Forum for Operational Oceanography

Australian Forum for Operational Oceanography

FOO 2015

21–23 July, 2015

Esplanade Hotel, Fremantle WA

CONFERENCE HANDBOOK

Major Sponsor

Australian Government

Department of Industry and Science

Handbook Contents

Welcome to FOO 2015

On behalf of the organising committee we welcome you to the inaugural Australian Forum for Operational Oceanography – FOO 2015.

Operational oceanography is a field that is growing rapidly around the world, and Australia has good reason to keep pace. With a vast and valuable marine estate, there are many opportunities for Australia to better utilise marine observations, modelling, and computational and information systems to improve the safety and efficiency of our marine industries. Experience overseas suggests that to achieve this we will need to establish a new kind of dialogue between marine industries, service providers, government agencies, and research providers. This is what the Forum is aiming to do.

With generous sponsorship from the Australian Government Department of Industry and Science, we have been able to put together a strong program for FOO 2015. There are three keynote speakers, another three international speakers, and eighteen invited talks from national experts. In addition there is a Future Challenges and Opportunities Session with six talks selected from a high-quality field of submitted abstracts, and a well-subscribed Poster Session. Two panel discussions at either end of the program will help with setting the scene, and summing up.

We greatly appreciate your interest and engagement, and look forward to seeing you in Fremantle. We hope it's the start of a new era for operational oceanography in Australia.

From the FOO Steering Committee Co-Chairs

Tim Moltmann, Director - Integrated Marine Observing System (IMOS)
Jan Flynn, Shell Australia - Lead Metocean Engineer

Forum for Operational Oceanography

FOO Steering Committee

Co -Chair	Jan Flynn, Shell Australia
Co -Chair	Tim Moltmann, Integrated Marine Observing System (IMOS)
Executive Support	Emma Sommerville, IMOS
RPS Group	Brian King
Fugro GEOS	Simon Foster
Carnegie Wave Energy	Tim Sawyer
Austral Fisheries/ Commonwealth Fisheries Association (CFA)	Martin Exel
Royal Australian Navy (RAN)	Martin Rutherford
Australian Maritime Safety Authority (AMSA)	Craig Longmuir
Australian Coastal Councils/ National Sea Change Task Force	Alan Stokes
Australian Fisheries Management Authority (AFMA)	Nick Rayns
Australian Institute of Marine Science (AIMS)	Richard Brinkman
Bureau of Meteorology (BoM)	Boris Kelly-Gerreyn
Commonwealth Scientific & Industrial Research Organisation (CSIRO)	Andreas Schiller
Geoscience Australia (GA)	Stuart Minchin
National Computational Infrastructure (NCI)	Ben Evans
Intergovernmental Oceanographic Commission (IOC), UNESCO	Nick D'Adamo

FOO 2015 at a Glance

Tuesday 21st July		
Time	**Session**	**Room**
1100 - 1300	Registration	Orion Room
1200 - 1300	Lunch	Atrium Garden Restaurant
1300 - 1440	Oral Presentations	Orion Room
1440 - 1510	Afternoon tea	Orion Room
1510 - 1720	Oral Presentations	Orion Room
1720 - 1810	Panel Session	Orion Room
1810 - 1830	Free time	
1830 - 2030	Cocktail Reception and Poster Session	Rottnest/ Garden Room

Wednesday 22nd July		
Time	**Session**	**Room**
0800 - 0830	Arrival tea and coffee	Orion Room
0830 - 1015	Oral Presentations	Orion Room
1015 - 1030	Morning tea	Orion Room
1030 - 1310	Oral Presentations	Orion Room
1310 - 1340	R&D Tax Incentive workshop	Orion Room
1310 - 1410	Lunch	Atrium Garden Restaurant
1410 - 1530	Oral Presentations	Orion Room
1530 - 1600	Afternoon tea	Orion Room
1600 - 1720	Oral Presentations	Orion Room
1720 - 1830	Free time	
1830 - 2300	FOO 2015 Dinner	Island Suite

Thursday 23rd July		
Time	**Session**	**Room**
0800 - 0830	Arrival tea and coffee	Orion Room
0830 - 1050	Oral Presentations	Orion Room
1050 - 1120	Morning tea	Orion Room
1120 - 1220	Panel Session	Orion Room
1220 - 1330	FOO 2015 Close followed by Lunch	Atrium Garden Restaurant

Delegate List

If you would like a copy of the Delegate List, please email Emma Sommerville

emma.sommerville@utas.edu.au

Acknowledgements

Thank you to Real Events Pty Ltd (Narelle Hall) for helping to organise FOO 2015.

FOO 2015 would not have been possible without the generous support of our **Major Sponsor**:

Australian Government

Department of Industry and Science

What is Operational Oceanography?

Operational Oceanography is like weather monitoring and forecasting for the ocean. It can provide estimates of essential ocean variables (e.g. sea level, temperature and currents) for the present and the future, as well as for the past.

Present estimates are called Nowcasts and provide descriptions of the present state of the ocean. Future estimates called Forecasts are updated regularly, typically for one to two weeks ahead. Reanalyses and hindcasts can also be produced to provide descriptions of past states, and time series showing trends and changes. Hindcasts are typically the "best" estimates having the greatest number of observations and the best available quality control.

Operational Oceanography depends on availability of ocean observations and super-computer facilities, and uses computer models and mathematical techniques that have been developed over several decades. It is designed to deliver stakeholder defined outputs and products on a routine basis, using robust and fully supported production and dissemination techniques.

Ocean observations are required in real-time and near-real-time (within a few days or minutes of collection) and sourced from various national and international programs. Some are run in an operational setting (e.g. IOC/WMO), and some are maintained through research funding (e.g. IMOS).

Most Operational Oceanography systems are run at national weather centres (e.g. Bureau of Meteorology), and often depend on coordinated efforts from multiple organisations (e.g. Bureau of Meteorology, CSIRO and RAN). Australia's operational ocean forecast system operated at the Bureau has been developed under a partnership called BLUElink> (http://wp.csiro.au/bluelink/).

Operational Oceanography can be used to improve safety of life at sea, help create wealth, and assist in the security and protection of the marine environment. Outputs can be used to generate data products, applications and services through national authorities, as well as in some cases through other organisations such as metocean service providers and environmental consultants. Examples are:

- warnings about coastal floods, storm impacts, harmful algal blooms and contaminants,
- electronic charts, sea state conditions, optimum routes for ships,
- prediction of primary productivity, ocean currents, ocean climate variability; and
- modelling of and response to oil spills and dredging.

Operational oceanographic programs are well established in countries such as USA, Japan and France. In Australia, a number of products and services are well established while others are developing, and include:

- observational products, e.g.
    - IMOS OceanCurrent; http://oceancurrent.imos.org.au,
    - SST analyses; http://www.bom.gov.au/marine/sst.shtml and
- ocean real-time analyses, warnings and forecasts, e.g.
    - BLUElink> OceanMAPS; www.bom.gov.au/oceanography/forecasts/index.shtml.
    - Tide predictions: http://www.bom.gov.au/australia/tides/
    - Waves and marine weather: http://www.bom.gov.au/marine
    - Tsunami warnings: http://www.bom.gov.au/tsunami

There is, as yet, no widely accepted definition of Operational Oceanography. However a working definition provided by the European component of the Global Ocean Observing System (EuroGOOS) is as follows:

"Operational Oceanography can be defined as the activity of systematic and long-term routine measurements of the seas and oceans and atmosphere, and their rapid interpretation and dissemination".

General Information

Conference Venue

Esplanade Hotel Fremantle – by Rydges
46-54 Marine Terrace, Fremantle WA 6160
Telephone: +61 8 9432 4000

Registration Desk

The registration desk will be located in the Orion Room and will be staffed between 11:00am and 1:00pm on Tuesday 21st July.

Name Badges

Delegates are requested to wear their name badges at all times during the conference. Your name badge is also your ticket to the included functions.

Speaker Preparation

All speakers will need to refer to the final program in this book to confirm their timeslot. Please ensure your presentation is loaded onto the laptop computer at the front of the Orion Room well in advance of your timeslot. It is advised that you check your presentation is working in the break prior to your session if possible.

Posters

Display - Pin boards will be located at the back of the Orion Room from 11:00am on Tuesday 21st July and posters need to be hung prior to the commencement of presentations at 1:00pm. The pin boards will then be transferred to the Rottnest/Garden Room for the poster session that evening.

During the session - It is expected that authors will be present for discussion during the poster session.

Removal - Please remove and collect your Poster at the closure of the session or from the organiser on the Thursday. The organisers will not be responsible for any posters remaining on site after the end of the conference day program.

Social Functions

Your registration includes ticket to two social functions:

- A Poster session held on the evening of Tuesday 21st (6:30pm and 08:30pm) in the Rottnest/Garden Room, where a selection of canapés and drinks will be served. Poster presenters will be standing with their posters during this session to answer any questions.
- The FOO 2015 Conference Dinner held on Wednesday 22nd (from 06:30pm onwards) in the Island Suite. The dinner will be a three-course table-service meal.

Sponsor Booth

A display from our major sponsor, the Department of Industry and Science, will be located at the back of the Orion Room. Please make the time to wander over and meet the staff, look at their display materials and make them feel welcome.

Parking, public transport, taxis, ATM and Banking

Please check with the Hotel Reception.

Internet access

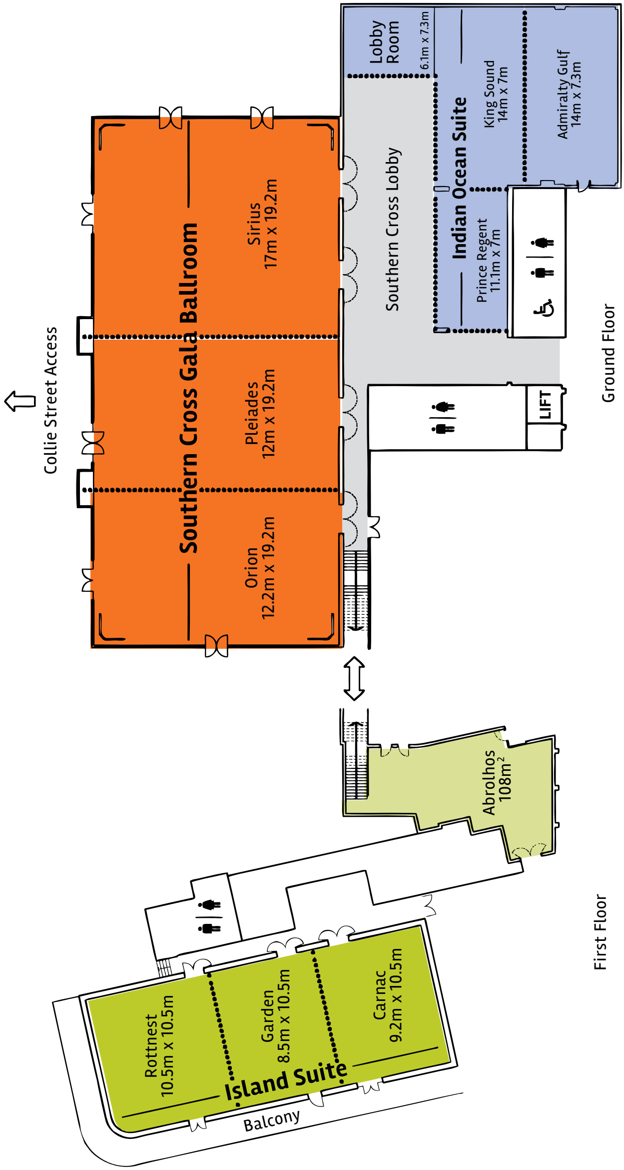
The Hotel offers complimentary Wi-Fi for all delegates throughout the Hotel.

