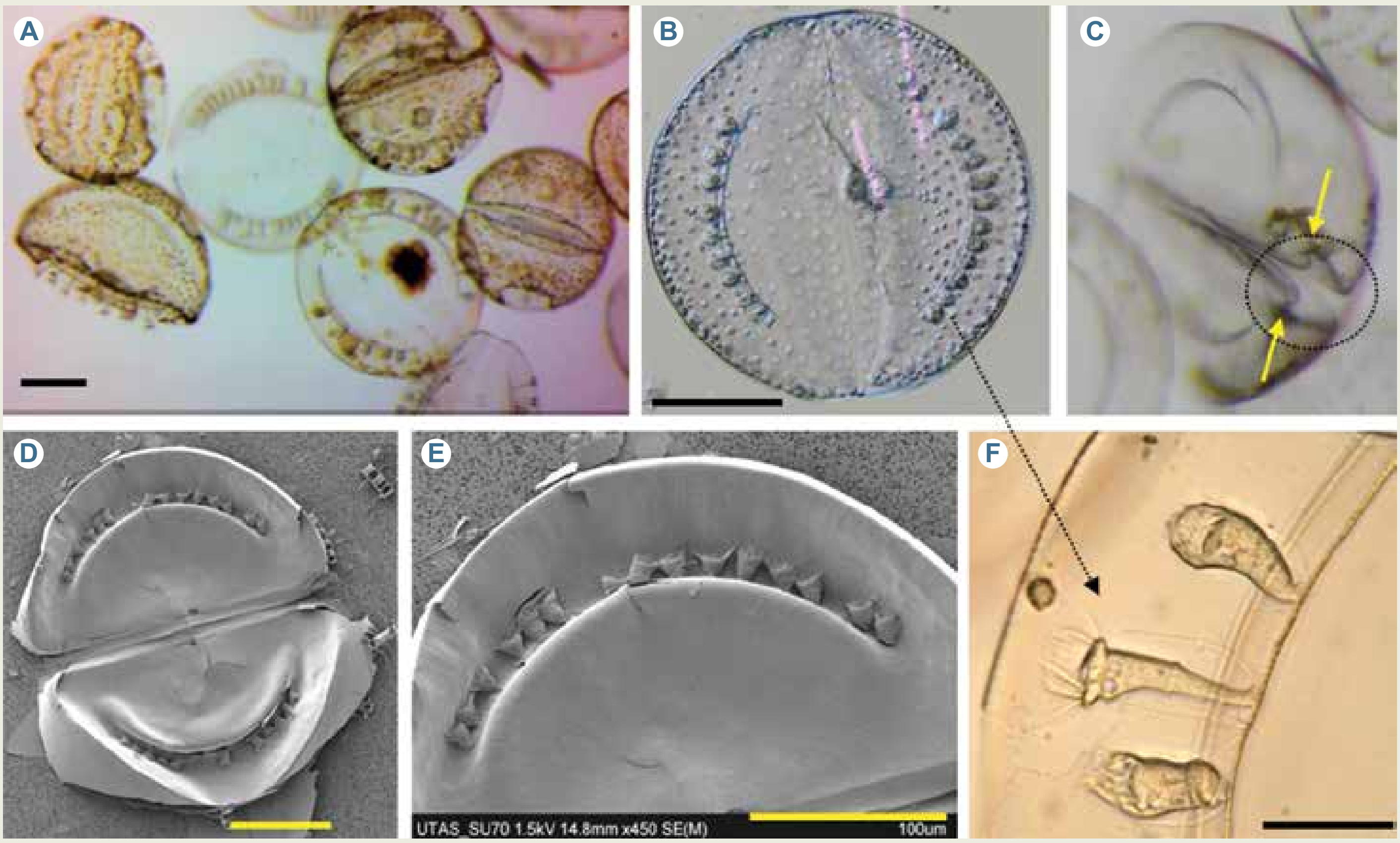
Written by Julian Uribe-Palomino, Gustaaf Hallegraeff, Nick Wade, Frank Coman and Anthony J. Richardson

A large diatom (300-650 µm), shaped like half of an orange, was found in high densities in plankton samples collected at the National Reference Station in Moreton Bay after the Brisbane floods in February 2011. This species, *Palmerina ostenfeldii*, had never been reported before from this Bay, despite previous intensive sampling. This diatom is unusual in that it hosts a necklace of ciliates on its surface, but the nature of this symbiotic association had remained unstudied.

