IMOS
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Integrated **Marine Observing** System

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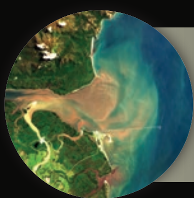
Anita Slotwinski, CSIRO

Modelling What We Sample and Sampling What We Model: Challenges for Zooplankton Model Assessment.

A new review article written by the IMOS Zooplankton Ocean Observations and Modelling task team summarizes many of the fundamentals of zooplankton modelling for observationalists and zooplankton observations for modellers.

IMOS farewells Dr Susan Wijffels as she heads to the Woods Hole Oceanographic Institution to take up a new position.

Marine heatwaves – surface temperature doesn't tell the whole story



IMOS Task Team goes troppo to solve radiometry challenges

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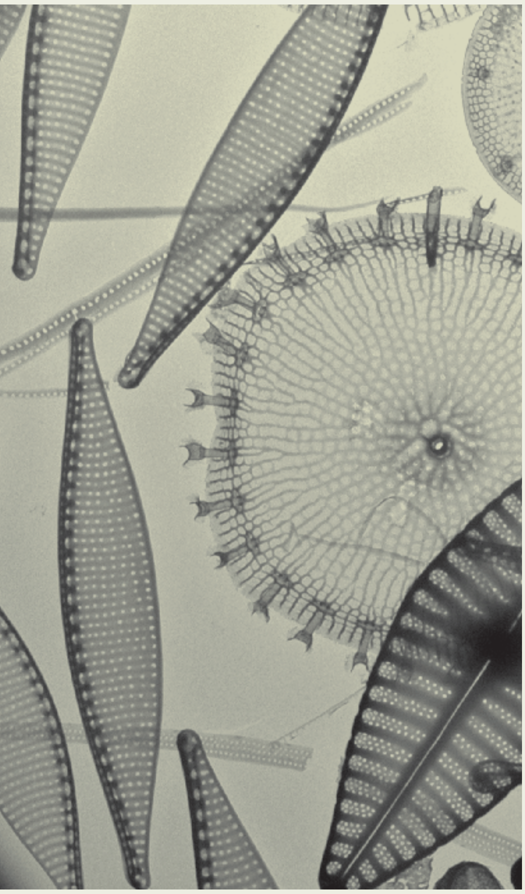
director's corner



Welcome to the latest edition of *Marine Matters*. The headline news as we go to press is that IMOS has been identified as an ongoing priority under NCRIS 2017. We have been provided with two years of funding to 30 June 2019, and are now very well positioned to secure a long-term allocation of funding beyond that date. This will be determined by the Government response to the 2016 National Research Infrastructure Roadmap, which we understand will happen by the end of the year. A second decade of IMOS is now well on the way.

Continued public investment in IMOS brings with it a responsibility to deliver significant social, economic and environmental benefits to Australia. The rationale for IMOS has always been that greatly enhanced ocean data, information, and knowledge about our vast and valuable marine estate should impact positively on the nation's 'triple bottom line'. The latest AIMS Index of Marine Industry clearly demonstrates the scale and trajectory of this opportunity. As noted by Minister Sinodinos when releasing the report, Australia's blue economy "has made a significant contribution to the nation's prosperity and is increasingly recognised around the world as a high value, high potential growth sector".

Building and exploiting big datasets and long time series is a key aspect of how IMOS goes about its business. Stories on the 2016 State of the Environment report and recent NCRIS symposium on environmental information highlight the progress we are making. Use of satellite remote sensing features in a number of stories in this edition. Australian derives huge benefits from civil earth observation data made available by international satellite agencies. IMOS is focused on ensuring we make the most of ocean remote sensing data through investment in calibration and validation, and delivery of national datasets and products. This includes daily maps produced by IMOS *OceanCurrent*. New satellite missions, both launched and planned, will make these activities even more important into the future.

As a research infrastructure, IMOS has always had strong uptake in research training through post graduate projects. We are thinking hard about how to accelerate broader uptake in 'Marine STEM' education. Practical courses developed by staff from our Australian Ocean Data Network (AODN) team provide one recent example.

At the end of the day, it's all about the people who operate and use IMOS on a daily basis. CSIRO's Dr Susan Wijffels has been an outstanding leader within the ocean observing community since the days when IMOS was just 'a twinkle in our eye'. We farewell Susan who is heading back to the USA to take up a prestigious position at the Woods Hole Oceanographic Institution (WHOI). We thank her for her stellar contribution, and wish her and her family every success with the move. IMOS loses a national leader, but we gain a wonderful international collaborator.

We hope you enjoy reading this edition of Marine Matters.

Tim Moltmann

State of the Environment Report released

The broader benefits of sustained ocean observing and open data access have been highlighted in the 2016 State of Environment (SoE) Report.

Released on 7 March by the Minister for Environment and Energy, Josh Frydenberg, SoE 2016 is the fifth national assessment of the state of Australia's environment, reporting on the current condition of and likely outlook for our environment. Full details can be found **here**.

The report includes a chapter on the Marine Environment with many references to IMOS. These cover research using IMOS observations as well as targeted analysis of datasets and time series that simply did not exist before IMOS, and were not available for previous SoE reports.

IMOS has been used to help understand pressures on the marine environment, such as climate variability and change, and to help assess state and trends of marine biodiversity and ecosystem health.

In considering the effectiveness of marine management, the report notes that the August 2016 review of Commonwealth Marine Reserves said "Continuing support for IMOS and the Australian Ocean Data Network was identified as a vital part of the monitoring process". This is reiterated in the section on outlooks for the marine environment, where IMOS is heavily referenced under sustained ocean monitoring.

"The use of IMOS in State of Environment reporting is a good example of effective and efficient use of government funding" says IMOS Director, Tim Moltmann.

"As a national research infrastructure, our core mission is to underpin high quality science and research. By engaging a broader stakeholder base in our planning, and making all of the data available, we can have impact across government portfolios, including Environment and Energy."

CSIRO's ECOS blog also highlights the importance of IMOS in articles by Marine Environment chapter co-author, **Dr Karen Evans**, and by **Professor Anthony Richardson** who leads the IMOS plankton program.

Marine Environment co-author Dr Karen Evans notes that the most significant advancement since the last State of Environment report has been data.

"With thanks to the role of IMOS (Integrated Marine Observing System) and other long-term observation and monitoring programs, we have seen a progressive building of data sets that are long enough for us to actually determine, with confidence, trends in the marine environment. This has been lacking in the past. If we want to continue to provide good science-based State of the Environment reports in the future, we must continue to support those marine data streams."

Anita Slotwinski, CSIRO

74.2 billion reasons to observe Australia's ocean estate

The latest AIMS Index of Marine Industry was released on 17 March by Senator the Hon Arthur Sinodinos, Minister for Industry, Innovation, and Science.

The rationale for establishing an Integrated Marine Observing System (IMOS) in 2006 was based on very strong social, economic, and environmental drivers. Australia has a vast and valuable marine estate, and the greatly enhanced ocean data, information, and knowledge available through IMOS should impact positively on our nation's 'triple bottom line'.

The Australian Institute of Marine Science (AIMS) has been measuring economic value of marine industries on a biennial basis since 2008. The latest AIMS Index of Marine Industry was released on 17 March by Senator the Hon Arthur Sinodinos, Minister for Industry, Innovation, and Science. Full details can be found **here**.

The headline news is that Australia's marine industries contributed $74.2 billion to the national economy in 2013–14. This accounts for 4.8 per cent of national Gross Domestic Product and directly and indirectly provides almost 400,000 jobs. The Minister noted that Australia's blue economy "has made a significant contribution to the nation's prosperity and is increasingly recognised around the world as a high value, high potential growth sector".

Up from $47 billion in 2011–12, these numbers clearly demonstrate the growing importance of the blue economy to Australia's future.

"Understandably, Australian Government is looking for publicly funded research to underpin new jobs and economic growth" says IMOS Director, Tim Moltmann. "IMOS has worked hard to position itself as being relevant to marine industries in an Australian context. We have many success stories. These new numbers provide important economic and societal context for what we need to do into the future. They help us to quantify the return on future investment in IMOS."

> *"IMOS has worked hard to position itself as being relevant to marine industries in an Australian context.*

Bruce Miller, CSIRO

IMOS farewells Dr Susan Wijffels

Dr Susan Wijffels of CSIRO is recognized nationally and internationally as an outstanding leader within the ocean observing community. She led the Australian component of the Argo program prior to the start of IMOS in 2006, and since then she has continued to lead the IMOS Argo Australia Facility. We are preparing to farewell Susan who is heading to the USA to take up a prestigious position at the Woods Hole Oceanographic Institution (WHOI).

The Argo float was one of the more established ocean observing technologies that formed Australia's new Integrated Marine Observing System in 2006. The international Argo program brought with it nearly a decade's worth of experience in technological development, operational experience in the oceans and well established international links. Argo also brought the expertise of Dr Susan Wijffels, an oceanographer with CSIRO's Marine and Atmospheric Research Division (now CSIRO Ocean and Atmosphere).