Meals and Refreshments

Tea and coffee will be served in the morning from 8:00am to 8:30am on Day 2 and Day 3 in the Orion Room. Morning and afternoon tea will be served in the Orion Room. Lunch will be a buffet served in the Atrium Garden Restaurant.

Delegates who provided information regarding special dietary requirements will be catered for.

FLOOR PLAN



Visit **www.rydges.com/fremantle**
Call 08 9432 4801 or email functions_esplanadefremantle@rydges.com
Corner Marine Terrace and Essex Street, Fremantle, WA

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Australian Government
Department of Industry and Science

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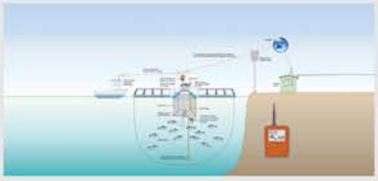
"The R&D Tax Incentive provides a source of capital which is crucial for our success."

Managing Director,
Dr Michael Ottaviano,
Carnegie Wave Energy



"The R&D Tax assistance has allowed us to maintain a core engineering team within the company for an extended period of time. Our products would not be as far advanced without R&D Tax assistance."

Chief Executive Officer
Ross Dodd
AQ1 Systems

"Accessing R&D Tax assistance has allowed us to progress ideas and innovations faster than may have been otherwise possible."

Managing Director
Mr Mike Grainger
Liferaft Systems Australia

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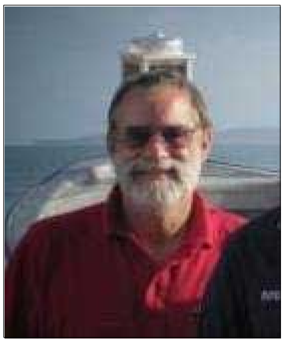
Keynote Speaker Brief Biographies

Art Allen – United States Coast Guard Office of Search and Rescue



Art Allen is an Oceanographer with the United States Coast Guard Office of Search and Rescue supporting the USCG Search and Rescue mission. He received his B.Sc from University of Massachusetts and M.Sc in physical oceanography from Dalhousie University. Mr. Allen has been with the USCG Office of Search and Rescue for 11 years, where his areas of expertise include the determination of the drift of common search objects; the determination of environmental data sets for operational use by CG SAR planning tools; the use of survival and hypothermic models in SAR planning; and the implementation of probability of detection data into SAROPS. Mr. Allen provided support to BEA and AMSA in the search efforts for AF447 and MH370, respectively. Previously, Mr. Allen worked for 20 years at the USCG Research and Development Center on the Improvements to Search and Rescue Capabilities project where he developed a new method to determine the leeway drift of objects on the ocean and the Self-Locating Datum Marker Buoy (SLDMB).

Dr Colin Grant – Consultant

Dr Colin Grant retired from full time work at BP in January 2014. He spent some 35 years in meteorological and oceanographic (metocean) matters in the offshore industry. After obtaining a B.Sc. and Ph.D. from Bristol University, his early career was as a marine weather forecaster. He then worked in Brunei Shell Petroleum as a forecaster and metocean specialist. He joined BP in 1984 and was ultimately responsible for developing the design and operational metocean criteria for many offshore projects across the globe. He chaired the global offshore industry's (OGP) metocean committee from 2008 to 2013.

Colin is a CMarSci, CSci and a Fellow of the IMarEST. He is member of IMarEST's Operational Oceanography Special Interest Group (OOSIG). He is currently a Board Member of the UK Science Council and a member of the National Oceanography Centre's Advisory Committee. Since retiring from BP, he has established a consultancy company in order to provide metocean services to the industry. He has recently been engaged by the IOGP/IPIECA Oil Spill JIP to coordinate work packages on surveillance, modelling and visualisation.

Dr Ray Canterford – Bureau of Meteorology

Dr Ray Canterford is Deputy Director, Hazards, Warnings and Forecasts at the Bureau of Meteorology. Dr Canterford has a PhD in Physics and a Grad Dip in Meteorology and was awarded a Fulbright Postdoctoral Fellowship to work in the USA National Oceanic and Atmospheric Administration (NOAA). In the Bureau he has national responsibility for Aviation Weather, Defence Weather, Public and Marine Services, Severe Weather, Floods, Space Weather and Ocean Services. He is also a Chartered Professional Engineer and has over 40 years' experience in research and operations and is Australia's representative to the UNESCO International Oceanographic Commission.

In 2014 Dr Canterford was awarded a Public Service Medal: "For outstanding public service in the delivery of improvements in forecasting and warning of natural hazards and weather, most notably for emergency and natural disaster response."

FOO 2015 Program – Day 1, Tuesday 21st July 2015

DAY 1 – Tuesday 21st July 2015 (Orion Room)		
11:00–13:00	**Registration**	
12:00–13:00	**Lunch (Atrium Garden Restaurant)**	
13:00–13:10	**FOO 2015 Welcome and Introduction**	
Theme 1 – What is Operational Oceanography and what does it mean in the Australian context? Session Chair: Boris Kelly-Gerreyn		
13:10–13:30	What is operational oceanography?	Andreas Schiller*, Boris Kelly-Gerreyn and Tim Moltmann
13:30–13:50	Why have we established a Forum for Operational Oceanography and who is it relevant to?	Jan Flynn* and Tim Moltmann
13:50–14:20	**Keynote #1** **Operational oceanography and the oil and gas industry – the UK experience**	**Colin Grant, CG Metocean Consulting Limited, UK**
14:20–14:40	Q&A Session	
14:40–15:10	**Afternoon Tea**	
Theme 2 – Assessing Present Capabilities - what can we do now? Session Chair: Craig Longmuir		
15:10–15:30	Scope of capabilities under consideration – ocean circulation, sea state and weather, climate, atmosphere and ecosystems	Richard Brinkman
15:30–15:50	Observing systems – research and operational	Tim Moltmann*, Boris Kelly-Gerreyn, Lyndon Llewellyn and Adam Lewis
15:50–16:10	Modelling systems – research and operations	Peter Oke* and Gary Brassington
16:10–16:30	New advanced computing research infrastructures to support operational oceanography	Roger Proctor* and Ben Evans*
16:30–17:00	**Keynote #2** **Operational marine and ocean services at the Bureau**	**Ray Canterford, Bureau of Meteorology**
17:00–17:20	Q&A Session	
17:20–18:10	**Panel Session** **What are the business drivers for operational oceanography in Australia?** **Panel:** Research – Ken Lee (CSIRO), Operations – Ray Canterford (Bureau of Meteorology), Services – Steve Buchan (RPS Group), Marine Industries – Jan Flynn (Shell Australia), Government – David Wilson (Department of Industry and Science) **Facilitator:** Tim Moltmann (Integrated Marine Observing System)	
18:10	**CLOSE DAY 1**	
18:30–20:30	**Cocktail Reception and Poster Session (Rottnest/Garden Room)**	

Forum for Operational Oceanography

FOO 2015 Program – Day 2, Wednesday 22nd July 2015

DAY 2 – Wednesday 22nd July 2015 (Orion Room)		
Theme 3 – Uses of Operational Oceanography		
Topic 1 – Emergency Response		Session Chair: Jan Flynn
08:00–08:30	**Arrival Tea and Coffee**	
08:30–09:00	**Keynote# 3** **The U.S. Coast Guard's Search and Rescue mission and operational oceanography: use, challenges, and opportunities**	**Art Allen, Office of Search and Rescue, United States Coast Guard**
09:00–09:20	Operational drift forecast modelling in support of the AMSA search for Malaysia Airlines MH370	Ben Brushett*, David Griffin, Sasha Zigic, Murray Burling, Ryan Alexander, David Wright and Neal Moodie
09:20–09:40	Numerical model to simulate drift trajectories of large vessels	Simon B. Mortensen*, Kasper Kaergaard, Alex Harkin, Jonas Mortensen, Sabine Knapp and Geoff Wake
09:40–10:00	Practical application of drift modelling to search and rescue	Craig Longmuir
10:00–10:15	**Address to the Forum attendees by the Minister for Industry and Science**	**The Honourable Ian Macfarlane MP**
10:15–10:30	**Morning Tea**	
10:30–10:50	AMSA marine search and rescue prediction system (Nett Water Movement)	Graeme Hubbert* and Sam Blake
10:50–11:10	Q&A Session	
Topic 2 – Coastal and Marine Management, Ports and Shipping		Session Chair: Tim Moltmann
11:10–11:30	**International Speaker #1** **Marine forecasting in coastal and nearshore waters using dynamical process models**	**Peter McComb, MetOcean Solutions Ltd, NZ**
11:30–11:50	Real-time information needs for ports and shipping: status and gaps	Captain Allan Gray
11:50–12:10	Information needs for marine resource management: status and gaps	Tom Holmes
12:10–12:30	Dredging and Associated Environmental Aspects: Real-time and Longer Term Information Gaps	Piers Larcombe* and Angus Morrison-Saunders
12:30–12:50	A National Shelf Re-analysis (ANSR) project for Australia	Moninya Roughan*, Emlyn Jones*, Peter Oke, Tim Moltmann, Peter May and Andreas Schiller
12:50–13:10	Q&A Session	
13:10–13:40	**Department of Industry and Science presentation on the R&D Tax Incentive Program** (optional)	
13:10–14:10	**Lunch (Atrium Garden Restaurant)**	

Forum for Operational Oceanography

FOO 2015 Program – Day 2, Wednesday 22nd July 2015 cont.