As we were able to collect live samples of the diatom *Palmerina ostenfeldii*, we newly clarified its genetic distinction from a very similar diatom (*Palmerina hardmaniana*, never carrying ciliates); newly described the ciliate species; and demonstrated how the ciliates rotate the diatom as in a ferris wheel potentially benefitting the diatom by enhanced photosynthesis and nutrient uptake.

Palmerina ostenfeldii had previously been reported in waters from the Gulf of Thailand, Java Sea and tropical north-western Australia. The recent discovery of this species in National Reference Station samples on both the east and west coasts has extended the known southern range of its distribution to Moreton Bay in Eastern Australia and Ningaloo in Western Australia. The monitoring of this large and easy to identify diatom might help to find inclusions of warm water further south of Moreton Bay which is the most southern record for this species in Australian waters.

By contrast, *P. hardmaniana* has a broader distribution in tropical-subtropical waters. It has been found in coastal waters from Florida to the south part of Brazil, western coast of Madagascar, Red Sea, Arabian Sea, South China Sea, Arafura Sea and recently we found it for the first time in a sample from Rottnest Island National reference station (NRS) in Western Australia.



***Palmerina ostenfeldii* (Von Stosch) Hasle.** A. group of live diatoms and symbiont ciliates, B. Folds colonised by peritrich ciliates, C. diatom in division, notice the genesis of the new folds, D, E. SEM images of the diatoms and the ciliate's lorica and F. *Vaginicola collariforma* Sp. Nov. Scale bar 100 µm A-E, 50 µm F. Images: A-C, F J. Uribe-Palomino and D-E G. Hallegraeff.

Facility 6: National Mooring Network

Long Term Data Series from the Rottnest Island National Reference Station

Written by Ryan Crossing

The best predictor of future trends in the ocean is from past records. Six-and-a-half decades of oceanographic measurements have captured an enviable time series of the waters that surround Western Australia's Rottnest Island. IMOS has provided a higher degree of coverage by introducing moored sensors to compliment the extensive water sampling regime.

The CSIRO Division of Fisheries and Oceanography commenced coastal monitoring programs around Australia to establish a long term data series in the 1940s and 50s. For Rottnest Island collecting of biogeochemical samples (BGC), from the western end of the island began in 1951 and continued until 2009 when with the advent of IMOS, an in-situ mooring program bolstered the sampling. IMOS enhanced several of these historic sites around Australia as part of the network of IMOS National Reference Stations (NRS).

The Rottnest Island NRS lies in 48m of water with two mooring structures. A biogeochemical mooring that consists of two Wetlabs Water Quality Monitors (WQMs), that record temperature, salinity, dissolved oxygen and fluorescence for one minute bursts every 15 minutes. Two Seabird SBE 37 temperature loggers are placed at intervals between the main WQM sampling instruments.

A second float integrates an acoustic Doppler current profiler (ADCP) mooring system features a 600 kHz RDI Sentinel. The two moorings are 'hot-swapped' on a quarterly roster, thus, a near seamless metadata record exists for the moorings since their introduction in 2009.

The BGC sampling continues on a monthly basis and serves to validate and enhance the moored instrument data streams. Basic historical parameters remain the same; temperature, salinity, silicates, nitrates and dissolved oxygen but have now been enhanced to include measures for ocean acidification via dissolved carbon and alkalinity, drop net casts for plankton compositions and a suite of post sampling filtrations to cover water column suspended solids (TSS), and high performance lipid chromatography (HPLC).

The Rottnest Reference station is second only to its counterpart at Maria Island in Tasmania in its longevity. After 64 years of data collection, it continues to provide a seamless and highly accurate record for coastal oceanography in Western Australia.