Dr Wijffels' recalls the advantages joining a national collaborative ocean observing program, such as IMOS, provided the Argo program.

"IMOS put Argo into a national framework that recognized the value of ocean observing.

Before the NCRIS funding the Argo program in Australia was vulnerable as it was spread across a number of agencies," says Dr Wjiffels.

"The NCRIS funding doubled the scale of the Argo program in Australia, formalising partnerships that were established in operating the program, for example between the CSIRO, the ACE CRC and the Bureau of Meteorology."

The NCRIS funding brought about a profound shift in the marine science community in Australia. Prior to IMOS agencies and institutions would compete against each other for funding.

> *"IMOS is the envy of many countries, especially as the NCRIS programs encourages collaboration.*

"IMOS facilitated and rewarded the inter-institutional collaboration which is absolutely vital for observing the ocean," says Dr Wijffels.

Another important advantage provided by NCRIS was that the actual data streams were recognised as the infrastructure that needed to be maintained, rather than the observing equipment itself.

As mentioned, the international Argo program pre-dated IMOS, operating since late 1999 and at the beginning of the IMOS era, involved 15 float-deploying countries. However, over the first decade of IMOS, improvements continued to be made.

Dr Wijffels recalls the most important improvement in the last ten years of Argo in Australia was actually making the floats work for longer in the hostile ocean.

"We worked on opening and checking them to understand the technology. We wanted to ensure we got the maximum value for every float purchased."

"The international Argo network provides the links to make sure that any problems encountered are shared. This has helped the Argo program to stay at design density and to ensure data quality remains high."

"In fact, the quality of the data set for climate studies has surpassed our initial expectations," notes Dr Wijffels with pride.

The ocean is a globally connected system, and marine observing is an international endeavor. The investment through NCRIS into IMOS as the national marine observing system has successfully provided both an independent capability to assist Australia in managing its own marine estate, and a significant attractor of international collaboration and co-investment.

Dr Wijffels says this has been recognized by the global community. "IMOS catapulted Australia to the level of international best practice."

"Before IMOS marine observing in Australia was agency by agency, and discontinuous. Now IMOS provides a mechanism for national design, implementation and leadership."

"IMOS is the envy of many countries, especially as the NCRIS programs encourages collaboration," says Dr Wijffels.

Over the last 20 years the game-changing robotic technology provided by the Argo float has revolutionized our ability to observe the global ocean to 2000 metres deep. This incredible data set has been used in over 3000 papers internationally.

The sheer number of publications makes it difficult for Dr Wijffels to pick the most important scientific highlights from the Argo data.

After a moment though she starts off with, "discovering the climate drift signal that demonstrates the ocean is warming. I was surprised that it was detected so quickly, only after eight years of observations. Originally we thought it would take 15 years of data."

"Another paper by Silvia Cole that looks at understanding the mixing of temperature and salinity. Another paper by Michele Ollitraut using Argo

trajectory data contains beautifully detailed maps of the 1000m ocean circulation, including zonal jets, only made possible by the high-quality data and geographical coverage the Argo program provides."

Lastly, she selects a paper by Jean-Baptiste Sallée that studied the exchange of heat and gases with the atmosphere in the Southern Ocean during winter.

"The Argo program made these observations possible for the first time. Prior to Argo there were very few winter surveys of the Southern Ocean as the research vessels would only go south during summer," Dr Wijffels explains.

"The Argo data set made it possible to map the geography of these exchanges between the ocean and atmosphere, providing a profound new understanding of how the ocean and atmosphere interact."

In looking forward to the next frontier for ocean observing Dr Wijffels recalls the conclusions of the last OceanObs conference in 2009.

"When the international community gathered at OceanObs we pledged to work together towards an integrated system. We recommended a framework for moving global sustained ocean observations forward in the next decade integrating new biogeochemical, ecosystem and physical observations while sustaining present observations."

"We need to go deeper into the ocean and at the same time observe the coastal and offshore interactions."

"In addition, we now realise we need to target the fast coupling between ocean and atmosphere. The global ocean observing systems needs to tackle this and Argo is only one part of the technology needed to observe this," says Dr Wijffels.

Finally, Dr Wijffels points to the huge data sets accumulating from satellite observations.

"The next generation geostationary satellites are providing observations every 10 minutes. These huge data sets represent an amazing opportunity, but will be hard to use. Science users want products, which make the data easier to use and integrate with other data types."

Dr Wijffels will leave Hobart in July to take up her new positon as a Senior scientist in physical oceanography at the Woods Hole Oceanographic Institution (WHOI). She will remain the international co-chair of the global Argo program, and part of the WHOI Argo team, so through this will remain in contact with IMOS.

"I am excited to reinvigorate and establish new collaborations in my new role at WHOI. I will be doing fundamental process science, looking at ocean-atmospheric coupling. There is also the opportunity to be involved in developmental engineering at WHOI, creating new platforms and sensors."

IMOS Director Tim Moltmann recognises the outstanding leadership Dr Wijffels has provided not only for the IMOS Argo Facility but also in the IMOS Bluewater and Climate Science Node.

"We thank Susan for her stellar contribution, and wish her and her family every success with the move. IMOS loses a national leader, but we gain a wonderful international collaborator.

CSIRO

This photo was published in the second issue of Marine Matters in July 2007. The original caption read: Dr Susan Wijffels (centre) stands with an Argo float next to John Gunn (left), Deputy Chief of CSIRO's Marine and Atmospheric Research Division, and Capt. Evan Solly (right), Master of the New Zealand research vessel Kaharoa, which has deployed more Argo floats than any other research vessel – more than 400 in the past three years in remote parts of the South Pacific and Indian oceans.

IMOS Task Team goes troppo to solve radiometry challenges

Images of the ocean from space show a range of colours that indicate levels of algae and other factors influencing ocean colour. Observations much closer to the ocean surface are required to validate images produced by satellite techniques and to improve the accuracy of inferences based on those images. The IMOS Radiometry Task Team met in tropical north Queensland to tackle shared challenges.

Satellite S2A MSI RGB composite image of Lucinda Jetty taken on 25 March 2017.

Craig Donlon, European Space Agency

Representatives of the Australian ocean colour remote sensing research community from CSIRO, Curtin University and University of Technology Sydney recently joined forces to investigate the experimental uncertainties associated with a variety of commonly used multi- and hyperspectral radiometers for the calculation of above-water remote sensing reflectance; a key parameter in ground-truthing ocean colour satellites and other bio-optical studies.

Accurate sea-truth radiometric measurements of ocean colour are required to monitor the temporal stability of airborne and space-based ocean colour sensors, as well as the accuracy of any atmospheric correction procedures applied to the remote sensing data. Thus, the accuracy of any sea truth radiometric measurements needs to be established.

In addition to ground-sensor performance, deployment and post-processing methodologies can contribute significantly to the overall accuracy of radiometric measurements. In Australia, there are a relatively small number of geographically isolated researchers and technicians that study ocean optics. They are from different backgrounds with different perspectives and use different instrumentation. IMOS one-year funding provided the opportunity for a group of these researchers to form a **Radiometry Task Team** in which to compare their approaches.

First, the group pooled their sensors and sent them to a commercial radiometric calibration facility where lamp-based calibrations were performed for each sensor at three different internal temperatures encompassing the range of temperatures encountered in above-water Australian field conditions.

Next, the task team inter-compared the calibrated instruments in the field at the IMOS/CSIRO funded Lucinda Jetty Coastal Observatory in tropical North Queensland. Situated at the end of a 5.76 km long bulk sugar loading facility, this unique location adjacent to the Great Barrier Reef World Heritage area exhibits a wide range of Great Barrier Reef water inherent optical property (IOP) throughout the year.

Suspended some 20 metres above the ocean surface, the dedicated work platform has long-term IOP, SeaPRISM radiance and DALEC above water remote-sensing reflectance installations.

The task team assembled for a two-day campaign (9-10 Nov 2016) in the beautiful fishing village of Dungeness; woke every morning to a view of the warm tropical mist-clad mountains of Hinchinbrook Island, looking past the invitingly glassy but crocodile-inhabited mangrove channel. After a 15-minute drive out over the jetty, the team performed consistent measurements for each of the radiance and irradiance device types, and two integrated DALEC above water reflectance systems and the autonomous SeaPRISM.

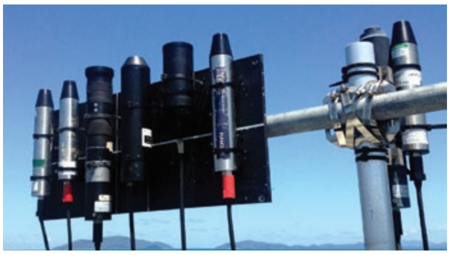
The tropical solar zenith angles approaching one or two degrees at noon allowed observations of the cosine behaviour of the irradiance sensors over a large angular range.