DAY 2 – Wednesday 22nd July 2015 cont.		
Theme 3 – Uses of Operational Oceanography cont.		
Topic 3 – Oil Spills		Session Chair: Andreas Schiller
14:10–14:30	**International Speaker #2** **Oil spills – perspective from an industry-owned cooperative**	**Liam Harrington-Missin, Oil Spill Response Ltd, UK**
14:30–14:50	Trajectory modelling for Australian maritime environmental emergency response	Paul Irving
14:50–15:10	Oil spill modelling - Montara case study	Brian King*, Trevor Gilbert, Ben Brushett, Jeremie Bernard and Nathan Benfer
15:10–15:30	Q&A Session	
15:30–16:00	**Afternoon Tea**	
Theme 4 – Identifying and Addressing Future Challenges and Opportunities		Session Chair: Brian King
16:00–16:20	**International Speaker #3** **Shell's experience using gliders for observational oceanography**	**Michael Vogel* (Shell US)**, Ruth Perry, Louis Brzuzy, Pak Tao Leung, Walt McCall, Kevin Martin and Ryan Vandermuelen
16:20–16:40	Future opportunities in earth observations	Stuart Minchin
16:40–17:00	Operational oceanography in the Australian Defence Force	Steve Wall
17:00–17:20	Q&A Session	
17:20	**CLOSE DAY 2**	
18:30–23:00	**FOO 2015 Conference Dinner (Island Suite)**	

Forum for Operational Oceanography

FOO 2015 Program – Day 3, Thursday 23rd July 2015

DAY 3 – Thursday 23rd July 2015 (Orion Room)		
Theme 4 – Identifying and Addressing Future Challenges and Opportunities cont. Session Chairs: Tim Moltmann and Jan Flynn		
08:00–08:30	**Arrival Tea and Coffee**	
08:30–08:50	Improved tropical cyclone wind and wave forecasts for offshore industries	Jeffrey D. Kepert*, Noel Davidson, Paul Gregory, Alister Hawksford, Andy Taylor, Xingbao Wang, Harvey Ye and Stefan Zieger
08:50–09:10	Assessment of metocean forecast data and consensus forecasting	Ben Brushett*, Brian King and Charles Lemckert
09:10–09:30	Advances in swell prediction for Australia's North West Shelf	Greg Williams* and Steve Buchan
09:30–09:50	Wave forecast and wave climate, advances and challenges	Alexander V Babanin*, Ian R. Young and Stefan Zieger
09:50–10:10	Enhanced storm surge forecasting services	Mikhail Entel* and Eric Schulz
10:10–10:30	Operational oceanography in the nearshore	Graham Symonds*, Ryan Lowe and Jeff Hansen
10:30–10:50	Q&A Session	
10:50–11:20	**Morning Tea**	
Theme 5 – Where to next?		
11:20–12:20	**Panel Session** Keynote speakers and Session Chairs will form a panel to summarise and discuss: • Capability • User Needs • Opportunities and Challenges • Mechanisms for Research/Industry Collaboration • Next steps Feedback and comments from conference participants will be encouraged	
12:20–12:30	FOO 2015 conference wrap-up	
12:30–13:30	**FOO 2015 CLOSE followed by Lunch (Atrium Garden Restaurant)**	

FOO 2015 Oral Presentation Abstracts (ordered by Themes/Topics)

Theme 1: What is Operational Oceanography and what does it mean in the Australian context?

What is operational oceanography?

Schiller, Andreas*[1], Boris Kelly-Gerreyn[2] and Tim Moltmann[3]

[1] CSIRO Oceans and Atmosphere Flagship, Castray Esplanade, Hobart TAS 7001, Australia

[2] Bureau of Meteorology, 700 Collins Street, Docklands VIC 3008, Australia

[3] Integrated Marine Observing System (IMOS), IMAS Building, University of Tasmania, Hobart TAS 7001, Australia

Andreas.Schiller@csiro.au

There is, as yet, no widely accepted definition of Operational Oceanography. However a working definition has been provided by the European component of the Global Ocean Observing System (EuroGOOS): "Operational Oceanography can be defined as the activity of systematic and long-term routine measurements of the seas and oceans and atmosphere, and their rapid interpretation and dissemination". Operational Oceanography is like weather monitoring and forecasting for the ocean. It can provide estimates of essential ocean variables (e.g. sea level, temperature and currents) for the present and the future, as well as for the past. Operational Oceanography depends on availability of ocean observations and super-computer facilities, and uses computer models and mathematical techniques that have been developed over several decades. It is designed to deliver stakeholder defined outputs and products on a routine basis, using robust and fully supported production and dissemination techniques. Most Operational Oceanography systems are run at national weather centres (e.g. Bureau of Meteorology), and often depend on coordinated efforts from multiple organisations (e.g. Bureau of Meteorology, CSIRO and RAN). Operational Oceanography can be used to improve safety of life at sea, help create wealth, and assist in the security and protection of the marine environment. Outputs can be used to generate data products, applications and services through national authorities, as well as in some cases through other organisations such as metocean service providers and environmental consultants. This presentation will cover key aspects of operational oceanography in Australia, including observations and forecasting activities, and will put these in the international context.

Why have we established a Forum for Operational Oceanography and who is it relevant to?

Flynn, Jan*[1] and Tim Moltmann[2]

[1] Shell Australia Pty Limited, 2 Victoria Ave, Perth WA 6000, Australia

[2] Integrated Marine Observing System (IMOS), IMAS Building, University of Tasmania, Hobart TAS 7001, Australia

Jan.Flynn@shell.com

In developed countries around the world, Government agencies, R&D providers and marine industries are realising the potential advantages of creating a systematic focus on operational ocean observing, short-range prediction, and delivery of services - covering marine and coastal environments, and physical and biogeochemical properties. This has come to be described as operational oceanography. Recent efforts in the UK to establish a Forum for Operational Oceanography (FOO) are one good example. As an island nation deriving massive social, economic and environmental benefits from its coasts and oceans, Australia has good reason to be keenly interested in these developments. A team of scientists and managers from across industry, government and academia have therefore come together and formed a steering committee to bring an Australian Forum for Operational Oceanography (FOO) into existence. The intended objectives of the FOO are:

1. To provide a mechanism for clearer and more coherent articulation of user needs and priorities from across diverse sectors and jurisdictions with common interests in operational oceanography;
2. To facilitate awareness and utilisation of existing operational oceanography systems by the community;
3. To keep the whole cross-sectoral operational oceanography community informed of developments and best practices in the field; and
4. To initiate the interactions and partnerships between groups in Australia that are essential to improve both exploitation of capabilities in operational oceanography, and transitioning of systems research to operations.

In organising the inaugural FOO 2015 Conference, particular attention has been paid to engaging research providers, government agencies, service providers and marine industries.

Operational oceanography and the oil and gas industry – the UK experience

Grant, Colin*

CG Metocean Consulting Ltd, Guildford, GU2 4EZ, UK

colin@cgmetoceanconsulting.com

The oil and gas industry in the UK, since its inception in the 1970's, has a tradition of applying operational oceanographic methods in its daily operations. Over recent years, the UK's involvement with the European Union, and the ever-increasing regulatory environment both at home and in the EU, has led to significant further requirements to be addressed. As well as some challenges, such regulations also offer some opportunities for the oceanographic community as a whole. The talk will address some of these lessons from the UK that may be useful in the Australian context.

Theme 2: Assessing Present Capabilities - what can we do now?

Scope of capabilities under consideration – ocean circulation, sea state and weather, climate, atmosphere and ecosystems

Brinkman, Richard*

Australian Institute of Marine Science, Townsville, Qld 4072, Australia

r.brinkman@aims.gov.au

Operational Oceanography can be described as a systematic focus on operational ocean observing, prediction of ocean variables across a range of timescales, and delivery of services based on observing and prediction system outputs. Outputs and services transcend spatial and temporal scales, from products describing ocean currents and ocean climate variability down to forecasting local coastal hazards associated with floods, storm impacts, sea level anomalies and coastal water quality. The capabilities that underpin these services are often hierarchical in nature and have various levels of maturity, driven by the developmental state of the underpinning science. For example, products delivering information on ocean biogeochemistry and marine ecosystem response aim to bridge the gap between mature ocean/atmospheric simulation capabilities and new and emerging applications in areas such as water quality, fisheries resource management and carbon cycle prediction. As the development of new applications progresses, so to must a systematic approach to formulating specific requirements for supporting ocean observations on the basis of improved understanding of data utility.

Observing Systems – research and operational

Moltmann, Tim*[1], Boris Kelly-Gerreyn[2], Lyndon Llewellyn[3] and Adam Lewis[4]

[1] Integrated Marine Observing System (IMOS), IMAS Building, University of Tasmania, Hobart TAS 7001, Australia

[2] Bureau of Meteorology, 700 Collins Street, Docklands VIC 3008, Australia

[3] Australian Institute of Marine Science, PMB 3, Townsville MC, Townsville Qld 4810, Australia

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Australia's marine observing system capability is met through a number of means. Since 2006, Australian Government has invested in the Integrated Marine Observing System (IMOS) as a national research infrastructure, representing a step change enhancement over the last decade. IMOS routinely deploys a wide range of observing equipment, making all of its data openly accessible to scientists, researchers and other users. IMOS observations cover the open-ocean, continental shelf, and coastal waters, measuring physical, chemical and biological variables. Designed to overcome historical problems with researcher-driven marine observing (including inadequate coverage, institutional fragmentation, and funding discontinuity), new investment of ~$150M through IMOS greatly enhances operational marine observing in Australia. The Bureau of Meteorology (BOM) is the government agency for operational oceanographic and meteorological products and services, providing sustained observations from a range of platforms. The latter include drifting buoys, tsunameters, volunteer vessels and Argo in partnership with IMOS. In addition, BOM has responsibility for the national wave buoy and tide gauge networks, which it achieves in partnership with State Governments and Industry. The Royal Australian Navy (RAN) has operational responsibility for hydrography and provision of met-ocean services to the defence forces. The Australian Maritime Safety Authority (AMSA) operates systems for vessel identification, navigation, under keel clearance, and oil spill monitoring and surveillance. Geoscience Australia (GA), undertakes marine surveys to provide bathymetry, sediment, and other data on marine habitats within Australia's marine jurisdiction. State and Territory Governments collectively undertake a wide range of other bio-physical observing/monitoring programs to meet their legislative and policy requirements. Significantly, many of these programs and institutions rely on ongoing access to international public-good satellite observations. Tremendous opportunities are emerging with next generation satellites (including wide-swath and geostationary), and planning is underway to exploit their potential. While gaps in capability exist, in combination, these marine observing capabilities provide significant impetus and enhancement to the development, use and impact of operational oceanography in Australia.

Modelling systems – research and operations

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The Australian ocean modelling community through multi-institutional partnerships, including Bluelink, MARVL, eReefs, and ARC-funded projects, has developed several ocean modelling systems over recent years. These systems have been applied to both the deep and coastal ocean for short- to medium-range prediction. Some systems include capabilities to assimilate observations to perform ocean reanalyses and forecasts. Ensemble-based data assimilation tools have been used for the past 5-10 years (under Bluelink and eReefs) – but recent efforts have expanded these tools to include 4dVar (ARC-funded efforts). Different capabilities are at different levels of maturity – some have been designed for operational application, some designed for research. An overview and assessment of Australia's current capabilities in ocean prediction will be presented, including a comparison to how we are positioned relative to our international counter-parts. There are many opportunities to exploit the present capability to deliver greater impact from ocean services through the assimilation of new observation platforms (e.g., HF radar, new/different satellites) and enhanced and adaptive sampling (guidance for where best to make observations) as well as estimating forecast uncertainty through ensemble prediction (to produce forecasts of "likelihood"). There are also opportunities to advance our capabilities – including modelling (highly resolved physics, unstructured gridding, coupled ocean-wave-atmosphere) and more advanced assimilation techniques e.g., hybrid methods (combining ensemble and variational data assimilation) and coupled data assimilation.

New advanced computing research infrastructures to support operational oceanography

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In Australia there have been considerable advances in national computational and data infrastructures to enable programmatic access to, and interoperability of, the rich national marine, climate, earth observation and environmental data. Data accessibility is now reliable through internationally adopted standards for data access as services (such as OpenDAP and Open Geospatial Consortium standards) and advanced catalogue searching for deep discoverability of the underlying datasets. These are compliant with relevant international geospatial standards, W3C, and stewarded through relevant community driven international consortia such as Ocean Data Interoperability Platform (http://odip.eu) and the Research Data Alliance (https://rd-alliance.org/).