R. Crossing, CSIRO

WA mooring technician Mark Snell preserving fresh samples.

R. Crossing, CSIRO

A float mounted ADCP ready for deployment and a typically fouled WQM being cleaned.

Facility 8: Animal Tracking – Making Connections

Written by Rob Harcourt

IMOS continues to break new ground not only nationally but internationally by contributing to the formation of new research networks in ocean observing. Rob Harcourt (Animal Tracking Facility Leader) and Clive McMahon (Animal Tracking Facility Biologging Manager) showcased the animal tracking components of the IMOS Ocean Portal at a meeting in the National Oceanic and Atmospheric Administration (NOAA) headquarters in Washington DC this April.

NOAA hosts the US Animal Telemetry network within the Integrated Ocean Observing System (IOOS). Like many data archive authorities around the world IOOS is making ocean observations available through a data portal. But, as is the case elsewhere in animal telemetry networks, working through issues of data sharing, ownership, appropriate recognition and data availability, is essential to win over the research community.

IMOS has grappled with exactly the same issues since formation, and is working with the US Animal Telemetry network led by Hassan Moustahfid (NOAA), and with the Ocean Tracking Network, led by Fred Whoriskey to ensure a coordinated international approach. Ultimately this will result in data becoming freely available greatly enhancing the power of all of these telemetry networks.

At the Washington meeting it was agreed that a key to facilitating data access and sharing is standardisation across databases, in particular metadata. A day-long workshop will now be held in conjunction with the 3rd International Conference on Fish Telemetry in Halifax this July to progress this standardisation. Xavier Hoenner from eMII will be at the meeting to share the IMOS expertise in database management.

As part of their USA visit Rob and Clive also took the opportunity to meet with colleagues from Montana Sate University (Jay Rotella, Bob Garrot and Terill Paterson) and the University of Alaska (Jennifer Burns) to discuss future deployments of IMOS CTD-SRDLs (Conductivity Temperature Depth Satellite Relay Data Loggers) on Weddell seals in the Ross Sea. These deployments will build on the 2014 success when 2033 CTD profiles were collected over winter. The new data will be combined with earlier US data to provide valuable information on the physical structure and changes in that structure for a highly productive and globally important ecosystem. Continuing these observations and initiatives in the Ross Sea provide an ideal conduit for building on the already strong Austral-American relations and Austral-New Zealand collaborations.

IMOS continues to break new ground not only nationally but internationally by contributing to the formation of new research networks in ocean observing.

IMOS in Washington DC. From left to Right Clive McMahon (IMOS), Hassan Moustafid (NOAA), Rob Harcourt (IMOS), Sam Simmons (Marine Mammal Commission) & Derrick Snowden (NOAA)

Securing CTD-SRDL deployments in the Ross Sea. From Left to Right: Clive McMahon (IMOS), Jennifer Burns (University of Alaska) & Rob Harcourt (IMOS).

Facility 9: Wireless Sensor Networks

Lizard Island: another year another cyclone

Written by Scott Bainbridge

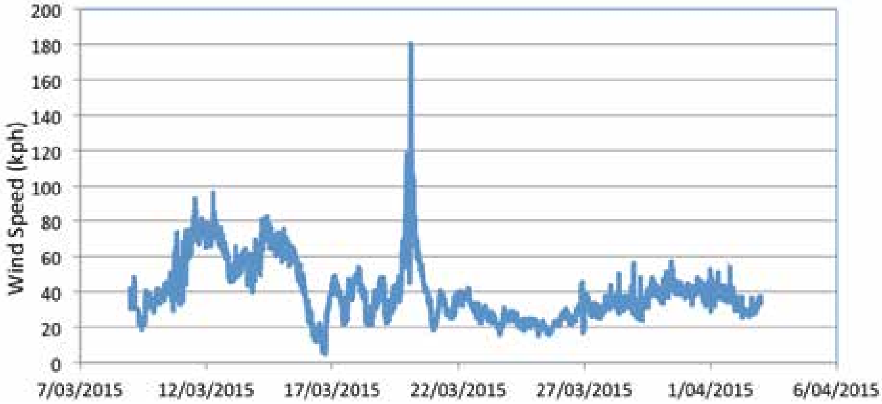
In April 2014 Lizard Island was battered by Tropical Cyclone *Ita*, a Category 4 system that passed within 10 kilometres of the island. The IMOS weather station on the island recorded a drop in pressure to 954 hPa and winds up to 160 kph as the cyclone passed over, taking some 10 hours to pass from the north-north-east.