Sky conditions were nearly ideal for the 2-day sampling period, with only a few wispy clouds in the morning, rapidly burning off in the hot tropical sun. The mornings were typically still and very humid until a sea breeze system developed, bringing wind speeds of 10 - 15 knots as measured by a permanently installed Vaisala Weather Transmitter (WXT520). These hot conditions ensured that all sensors that recorded internal temperatures were reading 35+ degrees Celsius; far hotter than typical temperatures factory calibrations are performed at. Fortunately, pre-deployment calibrations were performed for all instruments at these elevated temperatures, so suitable instrument responsivities were applied to field data in order to achieve improved radiometric accuracy.

The field deployment was an excellent chance for the often regionally separated researchers and technicians to meet, compare stories, and discuss methodologies and other technical considerations pertinent to ocean colour radiometry.

With the ongoing processing and analysis of the datasets acquired in this study, the community is learning more about the experimental uncertainties and resultant confidence which can be placed in using field radiometers to validate aerial and satellite-based ocean colour remote measurements.

Article written by Matt Slivkoff and David Antoine, IMOS Satellite Ocean Colour Sub-Facility, Remote Sensing & Satellite Research Group, Department of Physics and Astronomy, Curtin University.



M. Slivkoff

Irradiance radiometers lined up, with a view of Pelorus and Orpheus Islands in the background. 4 x Ramses, 2 x HyperOCR, 1 x USSIMO, and 1 x MS8 sensors are visible.

The Lucinda Jetty Coastal Observatory with field participants, L to R: M. Slivkoff, J. Lovell, D. Boadle, M. Doblin, B. Baker, D. Antoine, and T. Schroeder.

D. Boadle

Marine environmental information in Australia – how NCRIS has made a difference

IMOS Director, Tim Moltmann and the IMOS Scientific Officer, Dr Ana Lara-Lopez attended the Greater Impact through Environmental Infrastructure Symposium in Canberra in May.

The symposium celebrated the collaborative impact of Australia's environmental infrastructure and showcased the impact of 10 years of investment into environmental infrastructure. The symposium also provided a platform to foster new collaborations and shape future innovations to enable impact into the future.

Mr Moltmann gave a presentation that reviewed how funding through the National Collaborative Research Infrastructure Strategy (NCRIS) has made a difference to marine environmental information in Australia.

"At the dawn of the 21st century, Australia's efforts in marine observing and data management were inadequate, fragmented and discontinuous across time," said Mr Moltmann.

IMOS was established in 2006/07 to address these issues. It has successfully achieved this by creating brand new national facilities to observe the marine environment, encouraging collaboration and open data access, and turning sustained observations into data sets and time series for use and reuse.

IMOS, like all the NCRIS capabilities, is a research infrastructure. IMOS observations and data need to be taken up and used by the research community, and it is through the research community we deliver relevance and impact to the users and stakeholders of marine science.

"We've worked very hard to 'close the loop' from infrastructure to impact," said Mr Moltmann.

"For example, in the early years of IMOS we weren't mature enough to engage with the Commonwealth Environmental Research Facility (CERF). As IMOS matured and consolidated we were able to engage with the National Environmental Research Program (NERP), making good progress with the Marine Biodiversity and the Tropical Ecosystems Hubs."

"In the last couple of years this collaboration has matured to the point where IMOS is now a partner in the National Environmental Science Program (NESP) Marine Biodiversity and Earth Systems and Climate Change Hubs."

IMOS data has also been taken up in the recent 2016 State of the Environment report and in the review of Commonwealth Marine Reserves.

IMOS Director, Tim Moltmann then looked forward in his presentation to new horizons in marine environmental information.

"As we enter the second decade of NCRIS, new horizons are emerging that we would not have been able to embrace without NCRIS," said Mr Moltmann.

"We are looking to combine platforms, sensors, data, computation, analytics and visualisation. Bringing new capabilities to bear on contemporary issues in Australia's vast and valuable marine estate."

Dr Ana Lara-Lopez spoke in several sessions including: demonstrating impact; international impact; and integrating earth observations for essential environmental monitoring in Australia.

Deep water soft coral; *Anthomastus.*

CSIRO

The following NCRIS Facilities partnered together to host the Symposium: Atlas of Living Australia, Australian National Data Service (ANDS), Australia's Urban Intelligence Network (AURIN), AuScope, Bioplatforms Australia, IMOS, NCRIS, NCRIS Groundwater Project, National Collaboration Tools and Resources project (Nectar), Queensland Cyber Infrastructure Foundation (QCIF), Research Data Services (RDS) project, and Terrestrial Ecosystem Research Network (TERN).

Deployment of the IMOS AUV "Sirius" in the Flinders CMR by Marine Biodiversity Hub researchers.

Margot Delaporte, IMAS/ Marine Biodiversity Hub

NEWS

Marine heatwaves – surface temperature doesn't tell the whole story

Marine heatwaves are defined as 'discrete prolonged anomalously warm water events', and the associated mass mortality and habitat shifts are becoming more common with record events occurring around the world. However, little is known about the statistical characteristics of marine heatwaves due to the lack of long term in situ observations.

Professor Moninya Roughan, of the University of New South Wales, and leader of the IMOS New South Wales Moorings sub-facility, with colleague Amandine Schaeffer used two historical datasets to investigate temperature changes along the full depth of the water column dating back to 1953.

Around Australia, long- term sampling of the ocean temperature has been conducted at three sites since the 1940-50s, including Port Hacking off Sydney. Known as PH100, this mooring, instrumented to a depth of 110 m, was chosen as an IMOS national reference station (NRS), together with six other sites around the country.

The Port Hacking NRS and a second coastal mooring, ORS065, located 26 km to the north and maintained by Sydney Water Corporation since November 1990 in 65 m of water provided the data for this study.

Using a seasonally-varying climatology and temperature anomalies to identify and characterise marine heatwaves events down to 100 m depth, results showed that marine heatwaves regularly extend the full depth of the water column, with a maximum intensity below the surface.

These data have created one of the first long-term assessments of temperatures from the surface to the seabed as deep as 100 metres. The observations have highlighted that the extent of warmth wasn't being captured by the readily available surface temperature measurements.

'Satellites are not getting the full picture,' said Professor Roughan. 'They are missing the peak and intensity, and sometimes the duration (of marine heat waves),' she said.

Extreme temperatures at depth are driven by local downwelling favorable winds that mix the water column and reduce the stratification. These new results show the importance of considering sub-surface hydrography, and that sea surface temperature is insufficient to fully understand marine heatwaves which are having disastrous ecological consequences in coastal regions globally.

Marine heatwaves off Sydney – based on at least five consecutive days when temperatures were in the top 10 per cent of readings – were found to last as long as a month. The average duration was between eight to twelve days.

The biggest average anomalies were at 50 m depths and the most extreme temperatures were as much as six degrees above the norm, based on two data sets covering seven and 25 years.

The Great Barrier Reef has attracted much-publicised concern, where two warm summers in a row had triggered unprecedented coral bleaching, affecting about two-thirds of the reef.

Perhaps less widely known, the East Australian Current skirting the eastern seaboard including Victoria and Tasmania is also changing, extending southwards about 350 kilometres in 60 years.

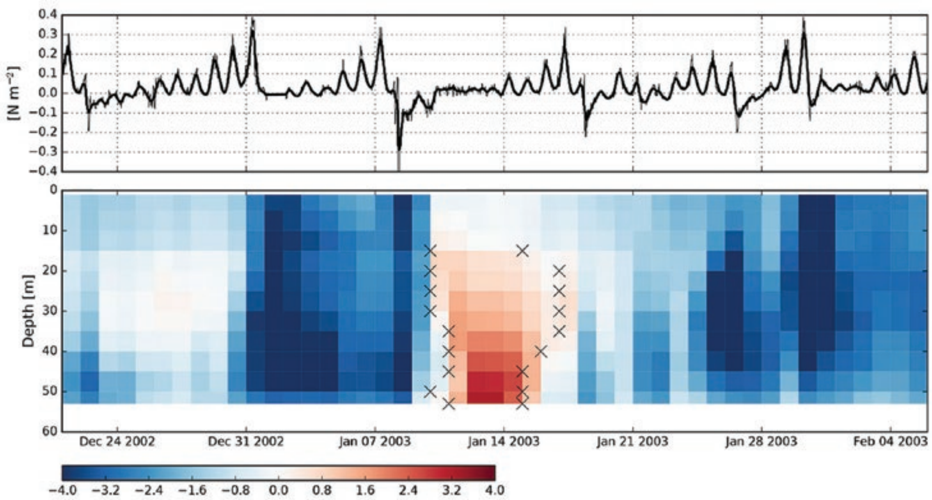
Tropical fish such as rabbitfish help keep seaweed off coral reefs but shift the ecological balance when they move into kelp forests such as those off the east coast of Tasmania.