Two examples: the Australian Ocean Data Network builds on the information infrastructure developed by the Integrated Marine Observing System (IMOS) and data is freely and openly available through these services and the IMOS Ocean Portal (http://imos.aodn.org.au); the National ComputationaI Infrastructure has a seamless Data Interoperability Platform, linking High Performance Data (categorised into six major fields all related to the environmental sciences) to the high performance supercomputer (raijin) and cloud (tanjin).

All datasets are available for very high performance access for model, data assimilation and data-intensive science, as conducted by the virtual laboratory infrastructures MARVL (http://www.marvl.org.au/) and Climate and Weather Science (http://cwslab.nci.org.au/).

Through the adoption of semantic technologies and authorisation controls, the data services are becoming increasingly available for direct, machine-to-machine programmatic access and, by design, the services are compliant with the National Environmental Information Infrastructure (NEII) reference architecture. This talk will discuss opportunities for Australian operational oceanography through the utilisation of oceanographic data and services.

Operational marine and ocean services at the Bureau

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The Bureau accomplishes its mission through the delivery of products, services and advice that informs decisions by governments, businesses and the community. The breadth of our activity in environmental intelligence has grown over the last decade and we expect it to do so over the next decade.

In extending our reach further, we plan to accord particular priority to marine services, spanning the deep ocean, the continental shelf and the coastal zone. The Bureau already provides a range of marine related observation, research and information services and represents Australia in the UNESCO Intergovernmental Oceanographic Commission. Noting the strategic significance of marine environments to Australians, we see a significant opportunity to do more.

We have identified increasing demand for support in areas as diverse as marine reserve management, air-sea rescue, fisheries management, marine transport, naval defence, coastal development planning and offshore resources industry operations. In response to such demand, the Bureau has developed a Marine Strategy guided by four key principles;

- User driven marine products and services;
- A phased approach to implementation;
- Effective partnerships; and
- Building on core strengths.

and by four priority areas;

- Coastal and ocean hazards;
- Coastal modelling;
- Marine climate analysis and advice; and
- Sustained and coordinated networks.

We recognise that other organisations are involved in the provision of marine information services, and seek to identify how we might productively partner with them in pursuit of national benefits. In doing so, we see the FOO as a promising partnership forum as the Bureau progresses marine and ocean services that supports Australia's growing need for marine environmental intelligence.

Theme 3 / Topic 1: Uses of Operational Oceanography – Emergency Response

The U.S. Coast Guard's Search and Rescue mission and operational oceanography: use, challenges, and opportunities

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An overview of the development of Search and Rescue (SAR) planning tools, including Self-Locating Datum Marker Buoys and the leeway studies from the 1970's to present day, is presented in the context of the relationships between SAR planning tools and environmental data. The influence of the development of the direct method of determining leeway on SAR planning tools is also discussed. Limitations of the computerized versions of the manual methods are demonstrated. The US Coast Guard's Search and Rescue Optimal Planning System (SAROPS) representing the state-of-the-art search planning tools is then highlighted. All SAR planning tools are heavily reliant on operational oceanographic models for surface current nowcasts and forecast fields. But until recently, SAR planners were unable to gauge just how accurate those oceanographic models were. A method for determining skill following a modification of the method presented by Liu and Weisberg (2011) is presented. Skill is a measure of the ability of a model to simulate drifter trajectories located within the model's area. This application is now available in real-time. The modification allows negative skill values, since projections in the wrong directions will take the SAR assets away from the survivor, decreasing the chance of locating the survivor or survivor craft. An example from a recent SAR case off Hawaii is used to illustrate the features of the skill tool for SAR operations. The presentation concludes with future work planned by the SAR and oceanographic communities in support of SAR planning.

Operational drift forecast modelling in support of the AMSA search for Malaysian Airlines MH370

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Once it was determined that the likely splash point of the Malaysian Airlines flight MH370 was in the Indian Ocean, RPS APASA, CSIRO and the Bureau of Meteorology (BoM) supported AMSA in their operational search area planning with daily drift and weather forecasting. Several different drift objects were simulated by RPS APASA using the nationally adopted SARMAP system, which allows multiple current and wind forecasts to be applied, to generate a consensus/combined forecast for the target search areas. Model forecast data included forecast currents from OceanMAPS/BLUElink (BoM), HYCOM (NCEP), and HYCOM (US Navy), and winds from ACCESS-R (BoM). Each day three forecasts were prepared and then combined to produce maps of spatial consensus based on the number of model hits on a grid, as well as the particle hit density in those areas. CSIRO drift forecasts also included the use of IMOS GSLA geostrophic currents and full-ensemble, hindcast/forecast currents from the OceanMAPS/BLUElink system. The drift forecast results from RPS APASA and CSIRO were used by AMSA to formulate the search areas each day, throughout the event. Comparison of forecasts with Self Locating Datum Marker Buoy (SLDMB) drift trajectories during the event allowed for comparison of the performance of the forecasts over different time-scales, highlighting the value in the consensus approach. Predictions were compared to, and matched very well with, those made by the US Coast Guard through their SAROPS system. We will outline the methods used during the search, and discuss the comparisons of model results with the SLDMB observations.

Numerical model to simulate drift trajectories of large vessels

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Increased shipping activities and multi-use of marine spaces create challenges for regulators to enhance emergency response services and adapt strategic planning aspects to mitigate risk. Of particular interest risk related to drift groundings due to their complex nature and the lack of any suitable tool that can simulate drift trajectories of large vessels accounting for effects wind, waves and currents.

Most research in this area so far has put emphasis on the determination of search areas for small objects where currents and winds are most relevant. Wave induced drift forces has either been neglected or derived directly from the wind force. For predicting drift trajectories of large vessels, wave induced forces cannot be ignored but are currently not well accounted for by existing approaches.

Floating vessels usually have asymmetric hulls, which generates lift forces when the vessel is moved by wind and waves. This will cause the vessel to drift on an angle to the resultant incident force direction. The phenomenon is called leeway drift and can vary significantly based on vessel type, loading, size and draft. Most previous methods have been limited to stochastic analysis of field data to provide a simplistic incorporation of leeway drift.

We present a new breed of numerical model capable of accurate prediction of drift of large commercial vessels. Wind, current and wave induced forces and turning moments are evaluated directly on full 3D vessel hulls, which allows vessel orientation, drifting speed and leeway drift angle to be evaluated explicitly and accurately. The model accounts for separate treatment of spatially varying wind, current and wave forces such as produced by 2D and 3D forecast and hindcast models.

Stochastic treatment of key variables associated with uncertainties in predicting drifting vessel fate is incorporated directly through customized probability functions that can be modified through an open source interface. Model outputs include discrete vessel trajectories, spatial time series of position likelihood and grounding risk probability.

At this stage, the models have been partially validated and AMSA is currently in the process of arranging a controlled drift experiment with the capsize dry bulk carrier from Rio Tinto to reduce uncertainties associated with input data and further validate the model.

The model is optimized for fast execution of concurrent simulations of thousands of vessels across large areas making it suitable for strategic assessment of vessel grounding risk in both local and regional water bodies.

Practical application of drift modelling to search and rescue

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Drift modelling is a fundamental component of maritime search area determination. Presentation will focus on how these model outputs are reviewed by search and rescue practitioners and implemented into a practical search plan. The discussion will cover;

- Determination of Targets
- Modelling Review by SAR operatives
- Overall Search Area
- Optimal Track Spacing
- Determination of Search Assets
- Search Compromise (if required)
- Allocation and Search planning
- Additional considerations
- Validation of Drift modelling

AMSA marine search and rescue prediction system (Nett Water Movement)

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The first version of the search and rescue prediction system was installed at the Australian Maritime Safety Authority (AMSA) in 1998. AMSA named the system "Nett Water Movement" (NWM) to reflect the need for AMSA to know the likely destination of objects drifting in the ocean. The principal components of the NWM system are:

- Bathymetry over the entire region of ocean for which AMSA is responsible for marine searches
- Tidal constituent data over the AMSA region
- Atmospheric model forecasts from the Bureau of Meteorology
- Large scale ocean model forecasts ("Bluelink")
- The GEMMS 3D Coastal Ocean Model (GCOM3D)
- The GEMMS Search and Rescue prediction model (SARTRAK)
- A GIS graphic user interface to provide user friendly operation of the system

Since 1998 the system has undergone a number of changes, primarily as a result of the availability of higher resolution atmospheric model forecasts and large scale ocean model forecasts (for GCOM3D boundary conditions). The NWM prediction system as it exists now will be described in detail in the presentation together with some examples of its operation in routine marine searches and in the search for MH370. During the search for MH370 comparisons were undertaken of drift track predictions with a large number of drifting buoys released by the searching aircraft, providing valuable insight into the accuracy (and hence usefulness) of the large scale ocean model (Bluelink). Results of a long term (10 month) prediction of the potential fate of debris will also be presented.

Theme 3 / Topic 2: Uses of Operational Oceanography - Coastal and Marine Management, Ports and Shipping

Marine forecasting in coastal and nearshore waters using dynamical process models

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Effective forecasting of marine conditions in coastal and nearshore areas is best conducted with dynamical process models, thereby resolving the complex, highly non-linear and interrelated aspects of winds, currents and waves. Here, a system that allows the efficient deployment of nested forecast domains for waves, winds and currents is described, and examples are provided for locations worldwide. Various port scale wave model domains are examined, showing the influence of using different wind sources (GFS and ECMWF) as forcing to the global WW3 forecasts, particularly evident in the outcomes in the Southern and Indian Oceans and resultant effects on the nearshore wave climate. The benefit of a nested WRF wind domain on the wave climate is demonstrated for the Bass Strait, along with the modulating effect of the tidal currents on wave height and period in the central regions of the Strait. An operational wave domain for underkeel clearance calculations in a complex harbour entrance in NZ will be shown, along with the coupled wave and current regime from the Mermaid Sound WA forecast model. Examples of 3D ROMS forecast models being used for guidance on the inner shelf and coastal regions in Malaysia, Brazil and the North Sea will be discussed. Finally, beyond a certain temporal horizon, the benefit of a full dynamical approach is known to reduce as the quantitative confidence in the boundary conditions recedes. There is a point where other approaches begin to have merit, such as ensemble downscaling from regional or global forecast domains, particularly for waves. In these situations, added valued can be found from both spectral and parametric downscaling, and practical operational guidance derived in this way will be demonstrated for locations in the Bass Strait, along with validation results.

Real-time Information needs for ports and shipping: status and gaps

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Fremantle Ports like many Ports throughout Australia and the world has seen a significant change in vessel size over the years particularly in relation to draft to depth ration and more recently length to turning basin ration. Coupled with this, and whilst science, politicians and the community debate the cause of climate change Ports operationally are recognising changes in seasonal conditions and more storminess. In 1991 deep draft vessels arriving at Fremantle Ports utilised static under keel clearance calculations based on past experience. Today the computer based calculation relies on reliable and accurate tide, wave and weather data to predict and mitigate the safe transit of deep draft vessels through port waters. Going beyond the day to day operations of the Port we now manage significant weather events which either weren't present in previous history or were not discernible given vessel size ratios and the need for reliable long range forecasting with particular attention to the movement of pressure cells and their impacts on swell generation, tidal residuals, squalls and meteo-tsunamis are now and in to the future essential to the Harbourmaster to ensure that they can appropriately prepare and respond to these events and the continued operation of the port given the vital economic contribution it makes to the country.