In April 2015, almost a year to the day, a second cyclone passed over the island. Tropical Cyclone *Nathan* passed as a Category 4/5 with a pressure minimum of 965 hPa but winds of over 180 kph. The cyclone moved quickly taking only three hours to pass and so while the winds were higher the system was moving faster than Ita a year before. *Nathan* was not only faster but came from a different direction passing more to the west and so different parts of the island were impacted by the two cyclones.

The IMOS weather station withstood both cyclones although *Nathan* damaged the power systems and so the station was off the air a number of days as the batteries ran flat. A trip in early May has seen the station repaired and back on line.

The data form an important part of understanding not only how cyclones impact the reef but how the speed, intensity and direction of the cyclone can dramatically change the impact both on the land and for the reefs itself.

Wind speed measured by the IMOS weather station at Lizard Island during Cyclone *Ita*.



Wind speed measured by the IMOS weather station at Lizard Island during Cyclone *Nathan*.

Australian Institute of Marine Science

Lizard Island IMOS Weather Station.

Facility 11 Satellite Remote Sensing

Twenty-three years of IMOS sea surface temperatures for coastal research

Written by Helen Beggs

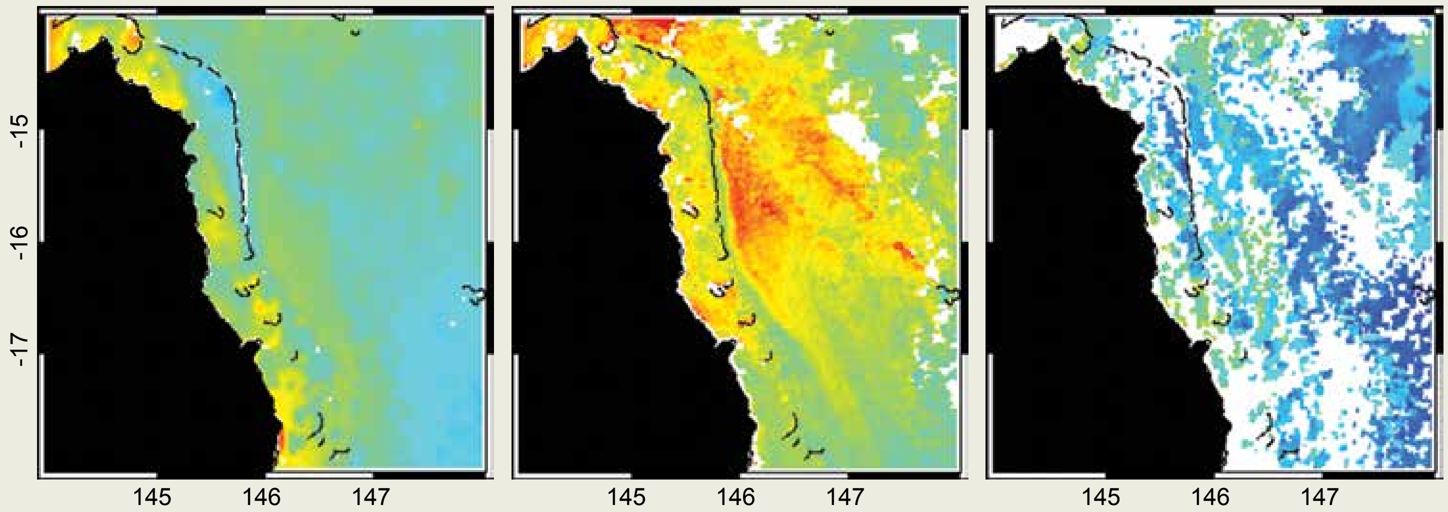
There is an increasing need for accurate sea surface temperatures (SST) within a few kilometres of coasts, for high-resolution weather and ocean prediction, environmental monitoring, fisheries and biological research. Infra-red sensors on polar-orbiting satellites provide the highest resolution SST observations from space (~1 km) but cannot sense SST under cloud. Prior to 2002 the only wide swath, 1 km resolution, satellite SSTs available were direct-broadcast Advanced Very High Resolution Radiometer (AVHRR) SST from NOAA polar-orbiting satellites.