'Weeks (of heatwaves) are a long time when you're a marine organism, a small creature, at the bottom of the food chain,' Professor Roughan said.

While the data periods were too short to identify longer term climate trends, an abundance of research suggested marine hot spots were likely to get hotter and there would be worsening impacts.

The paper presenting this research: Schaeffer A., and M. Roughan (2017), Sub-surface intensification of marine heatwaves off southeastern Australia: the role of stratification and local winds, Geophys. Res. Lett., 44, doi:10.1002/2017GL073714.

Parts of this article were originally published by the Sydney Morning Herald as 'Maximum damage': What's going wrong in our deep blue and warming sea, by Peter Hannam.



Example of a marine heatwave event at ORS065. (Top) Hourly upwelling favorable wind stress, (bottom) temperature anomaly from the 90th percentile climatology (which is the threshold used to identify marine heatwaves). Black crosses indicate the start and end of the event at each depth when detected. Note that the marine heatwave started during downwelling-favorable winds and was not detected at the surface.

Modelling What We Sample and Sampling What We Model: Challenges for Zooplankton Model Assessment

The IMOS Zooplankton Ocean Observations and Modelling (ZOOM) Task Team have written a review article following on from the IMOS Zooplankton Ocean Observing and Modelling workshop held in Hobart 15–16 February 2016.

In the review published in the journal *Frontiers in Marine Science*, Jason Everett, the primary author and leader of the ZOOM task team, along with his co-authors, summarize many of the fundamentals of zooplankton modelling for observationalists and zooplankton observations for modellers.

Zooplankton are the intermediate trophic level between phytoplankton and fish, and are an important component of carbon and nutrient cycles, accounting for a large proportion of the energy transfer to pelagic fishes and the deep ocean. Given zooplankton's importance, models need to adequately represent zooplankton dynamics. A major obstacle, though, is the lack of model assessment.

In the review article the authors try and stimulate the assessment of zooplankton in models by filling three gaps.

- The first is that many zooplankton observationalists are unfamiliar with the biogeochemical, ecosystem, size-based and individual-based models that have zooplankton functional groups, so the authors describe their primary uses and how each typically represents zooplankton.
- The second gap is that many modellers are unaware of the zooplankton data that are available, and are unaccustomed to the different zooplankton sampling systems, so the authors describe the main sampling platforms and discuss their strengths and weaknesses for model assessment.
- Filling these gaps in our understanding of models and observations provides the necessary context to address the last gap – a blueprint for model assessment of zooplankton.

  The authors detail two ways that zooplankton biomass/abundance observations can be used to assess models: data wrangling that transforms observations to be more similar to model output; and observation models that transform model outputs to be more like observations.

The authors hope that this review will increase the dialogue between modellers and observationalists, and provide the impetus for greater model assessment of zooplankton output through data wrangling and state-of-the-art observation models.

To read the full review:
Everett, JD *et al*. 2017 Modeling What We Sample and Sampling What We Model: Challenges for Zooplankton Model Assessment. *Frontiers in Marine Science*: 4, article 77. **doi.org/10.3389/fmars.2017.00077**.

Anita Slotwinski, CSIRO

Mass Fish Die-Off at Mallacoota: Upwelling and the EAC?

Written by Madeleine Cahill
4 April, 2017

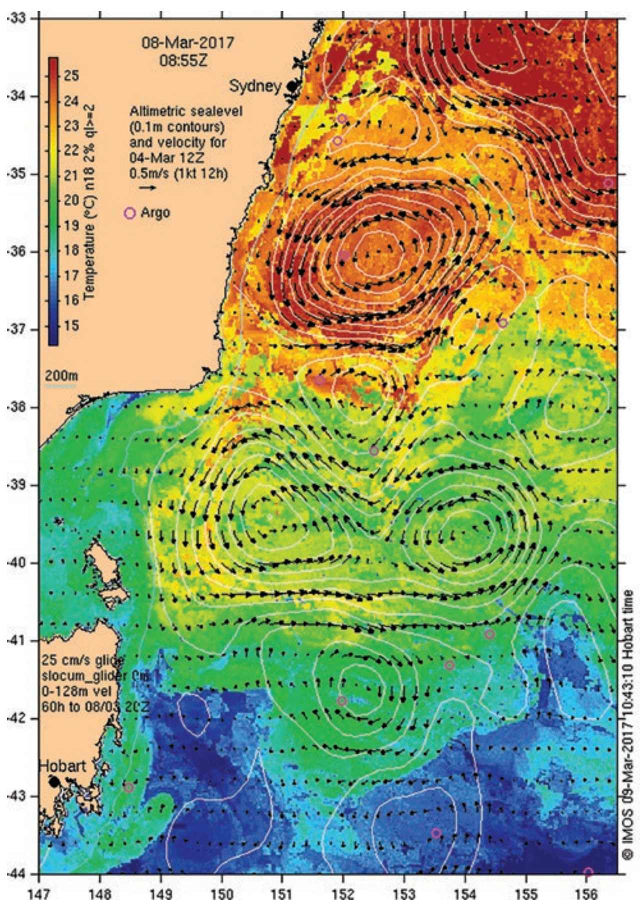
Thousands of dead fish washed up on the shores of far eastern Victoria and southern NSW in March. They started appearing on the beach in small numbers around March 11 but came in en masse in the last few weeks of March. Although most of the fish appeared to be leatherjackets, there were also whiting, black sole, puffer fish, boxfish, sea urchins, flathead and even some penguins. Locals noticed the die-off coincided with a drop in ocean surface water temperature of 7°C and a lot of algae (described as a browny-green sludge) in the ocean.

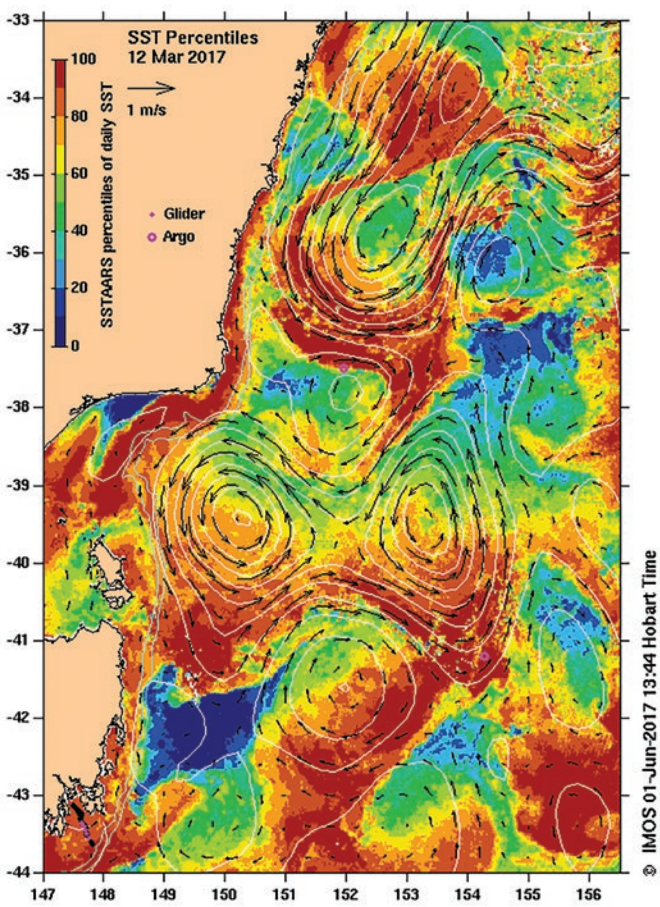
These observations are consistent with the satellite imagery. Cold upwelled water is evident from **Mar 8** (see figure below, left) and persisted for the rest of the month. SST images, **Mar 12** & **Mar 25**, indicated the upwelled water extended for 50–100km along the coast and across Bass Strait. These images also show the water offshore was a warm 22°C and at times is separated by only 25km from the 14°C upwelled water. The **Modis Chl-a image for March 14** showed an intense algal bloom associated with the upwelled water extending for almost 200km along the Victorian coast that persisted throughout the month.

The northeastern corner of Bass Strait is a well-known upwelling region and, as for the NSW coast, the two drivers for bringing cold, nutrient rich waters to the ocean surface are wind forcing and dynamic uplift created when the East Australian Current (EAC) encroaches onto the continental slope.

This March these two drivers seemed to have combined for maximum effect. Winds were persistently upwelling favorable for the far eastern Victorian coastline and a large EAC eddy sat just offshore for most of the month (Mar 12). **SST percentiles (Mar 12)** (see figure below, right) show the upwelled water was within the coldest 10% of temperatures observed in March for that region while the EAC waters just offshore were in the top 10% of temperatures. Colder upwelled water implies a higher nutrient concentration as it is likely to have come from deeper in the water column. Warm EAC water on the other hand, though depleted in nutrients, allows for rapid phytoplankton growth, so there may be increased algal growth where the two water masses meet.