Information needs for marine resource management: status and gaps

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The Department of Parks and Wildlife is legislatively responsible for the management of Western Australia's marine park network and threatened marine fauna. In order to meet their obligations, the department undertakes a range of research and monitoring programs investigating key ecological processes and trends in the condition of important biological assets, such as seagrass, macroalgae, coral, mangroves, coastal vegetation, turtles and marine mammals. Remote Sensing tools play a major role in these programs, facilitating broad scale assessments of community condition metrics and the investigation of key spatial and temporal research questions. While Remote Sensing already provides an informative and cost-effective method for marine resource management, particularly in remote locations where 'on the ground' assessments are expensive and logistically difficult, there are a number of significant challenges and issues that could be addressed in order for managers to make better use of available products. These include species and biota differentiation, broad scale chlorophyll-a and turbidity assessment, and overall product affordability. This presentation summarises the current uses of Remote Sensing for marine management within the department and sets out a number of knowledge gaps and future needs that would assist further information acquisition.

Dredging and associated environmental aspects: real-time and longer term information gaps

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Whilst it is clear that dredging activities have the potential to cause impact on the physical environment, the precise nature and consequences of changes are not fully understood. This paper notes two matters: 1 – how sediment transport is currently measured and assessed, and 2 – how dredged channels might physically interfere with long-term bed sediment transport pathways.

For sediment transport, the design of some field measurement programs risks them being unable to determine whether observed changes can be attributable to dredging or not. This undermines the purpose of the exercise. Further, some statistical techniques used to analyse whether real-time data represent a 'hazard' or not, have unrecognised uncertainties. Better experimental design, including improved operational monitoring, can help to limit these risks. For dredged channels, the potential to cause widespread, multi-decadal and essentially irreversible consequences to benthic habitats constitutes a major and seemingly unassessed environmental and corporate risk.

Water quality, sediment transport and seabed sediments are critical controls upon benthic habitats. Despite their high importance, these issues are weakly addressed in State and Federal environmental legislation. Decision making about the potential for dredging to impact the Great Barrier Reef shelf has been greatly weakened by a lack of credible marine geosciences input. The role of marine sedimentary science requires a considerable boost to support better development decisions around Australia.

A National Shelf Re-Analysis (ANSR) project for Australia

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Australia is a marine nation, and to enable sustainable marine development, adequate understanding of the shelf-scale marine environment is fundamental. Indeed, we could not imagine managing terrestrial environments without the weather and climate services that industry, community and government now take for granted on a daily basis. Australia needs a comparable effort in operational shelf-scale oceanography, a key component of which is ocean reanalysis. Reanalysis provides a realistic description of past states and time series showing trends and changes. Australia is presently in the fortunate position of having an unprecedented level of shelf ocean observations from the Integrated Marine Observing System (IMOS), as well as access to state-of-the-art numerical modelling and super-computing facilities. The time for an Australian National Shelf Reanalysis (ANSR) is now.

By combining the vast IMOS dataset with remote sensing products, and datasets held by individual institutions and stakeholders, the aim is to generate analysis fields for the Australian shelf for the past 20 years. The key dynamics such as boundary currents, upwelling systems and sub-mesoscale shelf features will need to be captured by the modelling system. Analysis fields for the key variables of temperature, salinity, currents (U and V) and sea-level will be produced by the assimilation system. Ultimately the re-analysis effort will produce gridded fields that have a higher spatio-temporal coverage than can be achieved by observational products alone, while having a lower error than using a numerical model in isolation. We outline the key steps needed to build ANSR nationally. In this presentation, we will identify the observational, modelling and computational requirements for undertaking this project.

Theme 3 / Topic 3: Uses of Operational Oceanography – Oil Spills

Oil spills - perspective from and industry-owned cooperative

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Since the Deep Water Horizon blowout accident of 2010, the oil spill response world has evolved more quickly than at any other point in history. Billions of dollars have been invested in innovative systems to stop or mitigate another deep water blowout event. Thousands of pages of lessons learnt and new research have been published and regulators, operators and response agencies have had to act quickly to keep abreast of the new material. Response agencies around the world have had to re-invent themselves, bringing new subject matter experts and new technology to an otherwise niche market.

In this 2-part presentation, one of the aforementioned experts; Liam Harrington-Missin, Global Geomatics Lead of Oil Spill Response Ltd., will introduce how he has observed the industry change. In part 1, he will broadly introduce the most significant developments in responding to an offshore oil spill. In part 2, he will discuss the challenges on his specialist area, the management of an ever evolving requirement to obtain, integrate, disseminate and communicate significant quantities of data in record times to a broad spectrum of stakeholders.

Trajectory modelling for Australian maritime environmental emergency response

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Operational modelling is crucial to Australia's capability to respond to maritime casualties and the spills of oils and other chemicals that follow. The Australian National Plan for Maritime Environmental Emergencies sets the framework for all aspects of prevention, preparedness, response and recovery from maritime emergencies. The Australian Maritime Safety Authority (AMSA) maintains a number of decision-support tools and services, including trajectory modelling for pollutants, search and rescue and vessel. These are provided on contract from commercial service providers, with extra technical support and advice provided from science and other operational agencies. As well as response use to augment incident intelligence gathering, the models are used for planning, exercises and training. Traditional 2D OILMAP and 3D CHEMMAP pollutant modules provide trajectory, fate and behaviour predictions. Search and rescue uses the SARMAP module for small floating objects, among others. To improve predictions for large vessel casualties drifting without power, AMSA is working with DHI, Oceanwaves, and Rio Tinto to develop models specifically for this purpose. Models have the advantage of producing impressive, credible, graphic outputs rapidly, but AMSA, and its wider National Plan technical group, want to understand the uncertainties and operational constraints inherent in their use. We also support the science community's efforts to improve the underlying oceanographic, meteorologic and other environmental data sets.

Oil spill modelling - Montara case study

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August 21, 2009, reservoir fluids and gases were released from the Montara Platform in the Timor Sea due to the accidental loss of control of the H1 well. As a result, crude oil rained down onto the ocean below and flowed for 72 days, releasing up to 28,880 barrels in total, before successful intervention. This presentation demonstrates the operational oceanography undertaken in the forecasting and hindcasting of this spill incident to support both the response and post spill monitoring studies. In particular, the Montara Incident, due to its protracted nature, had extensive operational oceanographic needs (eg. gas and vapour plume OH&S assessments, stochastic exposure risk assessment, Net Environmental Benefit Analysis of a response using dispersants, ongoing daily forecasts etc). Satisfying these needs in a very short time frame, involved the ability to integrate metocean datasets, overflight information, satellite and other observations into oil spill trajectory models (OILMAP and SIMAP) and chemical spill trajectory models (CHEMMAP). By combining high-resolution tidal currents, metocean forecast datasets, and the assimilation of daily overflight data and satellite images into the oil spill model ultimately provided the most accurate forecast methodology. This same integrating approach, using reanalysis datasets instead of the forecast datasets, allowed for a final comprehensive (hourly) record of a protracted spill event over time.

Theme 4: Identifying and Addressing Future Challenges and Opportunities

Shell's experience using gliders for observational oceanography

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In 2012, Shell deployed a Kongsberg Seaglider as a part of a collaborative program with NOAA NDBC. A principal goal of the Shell-NOAA collaboration is to acquire data that can improve understanding and prediction of tropical cyclone development in the Gulf of Mexico. Subsurface gliders were identified as a promising tool to meet this objective. An additional goal is to provide real-time observations of the Gulf of Mexico Loop Current dynamics. The key mutually-defined mission objectives are to measure the upper ocean heat content and evaluate glider performance transiting through the Loop Current. The structure of the collaboration was designed to leverage the respective strengths of the organizations; where Shell supplied the glider and field support through the use of its offshore vessel fleet, and NOAA piloted the missions, optimized glider performance, and disseminated the data. In 2014, the partnership broadened to include the University of Southern Mississippi, National Centers for Environmental Protection, and the Gulf of Mexico Coastal Ocean Observing System. In 2012, the Seaglider cruised 900 miles, collected 1000 profiles, and acquired data in Hurricane Isaac and the Loop Current. In subsequent years, the Seaglider (and a Teledyne Webb glider deployed in 2014) obtained nearly 4000 profiles from 1400 miles of coverage. As there were no hurricanes in the Gulf of Mexico in 2013-2014, the missions focused on the structure of the Loop Current/eddies and the central and eastern Gulf shelf and shelf-break. A major future program objective is to routinely assimilate the real-time glider observations in numerical ocean models to improve performance and forecast skill.

Future opportunities in earth observations

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The Australian Geoscience Data Cube is a sophisticated new approach to storing, organising and analysing large volumes of satellite imagery and other gridded geospatial datasets covering the Australian continent and marine estate. Geoscience Australia, in collaboration with the CSIRO and Australian National University – National Computational Infrastructure, developed the Data Cube to enable the rapid analysis of Petascale, high-resolution EO data, effectively 'unlocking' large EO data archives. This approach uses a high performance data structure, set within a high performance, data-intensive computing system. Data are assigned to a common grid framework that spans the full geospatial and temporal extent of the observations available for the area of interest. The approach is pixel-based, rather than the traditional scene-based analysis, and incorporates the calibration and quality-assurance of each Earth surface reflectance measurement.

In its first year of development the Data Cube has already taken in 25 years of information from the Landsat satellites, which has been analysed, and re-analysed, to produce a 'Water Observations from Space' product, a national summary of places where water occurs in the landscape. This includes the coast, where it is being used to map the extent and dynamics of the intertidal zone. Other marine applications of the data cube include the time-series mapping of shallow-water bathymetry, water quality and benthic habitats; the analysis of the full MODIS data archive; and the ingestion of new data streams from the European Sentinel satellite missions. As this work happens, the data cube will become a key national 'knowledge resource' for decision making across a wide range of issues.

Operational oceanography in the Australian Defence Force

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The ability to forecast the ocean environment has significantly changed how the Australian Defence Force (ADF) operates, especially in the maritime domain. Prior to this, forecast properties were not available operationally and the information provided to ADF operators was typically either climatology or local (usually point based) observations. These forecasting services provide a significant capability throughout the planning, conduct and post analysis of a wide spectrum of activities in the maritime domain enabling improved safety and optimal employment enhancing the ADF's effectiveness. As platforms, sensors and weapons become more dependant on geospatial data, the requirement for the ADF to have access to high resolution, accurate and timely sources of that data will only increase, requiring skill sets and expertise in areas where the ADF has limited resources at present. The ability to identify shortfall in data requirements and allocate resources to collect this data will also become more and more important in the future.