Australia has direct-broadcast AVHRR data back to 1992 from reception stations in Australia and Antarctica. As a contribution to IMOS, the Bureau of Meteorology has used this data set to produce Group for High Resolution SST (GHRSST) format products with error estimates and quality flags for each SST value. These 2 km resolution "level 3" gridded products are available up to real-time in a range of averaging periods from single orbit to 1 month, using day-only, night-only and day and night data, to suit different applications.

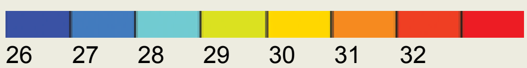
The products form a unique 23-year data set that supplies quality-assured SST values to within 2 km of coasts, covering oceans around Australia, Papua New Guinea, Indonesia, New Zealand and much of the south-west Pacific and Antarctica. See http://imos.org.au/sstproducts.html for more information.

In order to fill in the gaps in infra-red satellite SST data coverage due to cloud, it is necessary to either average over a long time period or combine with other, coarser resolution, satellite SST data. There are several statistically interpolated level 4 (L4) SST products, including NASA's 1 km daily global G1SST SST analysis (Figure 1 top), that interpolate 1 km satellite SST data. However, L4 products do not resolve either the diurnal cycle or the fine spatial ocean features close to reefs and coasts. Day-only or night-only IMOS SST products such as those shown in Figure 1 (middle and bottom) can be used to measure diurnal warming in coastal regions and SST changes over 2 km spatial scales to within 2 km of coasts.

IMOS day-only and night-only level 3 products are being used in PhD projects by Xiaofang Zhu (University of Miami) and Haifeng Zhang (UNSW@ADFA) to study diurnal warming over the Great Barrier Reef and the Tropical Warm Pool, respectively. Some applications that currently use IMOS-GHRSST level 3 products are real-time maps for recreational fishers (www.fishtrack.com), real time maps of SST and ocean currents (IMOS *OceanCurrent*) and nowcasting of coral bleaching (ReefTemp NextGen, http://www.bom.gov.au/environment/activities/reeftemp/reeftemp.shtml).



Sea surface temperatures from NASA's Global daily 1 km resolution SST "L4" analysis, G1SST (left panel) for 1st January 2014. G1SST ingested IMOS 1 km resolution SST data from NOAA polar-orbiting satellites, shown here for day-time (middle panel) and night-time (right panel) composite "L3S" products.



Postgraduate student profile

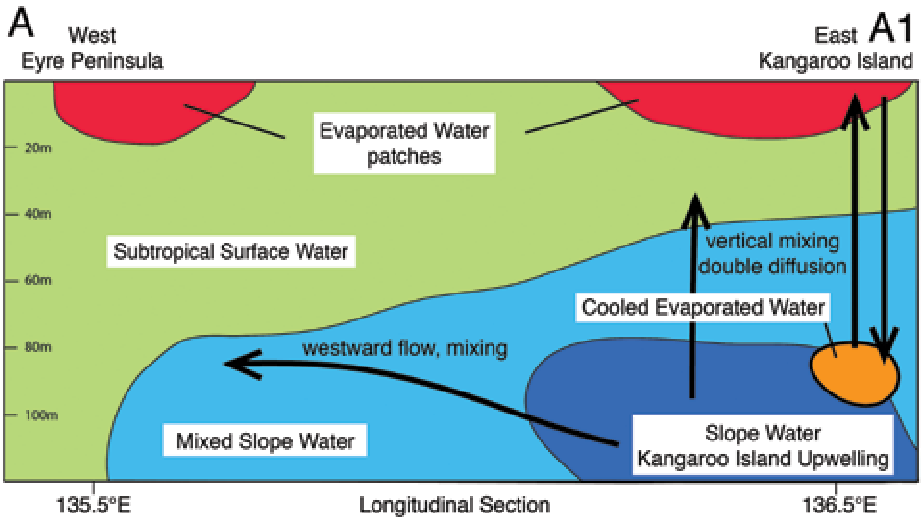
Students working with IMOS data for their postgraduate research