The cause of the fish deaths is still to be established but could include hypoxia caused through oxygen depletion when the algae die off or suffocation due to the algae blocking the fish gills or even shock due to the rapid change in temperature. The Victorian EPA is investigating the event to determine the exact cause of the deaths and the various factors could be complex. Whatever the cause of this fish kill it appears that increased southward extension of the EAC that has become apparent since at least 2014 has contributed to creating both a stronger upwelling event and higher gradients in temperature.





New South Wales Integrated Marine Observing System (NSW-IMOS):

Long-term phytoplankton time series data from the Port Hacking National Reference Station to be examined in three international collaborations.

Dr Penelope Ajani, from the Climate Change Cluster at the University of Technology Sydney, has been studying the long-term phytoplankton time series data from the Port Hacking National Reference Station (NRS), and currently she is involved in three international collaborations with a particular focus on this dataset.

In 1942, the Commonwealth Scientific and Industrial Research Organization (CSIRO) Division of Fisheries and Oceanography designated a coastal sampling station off shore from Port Hacking, Sydney (known as Port Hacking 50 m or PH50m). A second station, Port Hacking 100 m (PH100m) was designated in 1954 and was the focus of many subsequent phytoplankton and hydrological investigations.

The Port Hacking phytoplankton time series has now been extended to 2017 through IMOS, and Dr Ajani is part of three larger international studies that are examining this long-term data set. The first is in collaboration with colleagues from Mount Alison University, Canada, in which realised niche modelling is being used to examine if phytoplankton at the Port Hacking station are adapting to changing conditions over decadal time scales. Preliminary modelling suggests that phytoplankton at Port Hacking are indeed tracking/adapting to environmental changes through time.

The second collaboration is with the working group 'sMarD', at the Synthesis Centre for Biodiversity Sciences in Germany, which is looking at global changes in marine plankton diversity and productivity. This group have collated nearly 40 phytoplankton time series datasets and they are especially excited to examine the Port Hacking dataset as it is one of only a few datasets from the southern hemisphere.

Finally, Dr Ajani is working with collaborators from Texas University to use the Port Hacking dataset amongst other datasets to examine phytoplankton biodiversity models in the context of harmful blooms.

All of the collaborations will provide valuable long term insights into the productivity and diversity of phytoplankton in south east Australian coastal waters.

Transmission electron microscopy image of diatoms from eastern Australia

Penelope Ajani, UTS

Ocean gliders:

Challenger glider crosses equator on record journey

The underwater glider 'Challenger' is on a journey from Fremantle, Western Australia, to Galle, Sri Lanka. It departed Australia on 5 November and has just reached the Equator.

This ocean glider mission is a joint project between Rutgers University in the USA and The University of Western Australia (UWA) which operates the IMOS Ocean Gliders Facility. The mission aims to cover a distance of 6,200 km and, if successful, will set a new world record for distance covered by an ocean glider in a single journey. To date it has covered over 5,600 km and spent 221 days in the water.

Challenger recently reached an oceanographic mooring at the equator at 90ºE that has been deployed as part of the Research Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA). The glider spent a few days in the vicinity of the mooring undertaking rapid vertical profiles with the aim of capturing the variability in the diurnal cycle.

UWA's Professor Chari Pattiaratchi, who is the leader of the IMOS Ocean Gliders Facility, is pleased with the progress of Challenger to date.

"This is a remarkable journey for a remote-controlled vessel which doesn't even have its own powered propulsion system.

"By controlling the glider's direction and buoyancy and understanding the currents, we have been able to direct it to exactly the point in the Indian Ocean we needed it to go," said Professor Pattiaratchi.

Challenger is now travelling west along the equator. It completed a period of station keeping mode undertaking vertical profiles to 500 metres, sampling continuously (in the normal mode only one transect per day was being collected to conserve power).

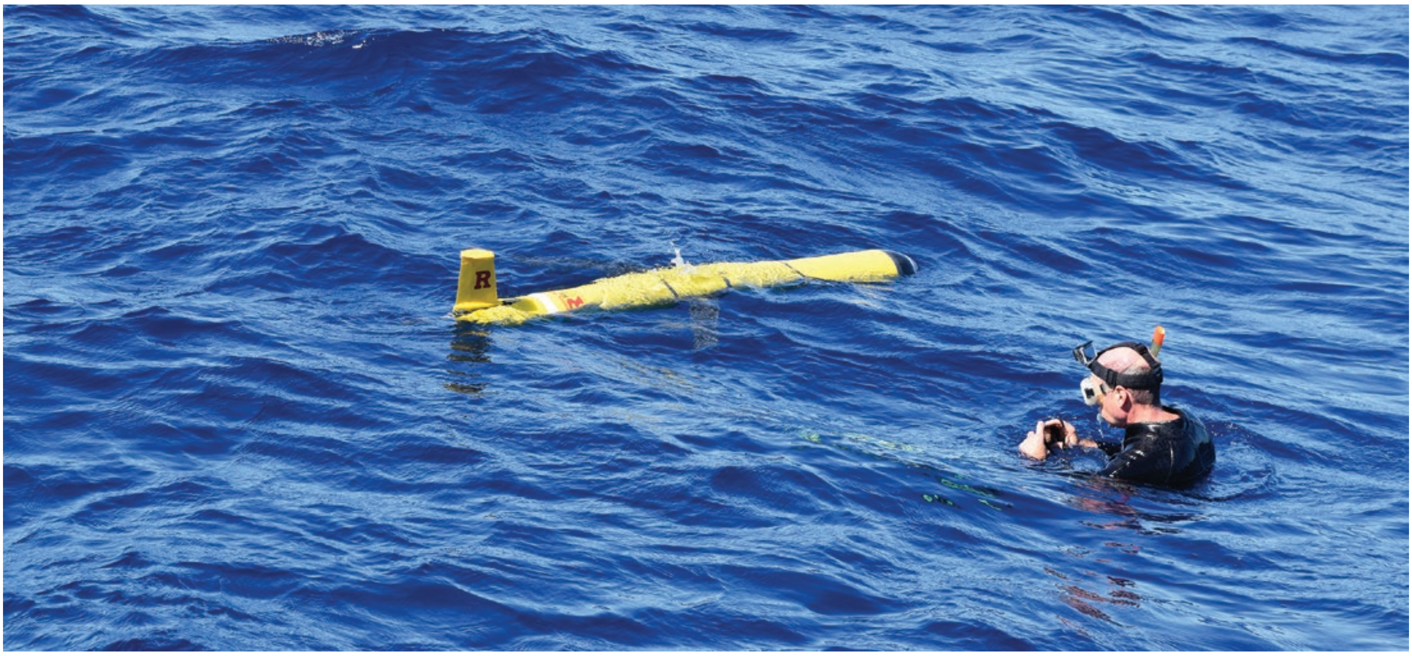
The aim of this sampling is to validate the temperature and salinity sensors with the RAMA mooring sensors.

Challenger will head west along the equator to another RAMA mooring at 80.5ºE and then head north to Sri Lanka. The challenger project team expects the glider to be recovered off Sri Lanka in mid-September.

On its way to Sri Lanka, Challenger is sending data back to the lab via satellite. Its position can be tracked via the **IMOS Ocean Gliders Facility website** or via the **Rutgers University site**. It is also available through the **IMOS Ocean Current website**. Measurements of temperature and salinity at depths up to 1,000 metres are available in near real time.

You can also view a video of Professor Chari Pattiaratchi talking about the Challenger glider mission on the **IMOS YouTube channel**.

Google Earth image shows the journey of the Challenger glider from Fremantle, WA to the equator.



University of Western Australia

Ocean radar:

Radar observations prove to be a useful tool for examining frontal eddies along the East Australian Current

A recent paper has used more than a year of high-resolution (1.5 km, hourly) surface velocity measurements from the IMOS high frequency (HF) radar at Coffs Harbour to quantify the propagation of frontal eddies and meanders along the eastern coast of Australia.

Ocean currents are usually characterized by instabilities, meandering and eddy shedding at different spatial and temporal scales. The East Australian Current (EAC) is a southern hemisphere western boundary current, closing the subtropical gyre in the South Pacific. Its temporal variability is associated with eddy-scale, seasonal, interannual, decadal and climate scales, however little is known about time scales on the order of days. Resolving these fine-scale structures in time and space requires high-resolution observations, as they are often too small to be captured by altimetry (see Figure below).

The study led by Amandine Schaeffer of the University of New South Wales used the surface current measurements from the ocean radars, in conjunction with data from IMOS moorings, and satellite observations. It was the first time, to the authors knowledge, that the characteristics and motion of frontal eddies in a western boundary current have been systematically observed at high resolution.