Improved tropical cyclone wind and wave forecasts for offshore industries

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The offshore oil and gas industry in north-western Australia operates in a harsh and remote environment, in which tropical cyclone winds and waves present a particular threat to safe, economical, effective and environmentally responsible operations. Industry time-frames for preparing their infrastructure and people for tropical cyclones are of the order of several days, challenging the capability of current forecast systems. Effective risk management must consider alternative scenarios, ideally in a probabilistic manner. Present forecasts systems are limited in their ability to meet these needs. The deterministic tropical cyclone forecast model, ACCESS-TC, developed and operated by the Bureau of Meteorology, provides forecasts to only three days and does not provide wave predictions. Ensemble prediction systems (EPS) have relatively coarse resolution, and therefore contain systematic biases in tropical cyclone structure and intensity. This project aims to develop new forecast guidance systems, designed specifically to overcome these limitations. A new tropical cyclone model, with higher resolution, a larger domain, and longer forecast horizon, will be coupled one-way to a wave model tuned especially for tropical cyclone conditions. We will diagnose and correct the systematic biases in tropical cyclone structure in a global atmospheric EPS, so that probabilistic wind forecasts are better calibrated. These corrected wind fields will be used to drive the wave model, leading to more reliable probabilistic wave forecasts. As well as the research aims, we are also in a close dialogue with the industry on how the improved guidance can be used to deliver better operational outcomes.

Assessment of metocean forecast data and consensus forecasting

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Successful maritime search and rescue (SAR) requires the ability to effectively predict the drift of floating objects. SAR drift models, used in conjunction with metocean (meteorological and oceanographic) forecast data, are used for this task. This presentation provides a summary of two studies involving comparisons of drifter trajectories (deployed in the Tasman Sea (2010), and the Indian Ocean (2012)) with corresponding model simulated trajectories. Each 5-day drifter trajectory was simulated independently, using four ocean models (BLUElink, FOAM, HYCOM, and NCOM). The studies quantify each dataset's ability to predict a search area that successfully contained the drifter (indicated by hit rate), and determine the associated errors (average distance error). Consensus forecasting was also examined, where all four forecasts for a single drifter were overlapped to determine potential areas of higher probability within an ensemble of model defined search areas. The results for the average distance errors at the end of each of the 5-day trajectories showed that NCOM (90km), had the lowest errors in the Indian Ocean study followed by FOAM (90.4km), HYCOM (101km) and BLUElink (109km); whilst FOAM (108km) had the lowest errors in the Tasman Sea study followed by HYCOM (109.9km), NCOM (124.2km) and BLUElink (140.7km). The models with the highest hit rates at 5-days in the Indian Ocean study were FOAM (80%) and NCOM (80%) followed by HYCOM (71.1%) and BLUElink (64.4%); whilst the model with the highest hit rate in the Tasman Sea study was HYCOM (82.5%) followed by NCOM (77.8%), BLUElink (68.3%) and FOAM (63.5%).

Advances in swell prediction for Australia's North West Shelf

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The Pilbara region in North West Australia is already the largest producer and shipper of iron ore in the world, and tonnages are projected to grow. Also, the North West Shelf region is scheduled to surpass Qatar as the world's largest producer of LNG by the year 2020. One of the constraints on iron ore exports from North West Shelf ports is underkeel clearance for the long shipping channels associated with each port. Improved forecasts of swell will reduce the underkeel clearance allowance – directly increasing productivity. The offshore Oil & Gas industry is also significantly affected by swell – both ambient conditions dominated by swell from the Southern, Indian and even Atlantic Ocean basins (affecting floating facility operability, FLNG carrier underkeel clearance, side-by-side LNG product transfer and fatigue loadings) and tropical cyclone generated swell (affecting facility survival, riser disconnect/reconnect windows, LNG loading windows and requirements for post-storm inspections). These industries, and the Port Authorities and Government instrumentalities which support and regulate them, would benefit from improved site-specific swell forecasting – both in terms of accuracy, and the extent of forewarning. RPS MetOcean have developed a sophisticated swell prediction system comprised of automated cyclone track assimilation and advanced cyclone wind blending, the latest release of Wavewatch III supporting highly tuneable wind-forcings and physics, and a calibration system based on remote-sensing and near-realtime measurement networks. In this presentation, we describe the key elements of the system, demonstrate the improvements and performance of the windfield blending and swell prediction components in a variety of tailored forecast and early-warning services, and discuss the applicability of the swell prediction system to similar regions worldwide.

Wave forecast and wave climate, advances and challenges

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The paper will address recent advances and new challenges in wave modelling, and observations of wave climate and its trends.

Major update of the physics of the third generation models will be presented. In particular, prediction of the long-term swell will be discussed. The new source terms for wind input, whitecapping dissipation, interaction of waves with adverse winds (negative input), swell attenuation, wave-bottom interactions have been developed and implemented in WAVEWATCH-III and SWAN models, others are under development. Physics and parameterisations for the new source functions are based on observations, which allowed us to reveal features and processes previously unknown and not accounted for in the default, often speculative physics. The new versions of the models have undergone extensive testing by means of academic tests, regional and global wave hindcast, tropical cyclone modelling.

Climatology of ocean waves and surface winds will be discussed on the basis of satellite altimeter observations spanning the period of 30 years. Global, regional and seasonal trends will be demonstrated.

Enhanced storm surge forecasting services

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The Bureau of Meteorology is responsible for issuing advice and warnings relating to anomalous sea-levels around the Australian coast that may impact on the public. Storm surge is manifested as sea-level variations caused by atmospheric extremes and can result in significant disruption to coastal communities, particularly when combined with other effects such as high winds and heavy rainfall. Storm surge can be associated with Tropical Cyclones (TCs) during the monsoon storm season and pose a significant risk to Queensland, Northern Territory and Western Australia. In addition, atmospheric extremes associated with synoptic weather; lows, storms and fronts can generate storm surges that have local and remote impacts as they propagate as coastally trapped waves, and affect all Australian coastlines. Storm surge has a wave set-up and run-up component and also interacts with the tides and river discharge to not only cause inundation due to heightened sea-levels, but also coastal erosion, damage to infrastructure and vessels, and heightened risk to people. The Bureau will be providing an enhanced storm surge warning service commencing this coming storm season. Due to the large uncertainty associated with forecasting TCs, an ensemble based approach has been adopted that will enable probabilistic information and warnings to be provided to the public. A national routinely operating system based on numerical weather prediction forcing will also be implemented enabling a storm surge warning service to be provided for all of Australia.

Operational oceanography in the nearshore

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The ability to provide real time observations and reliable predictions of nearshore waves, currents and morphological change over a range of space and time scales is sought after by various state and federal government agencies. Defence organisations undertaking amphibious operations, in conflict zones or emergency humanitarian responses, often require rapid environment assessment of the nearshore to aid in getting people and resources safely on or off unknown shores. Real time prediction of sediment plumes from dredging operations associated with coastal development can be used to help minimize environmental impacts and provide early warning of the potential of exceeding compliance thresholds set by state environmental protection agencies. Sea level and waves are the major climate drivers affecting the coastal zone and in turn are affected by changes in the magnitude and frequency of storm events at a range of space and time scales. Coastal monitoring can aid in mitigating the effects of inundation and coastal erosion across a range of time scales from local storms to decadal variability associated with climate change and will continue to be a focus of coastal councils and communities for the foreseeable future. Short term forecast may be provided by process based deterministic models while longer term projections rely more on probabilistic type models. In both cases high resolution observations including nearshore bathymetry are required to provide reliable operational products. In this presentation we will use a number of recent studies to illustrate some of the modelling and observational issues which need to be addressed.

23 years of sea surface temperature products from IMOS

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Long time series are an essential baseline data set, providing context for today's observations and a record of change. Building on the archives and processing expertise of CSIRO and the Bureau of Meteorology, IMOS has made the national collection of daily NOAA imagery available as consistently processed, calibrated and formatted maps of sea surface temperature (SST) for the Australasian region. The foundational data product, known as Level 2 Pre-processed (L2P), is an unmapped swath of geolocated and calibrated data from a single overpass. The collection consists of all overpasses (of sufficiently usable quality) recorded in the Australian region from any satellites in the NOAA Polar Orbiting series from April 1992 to the present, and stored with full resolution. The data are formatted and flagged according to the conventions and standards of the international GHRSST collaboration, facilitating the use of standard community tools and enabling the data to be contributed directly to the global SST record. For many applications, users prefer reprojected (mapped) products and products without gaps due to cloud. To meet these needs, a hierarchy of mapped and time-averaged data sets are derived from the L2P data. These data are known as Level 3 (L3) and comprise a variety of combinations of day-time only, night-time only, or both, formed from single sensors and multiple sensors. The multiple sensor data sets are available daily, averaged over 1, 3, 6, 14-day and 1-month intervals. The 2km resolution of the L3 products makes them particularly useful in coastal applications where the coarser (4 km or 9 km) globally-available NOAA satellite products are unable to provide sufficient detail. The L3 products are available from the IMOS data portal, and also directly from OPeNDAP and WMS servers, or as individual data files. See http://imos.org.au/sstproducts.html for further information.

Predicting the drift of Panga Skiffs: case study of maritime search and rescue in the Tropical Pacific

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Two case studies were conducted to determine the effect of four ocean models on the accuracy and size of Search and Rescue (SAR) modelled drift areas. The studies focused on the drift of a Pacific Island panga skiff over a 3-day and 5-day period in the tropical western Pacific. Four ocean models (BLUElink, HYCOM, FOAM and NCOM), and one wind model (GFS) were used as environmental forcing to the SAR drift model to generate four individual search area forecasts, defined as the convex hull which contained all 1,000 model particles. The four forecasts were analysed to determine which individual model had the lowest average distance error and whether the panga skiff was located within the forecast search areas. These forecasts were overlaid to form a multi-model consensus forecast, to determine where the model areas overlapped. An assessment of the size of each single model search area, and the consensus search areas was undertaken to establish whether there may be benefit in focussing on the smaller consensus overlap areas. The forecast using the FOAM ocean model returned the lowest average distance errors across both of the case studies, and in both cases all four ocean model forecast search areas contained the panga skiff. The four-model consensus search area was approximately one third the size of the average single model search area, whilst still containing the panga skiff. This demonstrated that the consensus search areas provided a more efficient search area, compared to the individual ocean model search areas.

IMOS OceanCurrent gridded sea level and ocean surface velocity

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IMOS OceanCurrent gridded sea level maps of the Australia region are evaluated daily in near-real time (NRT) and an archive of maps are available in delayed mode (DM) from 1993 to the present. The sea level maps incorporate all available altimeter observations of sea level anomaly, SLA, (at present including data from Jason-2, Envisat, AltiKa and HaiYang2) as well as using tide gauge data from around the Australian coastline. The maps of SLA are the basis for estimating the geostrophic ocean surface currents, the dominant long period (5-10 day period) currents and are represented with vectors on the IMOS OceanCurrent website. The OceanCurrent maps are unique in the world in being a direct map of sea surface anomaly that includes coastal tide gauge data and in so doing provides a coastal boundary condition of no flow through the coast.

When evaluated against surface velocities from the global drifter program drifter OceanCurrent velocities are found to provide estimates that are at least as good if not better than surface velocities from global ocean models. Both the NRT daily netcdf files and DM year files of gridded sea level (GSL), sea level anomaly (GSLA) and geostrophic velocities for the region (50E -190E and 60S -10N) can be downloaded from the IMOS data portal.