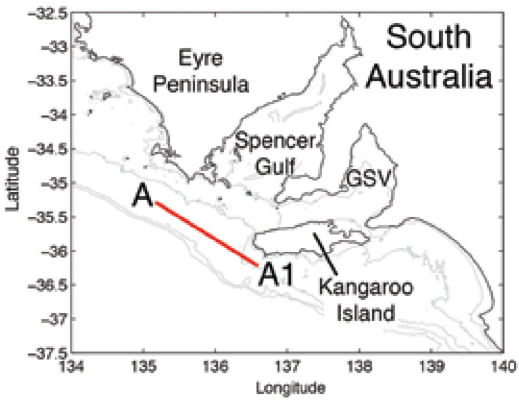
Laura Richardson | SARDI Aquatic Sciences, Australian National University

Project: Water Mass connectivity and mixing along the southern margin of Australia

Laura's PhD study used data collected through the Southern Australian IMOS (SAIMOS). Hydrographic data and water samples for nutrient and stable isotope analyses were collected using the SARDI research vessel RV *Ngerin* on the Lincoln Shelf, South Australia.

The Lincoln Shelf, South Australia, between Kangaroo Island and the Eyre Peninsula, is an area of complex oceanography where several different water masses and currents interact. Five water masses are defined for the shelf using hydrographic and stable isotope data collected between 2008 and 2011. Three water masses are present on the shelf and slope year round.





Schematic of summer shelf water masses during periods of upwelling for section A-A1 (see map left).

Slope Water with low temperature, salinity and isotope values is present on the slope at depths greater than 180 m, and is episodically upwelled onto the shelf during summer. During strong upwelling events this water can be upwelled from 300 m water depth and can provide nitrogen oxides (NOx)/phosphate concentrations as high as 13.35/0.94 µmol/L.

Subtropical Surface Water is a mixed water mass on the shelf and is transported year-round by the eastward flowing South Australian Current. Local heating and evaporation of this water mass on the shelf and within Spencer Gulf during summer forms *Evaporated Water,* a water mass with high temperature, salinity and isotope values.

Two mixed water masses form on the shelf during summer. *Mixed Slope Water* is formed when Slope Water mixes with Subtropical Surface Water during upwelling events. *Cooled Evaporated Water* is generated when surface Evaporated Water mixes vertically with cool, fresh bottom waters.

Nutrient data show average values of NOx and phosphate during months of strong upwelling to be 6.1 times and 4.6 times greater, respectively, than during winter months, and that upwelled water can have nutrient concentrations up to 90 times higher than those in summer surface waters.

Determining nutrient enrichment during upwelling events, as well as identifying mixed water masses on the shelf, has implications for mixing of nutrient-rich mesotrophic upwelled waters with oligotrophic surface waters, a situation that supports greater levels of primary productivity on the shelf.

The IMOS ‘circle diagram’ which is designed to be read from inside to out, illustrates how the system is operated by selected institutions but available for use by the entire community through open data access, generating a wide range of outputs that are relevant across portfolios and sectors.

The diagram has five layers:

1. IMOS at the core,
2. the eight operating institutions,
3. the broader research community,
4. various pathways for uptake and use of IMOS data and products, and
5. portfolios of relevance and impact.

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For more information about IMOS please visit the website www.imos.org.au

IMOS

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

Thanks to Christopher Watson, John Church, Matt King, David Reilly, Craig Steinberg, Warrick Glynn, David Griffin, Edward King, Julian Uribe-Palomino, Gustaaf Hallegraeff, Ryan Crossing, Simon Torok, Rob Harcourt, Scott Bainbridge, Helen Beggs and Laura Richardson.