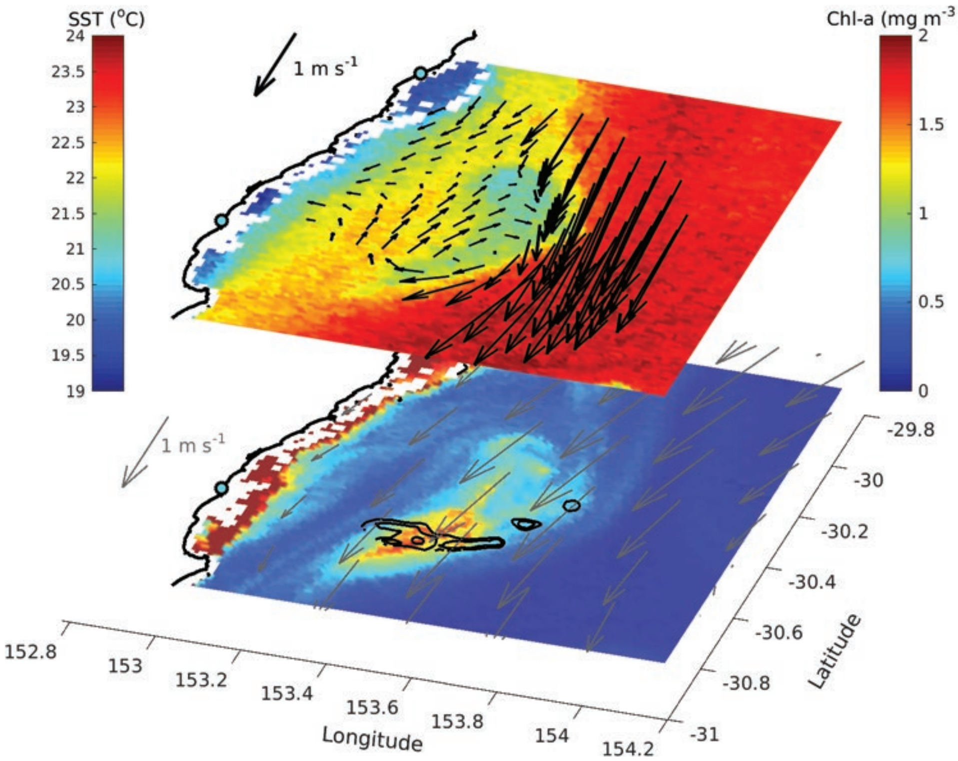
The results of the study show that cyclonic eddies occur frequently along the EAC on average every seven days over the year.

Cyclonic frontal eddies that are associated with the EAC meanders during weak wind stress propagate downstream with speeds of 0.3-0.4 m s-1. While frontal eddies propagate through the radar domain independently of wind stress, upfront wind can influence their stalling and growth, and can also generate large cold core eddies through intense shear.

The cyclonic frontal eddies are a major mechanism for the transport and entrainment of nutrient rich coastal or deep waters, influencing physical and biological dynamics, and connectivity over large distances.

To read the full paper:

Schaeffer, A., A. Gramoulle, M. Roughan, and A. Mantovanelli (2017), Characterizing frontal eddies along the East Australian Current from HF radar observations, J. Geophys. Res. Oceans, 122, doi:10.1002/2016JC012171.



Top view of MODIS SST (top section, left colour bar) and ocean color (bottom, right colour bar) remote-sensed images on 29 September 2013 showing the signature of a frontal eddy. Velocity vectors show the surface currents measured by HF radars on the 29 September 2013 08:00 (plot every sixth grid point, top, black) and geostrophic current from altimetry (bottom, grey). Black contours overlaid on the chlorophyll-a concentrations (bottom) show positive surface divergence calculated from the HF radar velocities (contours of 0.2|f|, 0.3|f|, 0.4|f|, 0.5|f|, increasing to maximum in the center). Blue dots indicate the location of the two HF Radar systems. Figure from the paper published in J.Geophys. Res. Oceans.

Wireless Sensor Networks:

IMOS data charts the course of the 2015-16 coral bleaching event on the Great Barrier Reef

WRITTEN BY: SCOTT BAINBRIDGE

The 2015-16 summer saw widespread coral bleaching along the Great Barrier Reef. Data from the IMOS Wireless Sensor Networks provided daily real-time measures of temperature, bleaching stress and risk which helped guide survey and monitoring work. The analysed data, recently published, documents the local and regional environmental factors that led to the bleaching event.

The Wireless Sensor Networks Facility of IMOS is the world's largest coral reef sensor network, with stations along the Great Barrier Reef (GBR) providing real-time information on reef conditions.

Following warmer-than-usual ocean temperatures in the northern hemisphere and predictions of an increased coral bleaching risk over the 2015-16 austral summer, data and web systems were developed from historical and real-time sensor network data to provide measures of daily water temperatures and associated bleaching risk.

The IMOS historical data was processed to give daily average temperature values for each site along with the statistical variability; these 'climatologies' provided a context to understand the daily temperatures as the summer progressed. The real-time temperatures were also compared to known empirical bleaching thresholds, temperatures above which field observations show bleaching can occur, allowing thermal stress and risk to be measured over the summer.

The on-reef temperature data for the summer indicated a number of unusual warm water events, with a prominent north-south gradient in warm water events and bleaching stress. On the southern reefs, water temperatures were within normal limits and were below the empirical bleaching threshold. Reefs in the central GBR closely followed historical bleaching thresholds, therefore predicting moderate bleaching. However, reefs to the north, such as Lizard Island, had four days over the bleaching threshold. Further north, in the Torres Straits, the Thursday Island station logged a new temperature record. Here, temperatures were above the empirical bleaching threshold for ten consecutive days.

The IMOS data successfully predicted bleaching severity along the GBR with field surveys confirming the north (extensive bleaching) to south (moderate to no bleaching) patterns. The IMOS data also revealed that warmer temperatures continued well past the summer - temperatures remained 1ºC above normal from March through to June 2016. This late summer warming may have implications for the fate of corals that were exposed not only to record high temperatures, but to subsequent months of above-normal temperatures.

The IMOS data provided real-time indicators of thermal stress and bleaching risk to the research community, including the Australian Institute of Marine Science (AIMS) Bleaching Response Group. Atmospheric and ocean data are currently being analysed to understand the factors that caused localised heating and cooling, such as occurred at Thursday Island.

Additionally, data from the IMOS sensor networks, moorings and ocean gliders are being compiled to deliver the most comprehensive record of the ocean conditions during the 2015-16 bleaching event. This information is critical in understanding the relationship between environmental forcing factors and the observed biological response. With a subsequent 2016-17 bleaching event currently underway the work demonstrates the value of IMOS in generating the long term data required to record, contextualise and understand events such as coral bleaching.

The full paper is available at: http://www.tandfonline.com/doi/full/10.1080/1755876X.2017.1290863.

Reef surveys at Arlington Reef showing areas of bleached coral.

Australian Ocean Data Network (AODN):

7th Ocean Data Interoperability Platform (ODIP) workshop held in Hobart, in March

The workshop in Hobart 7-10 March brought together marine data experts from the EU, USA and Australia for the second time as part of the Ocean Data Interoperability Platform (ODIP) project.

This project brings together marine data experts to discuss data interoperability problems and explore ways to develop common solutions. Over 40 data scientists attended the four-day workshop, hosted jointly by IMOS-AODN and CSIRO Oceans and Atmosphere. These workshops are held every six months.

ODIP is now in its fifth year and, in addition to providing a forum for the exchange of ideas, ODIP takes forward the development of prototypes – targeted activities designed to enable interoperability of particular data-centric processes carried out independently by group members. Current prototypes under development are: interoperability between Data Discovery and Access services using a brokerage service; development of a common Cruise Summary Reporting and publishing service; the application of Sensor Observation Service to deliver research vessel and real-time monitoring data.

The recent rise in the popularity of cloud computing has spawned a new prototype – exploring common tools for the 'digital playground' – tools such as Virtual Research Environments and Virtual Desk Tops. AODN interest in this prototype involves the NeCTAR-funded Marine Virtual Laboratory and the Marine Sciences Cloud.

Of course, to develop interoperability requires conformance to standards and the adoption of common data structures, so ODIP engages in a number of 'cross-cutting' activities including data citation and publication, persistent identifiers (e.g. DOIs, ORCiDs), controlled vocabularies and mappings, big data, data formats and model workflows and linked data to enable the prototypes to progress.

Workshop participants enjoyed a tour of RV *Investigator* and at the conference dinner, held at the Hobart Convention Centre on Elizabeth St Pier, diners were treated to the special sight of the arrival of the icebreaker *l'Astrolabe* at the end of its final scientific voyage. The meeting was lively and engaging, and participants are looking forward to furthering the prototypes between now and the next workshop in October in Galway, Ireland.

Australian Ocean Data Network (AODN):

AODN conducts three practicals for IMAS/UTAS course

In May the AODN contributed for the first time to the University of Tasmania (UTAS) course KZA324 - Oceanographic Methods. The course focuses on introducing students to research at sea, how to take measurements, and data access and preservation. AODN involvement focused on data discovery and access, illustrating methods of finding data through the AODN Portal (discovery, visualisation, filtering and download) and in the use of data tools like MARVL and Gliderscope.