IMOS OceanCurrent web site

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Bringing ocean observations to users is just as important, in a way, as actually making those observations. That's why Australia's Integrated Marine Observing System (IMOS) includes a comprehensive data management system as well as multiple avenues for delivering the data to a variety of users, including those with a need for the latest-available ocean observations from satellites, HF radars and gliders. One of these avenues is the OceanCurrent website, where a wide range of graphical representations (including animations) of the many types of IMOS data are just a few mouse clicks away. The site also has a News section, which 1) informs readers about ocean events such as extreme currents or water temperatures, and 2) shows people how to interpret the available graphics, to empower them to notice such features themselves. The site serves as a preview facility, showing the space-time coverage of the various data sets, both individually and in relation to each other. By overlaying point measurements made by current meters, gliders, etc, on maps of sea surface temperature, ocean colour and geostrophic velocity from altimetry, users can quickly see the broader context of the in-situ data, helping them to correctly interpret the point data. The imagery is updated several times a day, attracting users from outside the research community while also allowing members of the research community to locate and study particular ocean phenomena.

Remote Ocean Current Imaging System (ROCIS), a new airborne high resolution imaging system

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Remote Ocean Current Imaging System (ROCIS), a new airborne high resolution imaging system bridges the gap between satellite observations and vessel based measurements using high resolution imaging to measure surface currents over large areas.

Fugro and Areté Associates combined recent advances in remote sensing, aerial survey and data processing to develop ROCIS over the past 3 years. ROCIS uses an innovative surface current measurement technique to significantly enhance understanding of current phenomena in coastal and offshore areas. The system uses combination of high-resolution airborne digital photography and highly accurate positioning systems, to measure surface wave spectral densities. The system then uses advanced algorithms and the Doppler shift applied to wave the spectra measurements by the current to extract surface current vectors representative of the upper 5 m of the water column. Current data can be collected at altitudes of between 3,000 and 10,000 feet (900 and 3,000 metres).

Over a wide operational area, near real-time synoptic surface current data are provided, while fine resolution is available for assessing smaller scale current features. The data can be used in combination with satellite, numerical model and in situ measurements, offering better understanding of offshore current features and enhancing operational planning. Information can also support the calibration and validation of predictive models.

Offshore oil and gas operators are set to benefit from ROCIS, utilising the system's accurate information to mitigate against the impact of ocean currents on exploration, development and production activities. Other applications of the airborne system include oil spill events, where the detailed, wide-area information can be used for response operations and for validation of oil spill models. Search and rescue operations could use current mapping and information of surface drift patterns to aid emergency responders.

The Australian Wave Energy Atlas

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The Australian Wave Energy Atlas project (AWavEA), co-funded by the Australian Renewable Energy Agency and the CSIRO Oceans and Atmosphere flagship commenced in July 2014. The project is coordinated by CSIRO with involvement from five other partners – the Commonwealth Bureau of Meteorology, The Australian Maritime College – University of Tasmania, Swinburne University, Carnegie Wave Energy Ltd and Biopower Systems. The project seeks to address three key knowledge gaps which currently impede the Australian wave energy industry. These are:

- Limited (scientifically credible and industry independent) knowledge of the resource, including its temporal and spatial variability and its spectral characteristics;
- Difficulty assessing spatial information identifying multiple designated marine management regimes of Australian marine territories, and
- Limited evidence-base and methodology for assessing impacts of wave energy extraction on the marine and coastal environment.

Aiming to address these knowledge gaps, the AWavEA project will deliver:

- A pre-competitive, query-able, free and openly available spatio-temporal atlas of Australia's national wave energy resource and marine management uses, and

Best-practice guidelines on physical impact assessments for wave energy developments in Australia's marine domain, developed through case-study field and numerical experiments at Carnegie Wave Energy Ltds Perth Wave Energy Project.

Transitioning research into operations with informatics: the eReefs demonstration

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The eReefs partnership is a multi-agency project to build an interoperable coastal information platform for the Great Barrier Reef. Environmental information in eReefs is being generated from multiple sources and covers a diversity of formats. Although all originate as research activities, the goal is to deploy these capabilities as near-operational services. This implies the adoption of a stable platform upon which these services can run and, crucially, a unifying information framework within which their outputs can be discovered, described, accessed and their linked in a consistent way. This information framework utilises a range of semantic web and Linked Data methodologies to improve the discovery of, and access to information. In fact, many of the data services are already running on enterprise or national facilities which have a high degree of stability. The information model being developed comprises a data brokering layer based on semantically enabled data provider nodes (DPNs). The DPNs provide a mechanism for exposing each of the data services and their data products with a consistent ontology. End-user services can exploit this data brokering layer to discover the existence of, and then combine, different data products according to their needs, despite their disparate origins. An important innovation in the implementation of this system is the progressive and integrated deployment of the information technologies into the research environment, together with supporting infrastructure such as vocabulary and provenance servers. The eReefs system comprises sufficiently diverse data sources to provide a demonstration of the practicality and benefits of such an approach.

The Bureau of Meteorology's Marine Strategy 2014-2019

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The Bureau’s mission is to provide Australian’s with the information they need to manage and live within their natural environment, encompassing the atmosphere, oceans, water and land.. This mission is accomplished through the delivery of products, services and advice that informs decisions by governments, businesses and the community. In response to growing demand for environmental intelligence, the Bureau has accorded particular priority to marine services, spanning the deep ocean, the continental shelf and the coastal zone.

The Bureau already provides a range of marine services, encompassing observation, research and information services, including some mandated under the Meteorology Act 1955 and others required under international obligations such as those under the Convention on the Safety of Life at Sea.

Noting the strategic significance of oceans and coastal environments to Australians, the Bureau sees a significant opportunity to do more. Through our own consultations we have identified a demand for support in areas as diverse as marine reserve management, air sea rescue, fisheries management, marine transport, naval defence, coastal development planning and offshore resources industry operations collectively. We have used this guidance to envisage how we might extend our marine service offering for the benefit of Australia.

The Bureau’s Marine Strategy 2014-2019 encapsulates the Bureau's vision for its marine offerings over that period and in doing so targets four priority areas - coastal and ocean hazards, coastal modelling, marine climate analysis and advice, and a sustained, nationally coordinated network of marine observing networks. These priority areas rely on working with our diverse users, stakeholders and delivery partners. As such, the Bureau seeks to build on its ongoing engagements as well as respond to the needs of new marine stakeholders.

Near real time satellite SST for decision making

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Satellite sea surface temperature (SST) imagery are useful for detecting physical features in the ocean, including currents, eddies and up and down-welling systems. These can be of interest to research oceanographers, or for operational purposes such as commercial fishing, transportation or maritime security. The NOAA polar orbiting satellites carrying the AVHRR sensor have been the backbone of civilian satellite SST product delivery and, since the 1990s, CSIRO in Hobart has operated an AVHRR-based web-SST service for fisher clients in SE Australia, using local reception and processing to provide rapid delivery. As the NOAA satellite series approaches its end, there is a need to migrate to newer sensors, and also an opportunity to refresh the delivery systems. Underlying the IMOS SST and ocean colour production systems are infrastructures that bring the data from the national reception networks together in near real time. Building on these, CSIRO has developed a demonstration system to deliver SSTs from both AVHRR and MODIS sensors in near real time via the web. The AVHRR data come from the Bureau of Meteorology IMOS feed, while the MODIS data is processed by CSIRO as a branch off the ocean colour data pipeline. The system exploits community data formats and web mapping protocols to deliver the data directly to a web browser. The user selects images from a gallery of 50+ overpasses in a rolling archive of the past 48 hours of data acquisitions, and then is able to zoom to an area of interest and adjust the temperature scale to explore features in the data. Although the system is built on research platforms, the independent data pathways for the two sensors provide a high degree of robustness, while the use of CF-compliant netCDF as the storage format will make it straightforward to include additional sensors in future.

4-dimensional open-source dispersal modelling at a continental scale

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A fully four-dimensional (3D x time) open source (BSD-3), object-oriented biophysical dispersal model was developed to simulate the movement of marine larvae over semi-continuous surfaces. The model is capable of handling massive numbers of simulated larvae, can accommodate diverse life history patterns and distributions of characteristics, and saves point-level information to a relational database management system. The model was used to study Australia's northwest marine region, with attention given to connectivity patterns among Australia's north-western Commonwealth Marine Reserves (CMRs). This work was supported by the Marine Biodiversity Hub through the Australian Government's National Environmental Research Program (NERP).

IMOS observations for operational oceanography

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IMOS was established under an Australian Government research infrastructure program to deliver ocean observations for marine and climate scientists to undertake research of national and international significance. By focusing on systematic and sustained observing with open access to all data through a standards-based information infrastructure, IMOS can have broader utility including support for operational uses and applications. A number of partnerships have been put in place to enable use of IMOS for operational oceanography. With investment by Darwin Port Corporation (DPC) and the Australian Institute of Marine Science (AIMS), IMOS real-time mooring observations are enabling a better understanding of factors affecting Darwin harbor such as tides, currents, wave height and movement of sediment. Sensors on the reference station are providing data on over 30 parameters every 30 minutes which are of great benefit to the operations of the port of Darwin. In the Great Barrier Reef, eReefs is developing operational hydrodynamic, sediment transport and biogeochemical models. IMOS with co-investment by CSIRO and AIMS is providing core data sets to both assess the performance of the eReefs models and support the requirements of data assimilation schemes. BlueLink OceanMAPS is Australia's operational, short-range ocean forecasting system. It assimilates satellite and in situ observations of temperature, salinity, and sea-level in near-real time to initialise forecasts of the mesoscale ocean circulation around Australia. IMOS is delivering near-real time ocean observations for BlueLink from its Argo and ships of opportunity facilities, and also plays a key role in calibration and validation of satellite observations. This broad utility of marine observations makes it essential to have long-term infrastructure such as IMOS, with the capacity and capability to deliver this information for the benefit of the Australian community.

eSAMarine – phase 1: the first step towards and operational now-cast/forecast ocean prediction system for Southern Australia

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In this project the first phase of an operational model is planned to be developed for Australia's southern shelves by nesting SARDI's high resolution (2.5 km grid) ocean model SAROM inside the BoM's global 10 km grid operational now-cast/forecast model - Ocean MAPS. In turn, existing very high resolution models (< 600 m grid) of significant regions for fisheries and aquaculture (eg. Spencer Gulf) and marine exploitation (oil/gas production) will be embedded in SAROM to provide now-casts/forecast of ocean currents, temperature *etc*. The project will provide demonstrations of the information needs listed below that have been explored with government and industry that include:

- Rapid and accurate Information on the likely trajectory of harmful algal blooms/toxins/pathogens during a fish kill response.
- Information to inform best emergency response options (where to move tuna pens/oyster baskets etc): builds on previous FRDC Projects.
- Information on likely source of contaminants, toxins, pathogens during an emergency response.
- Now-casts/forecasts on ocean "weather" (e.g. for better planning pen maintenance, fish transfer).
- Reduction in vessel fuel costs through "surfing" now-cast/forecast ocean currents, waves and atmospheric winds.
- Possible now-casts/forecasts (out to a week) of likely location of Sardine & SBT schools – complimentary to CSIRO & SARDI work.
- Estimate the impacts of other human impacts on lease sites including pollution/ballast spills, and deposition during dredging and loading of mining and agricultural products.
- Hind-casting to provide information on extreme and possibly harmful events.
- Oil spill trajectories following possible production.