The AODN team, alongside a colleague from CSIRO, conducted three practicals as part of the unit schedule. The first practical was an introduction to IMOS and AODN including a hands-on lesson on data access through the AODN Portal. The second focused on the use of gliders in coastal and ocean environment monitoring, in particular in the River Derwent Hobart, the students explored the data collected by the IMOS Ocean Glider facility through the Gliderscope visualisation tool.

Workshop participants in front of the Marine National Facility *RV Investigator.*

Satellite Remote Sensing:

A tale of two eddies in the EAC: introducing Murphy and Freddy

Researchers in a recent study have contrasted two eddies, Murphy and Freddy, that had formed in the Eastern Australian Current, whilst onboard the Marine National Facility RV *Investigator*.

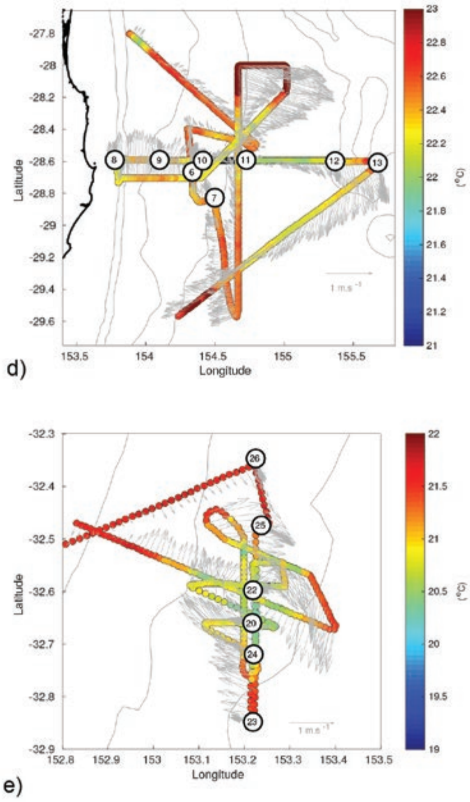
The study, led by Associate Professor Moninya Roughan at the University of New South Wales, was published in the Journal of Geophysical Research Oceans, and presents the first depth observations of a small (~35 km in diameter) cold core eddy ("Freddy") which formed along the landward front of the East Australian Current (EAC). The researchers contrast the observations with a typical larger (~160 km in diameter) cold core eddy ("Murphy").

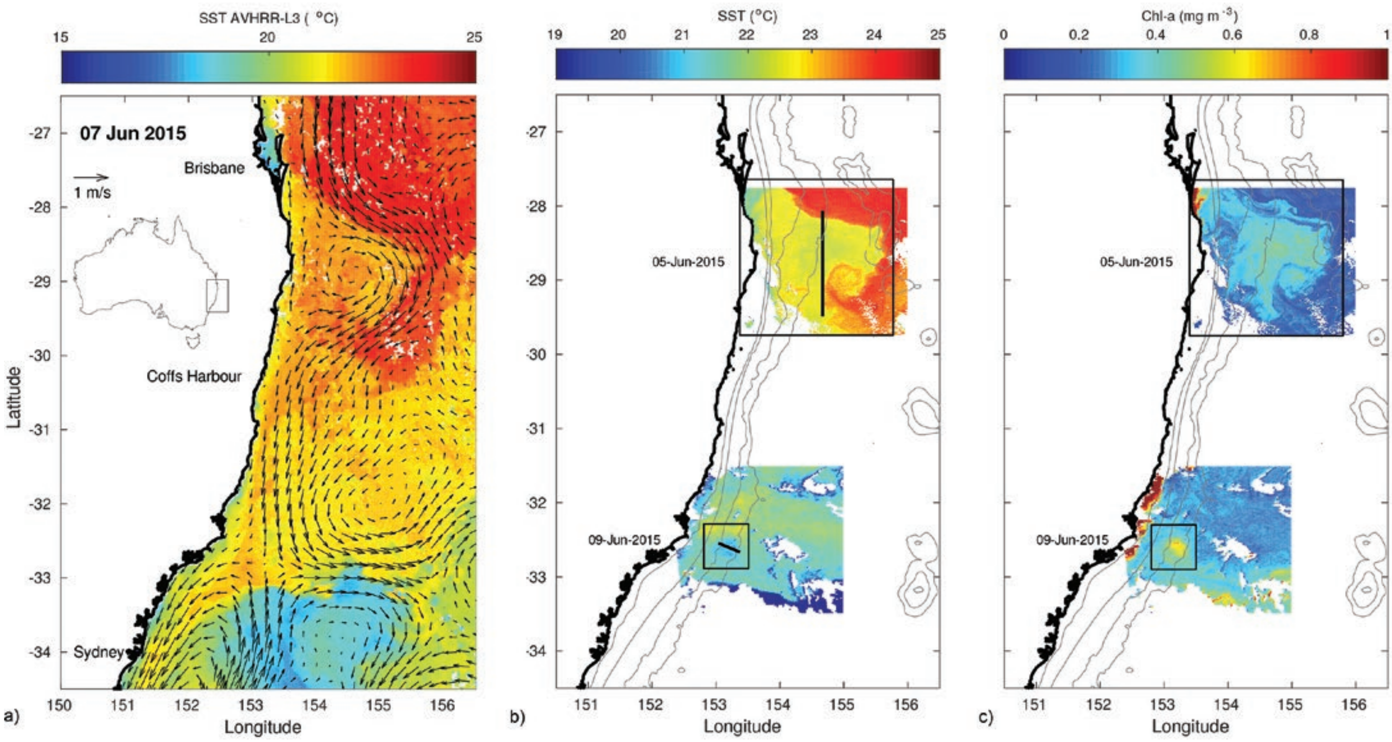
The in-situ observations were collected from a dedicated research voyage in 2015 aboard the Marine National Facility RV *Investigator*, the study also made use of satellite remote-sensed observations of AVHRR and MODIS sea surface temperature (SST) and ocean color on cloud-free days, processed and served through the **IMOS OceanCurrent website**.

Observational data sets depicting the 3-D structure of eddies are rare, and to date the dynamics of frontal eddies have primarily been diagnosed through modeling studies. The comprehensive data set revealing the 3-D structure and dynamics of two contrasting cyclonic eddies shows that not all cyclonic eddies are created equal, i.e., the smaller frontal eddy, Freddy, is significantly more energetic, and productive than the mesoscale cyclone, Murphy, despite its small size and short life. Freddy was a very dynamic feature. It rotated rapidly, extended to more than 1000 m in depth and was highly productive. The researchers believe these features make a significant contribution to the productivity of the Tasman Sea region.

To read the full paper:

Roughan, M., S. R. Keating, A. Schaeffer, P. Cetina Heredia, C. Rocha, D. Griffin, R. Robertson, and I. M. Suthers (2017), A tale of two eddies: The biophysical characteristics of two contrasting cyclonic eddies in the East Australian Current System, J. Geophys. Res. Oceans, 122, 2494–2518, doi:10.1002/2016JC012241.





(a) Three day composite SST and geostrophic velocities derived from SSH centered on 7 June 2016. (b) MODIS SST and (c) Ocean Color for Murphy (5 June 2015), top and Freddy (9 June 2015) bottom. Solid black lines indicate the location of the ADCP and Triaxus lines in subsequent figures. (d) and (e) are zoom insets (as indicated in Figures 1b and 1c) of cruise track colored by SST from the underway thermosalinograph, velocities at 30 m depth as measured by the shipboard ADCP, and the location of CTD casts (numbered circles). Bathymetric contours are 4000, 2000, 200, 100 m from east to west. Figure from the paper published in J.Geophys. Res. Oceans.

Postgraduate Student | **Ana Paula Berger**

PROJECT TITLE:

The dynamical partitioning of the Indonesian Throughflow

University of Tasmania (UTAS), Institute for Marine and Antarctic Studies (IMAS) and CSIRO.

The Indonesian Throughflow (ITF) is the only low latitude connection between two major ocean basins, the Pacific and the Indian oceans. It is important for the distribution of heat in the ocean and provides a pathway for the global ocean currents (Hirst and Godfrey, 1993; Wijffels *et al*. 2008). The Indonesian Throughflow has to flow through a region with many small islands. The flow is steered by the land and it is partitioned between three main exit passages to the Indian Ocean. The Lombok Strait is narrow and the most western passage, followed by Ombai Strait and the large and most eastern one, Timor Passage.

The surroundings of those Straits and the Indonesian Seas are covered by three IMOS expendable bathythermograph (XBT) transects (IX1, IX22 and PX2) and three mooring arrays (OMB, TIN and TISILL) as the Figure below shows.

The Indonesian Throughflow partitioning is not well understood. It is expected to behave as a current that is typical of flows along the western boundaries of the oceans. However, the observed volume transports in the exit passages do not show that. Most of the flow follows the eastward pathway to the most eastern strait, Timor Passage instead of Lombok Strait, in the west (Sprintall *et al*., 2009).

Since the topography is very complex, Ana is using a high-resolution model to investigate the partition of the flow between the exit passages. She is using the model to investigate the effects of different dynamics and evaluate the impact on the partition of the flow. Results showed a good agreement when comparing the high-resolution model outputs with the IMOS data. The XBT dataset is especially helpful on identifying particular zones with strong mixing along the ITF pathway and the mooring data are used to assess the model vertical velocity profiles. This information allowed her to make adjustments to the mixing parameter in the model, which brought a better understanding of the model limitation.

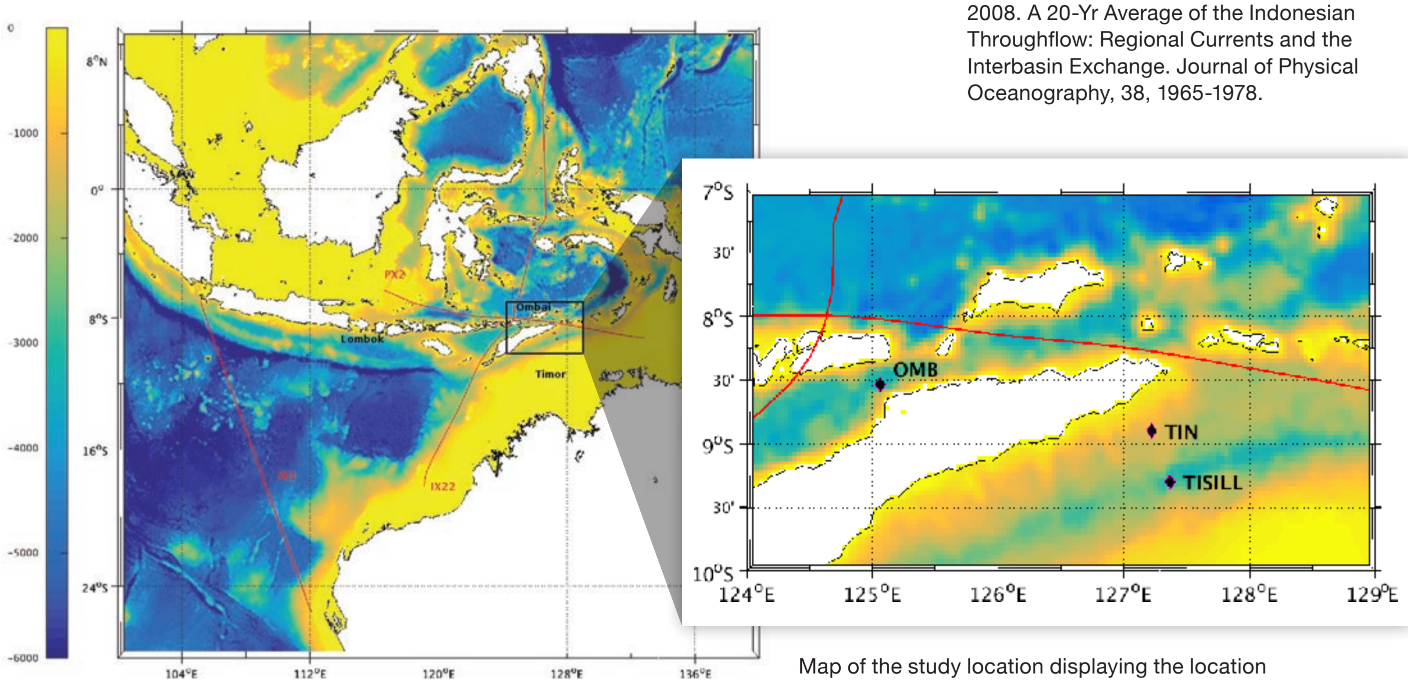
Ana's PhD project is a collaboration between IMAS and CSIRO and is sponsored by a Brazilian Agency for Science – CAPES. It also has the support of the ARC Centre of Excellence for Climate System Science.

Supporting references:

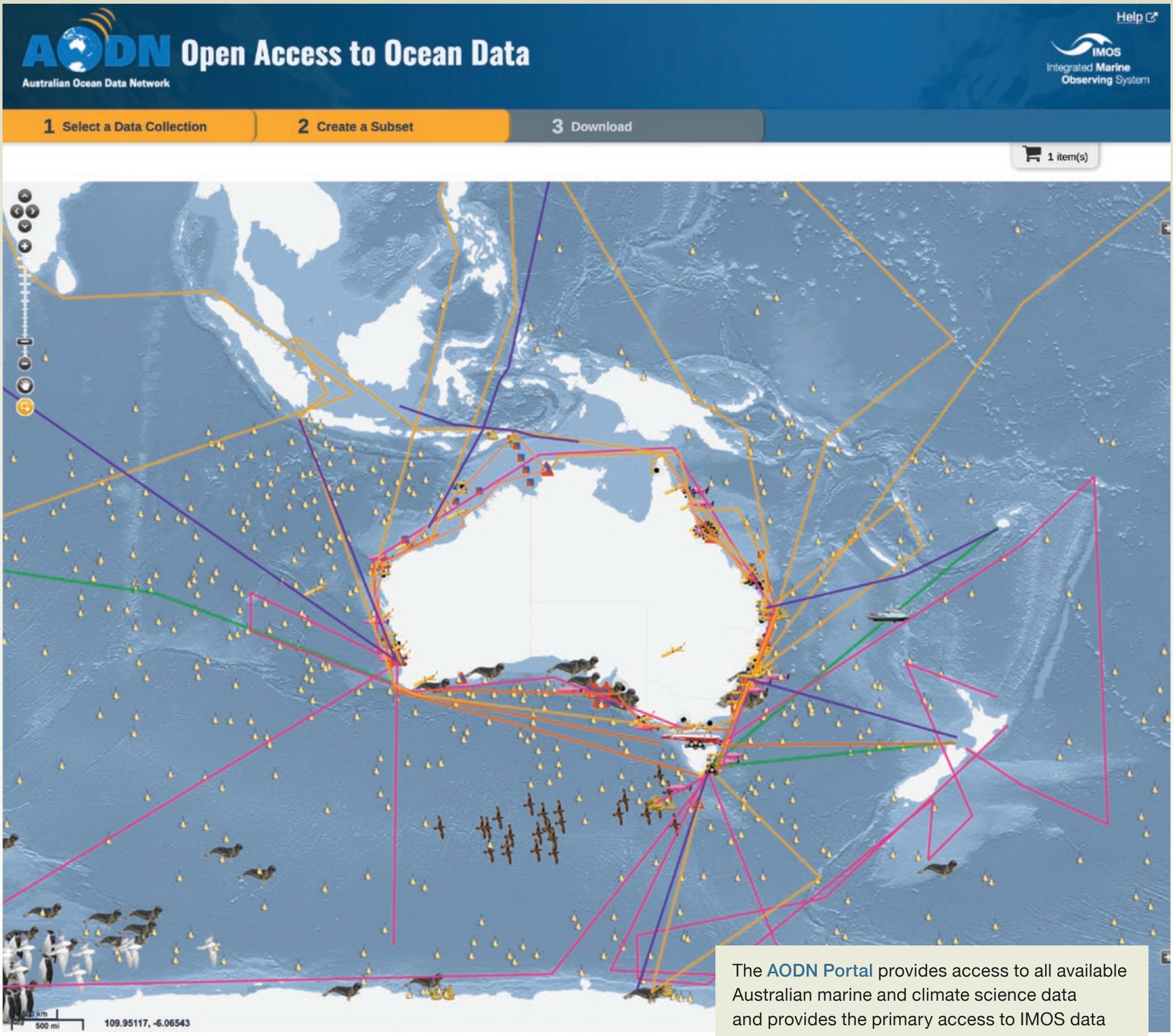
Hirst, A. C. & Godfrey, J. 1993. The role of Indonesian throughflow in a global ocean GCM. Journal of Physical Oceanography, 23, 1057-1086.

Sprintall, J., Wijffels, S. E., Molcard, R. & Jaya, I. 2009. Direct estimates of the Indonesian Throughflow entering the Indian Ocean: 2004–2006. Journal of Geophysical Research, 114.

Wijffels, S., Meyers, G., Godfrey, J. 2008. A 20-Yr Average of the Indonesian Throughflow: Regional Currents and the Interbasin Exchange. Journal of Physical Oceanography, 38, 1965-1978.



Map of the study location displaying the location of the IMOS XBT lines and moorings.



The AODN Portal provides access to all available Australian marine and climate science data and provides the primary access to IMOS data including access to the IMOS metadata.

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

IMOS is a national collaborative research infrastructure, supported by Australian Government. It is operated by a consortium of institutions as an unincorporated joint venture, with the University of Tasmania as Lead Agent.

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