The project is inexpensive (~ $209K) and represents the needed first phase of a fully operational system (24/7) where improved predictions and probabilistic forecast are determined using the "assimilation" of real time data into the SAROM model. For the southern shelves, the real time data sources that might be assimilated include satellite data (temperature, altimeter), coastal sea level, and live IMOS data including that from 2 HF RADAR systems and the PCO_2 mooring off Kangaroo Is.

Circulation and temperature on the Australian North West shelf

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Water temperature on the North West Shelf (NWS) of Australia not only affects the ecology of the region, but it drives many aspects of the dynamics on the shelf. For example, the temperature structure of the water column directly controls the formation and evolution of tropical cyclones and the response of the ocean to cyclone events. Internal tides are prominent features on the NWS, and the stratification determines both the generation and propagation of internal waves.

Temperature data are compared to current velocities to understand how the circulation along and across the shelf affects the stratification structure. Mooring data and HYCOM model output are compared here to see how well temperature variability is modelled on the NWS. Data and numerical model extrapolation of the limited mooring data set are then used to assess the temporal and spatial variability of temperature on the NWS. Interannual variability of temperature from 15 years HYCOM simulations are related to the ENSO variability.

Get your data here! – The Integrated Marine Observing System

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The Integrated Marine Observing System (IMOS, www.imos.org.au), funded by the Australian Government as a component of the National Collaborative Research Infrastructure Strategy, is a sustained enduring observing system for Australia. IMOS, a member of the GOOS Regional Alliances, is an integrated national array of observing equipment that monitors the open oceans and coastal marine environment around Australia, covering physical, chemical and biological variables. IMOS observations are guided by societal needs for improved ocean information, and focused through science planning undertaken collaboratively across the Australian marine and climate science community.

All IMOS data is freely and openly available through the IMOS Ocean Portal (http://imos.aodn.org.au) for the benefit of Australian marine and climate science. Data standards are adopted throughout - metadata conforms to the ISO 19115 geospatial standard and data is delivered through OGC web services (WMS, WFS). The portal adopts a three-step wizard-like process providing an easy to follow workflow. The open access and ease of download make these data a valuable resource for operational oceanography in Australian waters.

A tool for operational oceanography – the marine virtual laboratory

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In all modelling studies of realistic scenarios, a researcher has to go through a number of steps to set up a model in order to produce a model simulation of value. The steps are generally the same, independent of the modelling system chosen. These steps are time consuming and resource hungry, and have to be done every time irrespective of the simulation – the more complex the processes, the more effort is required to set up the simulation.

The Australian Marine Virtual Laboratory (MARVL) is a modelling framework for researchers in Australia, developed through the National eResearch and Collaboration Tools and Resources program (www.nectar.org.au). MARVL, a Java-based control system, enables a researcher to configure and run a model, automating many of the preparation steps needed to bring the researcher faster to the stage of simulation and analysis. The tool is seen as enhancing the efficiency of researchers and marine managers, is being considered as an educational aid in teaching, and offers fast model scenario options in operational oceanography.

Through a user-friendly web application (https://portal.marvl.org.au/) MARVL provides a number of model choices and includes search and recovery of relevant observations, allowing researchers to:

1. efficiently configure a range of different community ocean (ROMS, MOM4, SHOC) and wave models (SWAN, WaveWatch3) for any Australian region, for historical time periods, with model specifications of their choice,
2. access data sets to initialise and force a model,
3. discover and assemble suitable observations for model validation from the Australian Integrated Marine Observing System (https://imos.aodn.org.au), and
4. run the assembled configuration in a cloud computing environment, or download the assembled configuration and packaged data to run on a system of the user's choice.

Real-time marine observing systems: Challenges, benefits and opportunities in Australian coastal waters

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The Australian Integrated Marine Observing System (IMOS) is funded by the Australian Government, and designed to be a fully-integrated national array of observing equipment to monitor the open oceans and coastal marine environment around Australia. IMOS delivers physical, chemical and biological data comprising of observations from a wide spectrum of platforms including weather stations, oceanographic moorings, underway ship observations, seagliders, ocean surface radar, satellite image reception and reef based sensor networks. When data from ocean observing systems can be provided in near real-time, the operational aspects are further enhanced and provide potential for a range of value added products to be developed. Here we provide three examples of co-invested partnerships that have facilitated the development of real-time moored ocean observing systems in the coastal zone, operated by the Queensland IMOS node. For each of these examples, the project is introduced, a detailed technical description of the system is provided, operational aspects are summarised, and the uptake of data from stakeholders is discussed. These examples demonstrate the benefits of having a national collaborative approach to marine observing with a clear focus on open access to data. It is also demonstrated that the benefits and opportunities offered by real-time ocean observing can outweigh the technical challenges of developing and maintaining these complex systems.

Using multiple ocean observations to constrain a high-resolution model of the East Australian Current

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The East Australian Current flows as a jet over the narrow shelf of SE Australia, shedding vast eddies at the highly variable separation point. These characteristics alone make it a dynamically challenging region to measure, model and predict. In a first step toward improving our dynamical understanding of the circulation, we developed a high resolution reanalysis of the East Australian Current. In addition to the traditional data streams (SST, SSH and ARGO) we exploit the newly available IMOS observations in the region. These include velocity and hydrographic observations from the EAC transport array, 1km HF radar measurements of surface currents, CTD casts from ocean gliders, and temperature, salinity and velocity measurements from a network of shelf mooring arrays. We use the ROMS (Regional Ocean Modeling System) 4D-Var assimilation tools to combine all of the available data streams with the model fields providing a reanalysis of the ocean state at 3-6km resolution over a 2-year period. This reanalysis allows us to study the separation dynamics of the EAC by providing a dynamically-consistent “best estimate” of the ocean state along the east coast of Australia that is more useful that observations or model estimates alone.

High-resolution modelling of the Sydney Seaboard

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Shelf seas are highly dynamic transition zones connecting the open ocean and the coast. Along the east coast of Australia, submeso and mesoscale eddies are dominant features of the shelf circulation downstream of the EAC separation point. Offshore waters have been found to intrude onto the continental shelf and into the coastal zone mainly through cyclonic and anti-cyclonic eddy encroachment. However the impact of these intrusions on nearshore circulation, thermocline uplift and eventually productivity remains unknown. We use a combination of observations from an intensive field campaign and outputs from a high resolution regional ocean model (ROMS). We present results from a high resolution (750m) simulation of the circulation on the continental shelf along the highly populated region of the Sydney Seaboard extending from Wollongong in the south to beyond Newcastle in the north. The narrow shelf and the proximity to the EAC Separation Zone as well as the prevalence of mesoscale eddies make this a difficult region to model. We downscale from Bluelink (10km) to an intermediate 'EAC' grid (3-6km) and then to our 750m 'coastal' grid in the Stockton Bight Region. We impose tides at the coastal grid level and run simulations over 2 year period. We compare tidal and non-tidal runs to investigate the impact of including tidal forcing on upwelling and mixing across the productive Stockton shelf. An output of the study is a high resolution ROMS configuration for the productive Stockton Bight/Sydney Shelf region that will aid future assimilation and forecasting efforts.

IMOS foundational ocean colour time series products for Australia

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Ocean colour observations from satellite have been routinely available for nearly two decades; initially with the launch of the SeaWiFS sensor in 1997, then MODIS/Aqua in 2002 and, most recently, with VIIRS on Suomi/NPP launched in 2012. While NASA has sought to make products from these missions available, they have typically been in the form of derived products (e.g. Chlorophyll-a) binned and mapped at 4 or 9 km resolution globally and often are also time-averaged. These data sets are often unsuitable for coastal applications or for characterising product accuracy through *in-situ* matchups, where finer spatial resolution data is required. To address these needs, IMOS has supported the assembly of Australasian archives of raw data from all three missions and established a processing system, based on NASA's standard ocean colour processing software (SeaDAS), at the National Computational Infrastructure (NCI). This system provides:

- whole-of-mission temporal coverage for Australasian region ([5°S,90°E]-[55°S,180°E])
- the ability to reprocess, keeping calibration up to date without repeatedly downloading the data from overseas
- full resolution data (1km for SeaWiFS and MODIS, 750m for VIIRS)
- unmapped single swath products for matchup analyses
- a large suite of additional outputs such as reflectance at mean sea level, ancillary and diagnostic products for new algorithm development
- un-averaged daily product maps for specific regional subsets

The mapped products are available from the IMOS data portal, and also directly from OPeNDAP and WMS servers, or as individual data files while the unmapped products are also available at the NCI.

Toward sustained ocean observing across Tropical Northern Australian Shelf Seas

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Australia's Tropical Northern Seas encompass a region of rich oceanographic complexity and ecological diversity. The region extends from Ningaloo Reef in the west, the resource rich Northwest Shelf to Darwin and along Queensland's Great Barrier Reef (GBR). Two of the primary objectives of the Australian Government NCRIS funded IMOS mooring array is to monitor boundary currents and cross shelf exchanges. From late 2007 a total of 24 moorings have been progressively rolled out across the shelf seas. These complement other arrays in more temperate regions and the Indonesian Throughflow moorings deployed by the Australian Bluewater Observing System facility of IMOS. Observations reveal a rich amount of detail of the boundary currents which have a strong seasonal variation. Shelf waters exhibit a transition from well-mixed in winter to a strongly thermally stratified water column from spring-time warming through summer. Internal tides are then prevalent across the shelf. Along the GBR there are periods of sustained intrusions across the shelf through the reef matrix from a variety of mechanisms. The array has also been embedded in a number of shorter term process based studies and data is being utilised by a growing number of regional modelling efforts demonstrating significant research & management uptake of these observations. The moorings are operated for IMOS by AIMS through the Australian National Mooring Network. The regional nodes Western Australia (WAIMOS) and Queensland (Q-IMOS) determine the guiding principles in order to achieve science outcomes. All data is made publicly available through the IMOS data portal www.imos.org.au.

The eReefs marine model suite: tools for better quantifying and understanding the Great Barrier Reef circulation and water quality

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The Great Barrier Reef is under threat from catchment-derived human impacts and climate change. Through the eReefs Project, a suite of hydrodynamic, sediment, spectrally-resolved optical model and biogeochemical models have been developed. Here we describe the modelling system, including the ability to deploy relocatable high resolution embedded models, and the introduction of GBR-tailored biogeochemical processes such as carbon chemistry, corals, and improved seagrass and macroalgae models. We show results of the model together with comparisons to remote sensing, IMOS and NRS moorings and bottle observations to show how the model can be used to gain better understanding of carbon chemistry and biogeochemical dynamics close to the coast and on the reef. The biogeochemistry module of the eReef model is now run in near real time and historical model runs can be updated with model improvements and compared with observations. For further details and animation results from the near real time biogeochemistry see www.emg.cmar.csiro.au.

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